SUSTAINABLE, JUST AND PRODUCTIVE WATER RESOURCES DEVELOPMENT IN WESTERN NEPAL UNDER CURRENT AND FUTURE CONDITIONS

USAID's *Digo Jal Bikas Project*

MAIN REPORT

Submitted to

United States Agency for International Development (USAID)
Kathmandu, Nepal

Submitted by

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November, 2019

Acknowledgements

This study was made possible by the generous support of the American people through the United States Agency for International Development (USAID) under the *Digo Jal Bikas* (DJB) project. The research work was led by the International Water Management Institute (IWMI) with support from Duke University, USA, and Kathmandu University (KU). The Nepal Water Conservation Foundation (NWCF) provided support for field data collection from households. This research was carried out as part of the CGIAR Research Program on Water, Land and Ecosystems (WLE) and supported by Funders contributing to the CGIAR Trust Fund (https://www.cgiar.org/funders/).

Project

This research study was initiated under the bilateral Grant Agreement between the International Water Management Institute (IWMI) and the United States Agency for International Development (USAID) [Grant Award Number: AID-367-IO-16-00002].

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International Water Management Institute (IWMI)

Duke University

Kathmandu University

Nepal Water Conservation Foundation (NWCF)

Funding support

United States Agency for International Development (USAID)

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The West Seti River in Karnali Basin at Dipayal, Silgadi (*photo:* Sanita Dhaubanjar/IWMI).

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Front Matters

Executive Summary

Over the past decades, Nepal has undergone a period of rapid political, social and economic changes as it transitioned from a government led by a monarchy towards a democratically elected federal government. Water resources management cuts across multiple sectors such as agriculture, industry, sanitation, health, energy, environment, tourism, etc., and across several themes such as governance, equity and economic development. Despite the promotion of several frameworks for holistic management of water resources (e.g., integrated water resources management, nexus, water security, etc.), the management of water is still fragmented and sectoral in Nepal, which could potentially lead to conflicts, especially in the federal context. Furthermore, at present, less than one-tenth of available water resources are harnessed for productive uses.

With the new political changes, water development is expected to take momentum. Western Nepal is viewed as having huge potential for water resources development. It is likely that the relatively pristine nature of water resources in these basins will change to support regional development and national progress through investments in hydropower and irrigation. Planning for a sustainable and climate-resilient pathway for such development requires a thorough understanding of the existing status of water resources and management structures, and ways this may change in the future. Under this backdrop, the *Digo Jal Bikas* (DJB) project (April 2016-March 2019), funded by the United States Agency for International Development (USAID), was initiated with the goal of promoting sustainable water resources development in Western Nepal through balancing economic growth, social justice, and healthy, resilient ecosystems. With geographic focus on three basins in Western Nepal (i.e., Karnali, Mahakali and Mohana), the project unpacks biophysical characteristics, institutional and policy landscapes, social systems and gender, water sources and access, environmental flow requirements, and trade-offs and synergies among potential future development pathways.

Biophysical characterization

As water availability and its spatio-temporal distribution are affected by changes in land use/land cover (LULC), soil, topography and climatic characteristics, the DJB project activities strived to characterize these attributes, develop hydrological models, project future climate, and then evaluate changes in future water availability under projected future climate scenarios. The very first comprehensive regional climate model (RCM) selection framework for Western Nepal was developed with disaggregation of projections for the mountain, hill and Tarai regions. Based on the projections of 19 different South Asian RCMs, 18 climate future (CF) matrices and 10 plausible CF scenarios for Representative Concentration Pathways (RCPs) 4.5 and 8.5 were generated. Two hydrological models, one for Karnali-Mohana (KarMo) Basin and another for Mahakali Basin, were developed using the Soil and Water Assessment Tool (SWAT) to characterize spatio-temporal distribution of water availability under the past and future climates. The results showed:

- Current annual average precipitation (P) of the KarMo Basin is estimated at 1,375 mm and actual evapotranspiration (AET) is 34% (approximately) of P. There is, however, large spatio-temporal heterogeneity.

- Despite the seasonal and spatial heterogeneity, there is high water availability and high potential for water resources development in the basin. Average annual flow volume at the basin outlet under the historical baseline scenario is 46,250 million cubic meters (MCM), while the discharge at the upstream sub-basin outlets vary from 1.1 to 1,357.5 m^3/s. At the outlet, the monsoon season contributes 71% of the average annual flow.
- RCM projections suggest that high-risk scenarios with drier and warmer climates are more likely to occur in the Tarai plains than in the mountains. Average seasonal changes in total precipitation (Δpr) are much higher and variable (-51.6 to 196.8%) than annual values (-23.8 to 20.7%). The average annual changes in maximum temperature (Δtmax), ranging from 0.5 to 5.3 °C across the mountains and 0.8 to 4.5 °C across the hills and plains, are well representative of seasonal changes.
- Based on raw and bias-corrected RCM projections for RCPs 4.5 and 8.5, it can be concluded that further into the future, the hills and plains will see the highest fluctuation in precipitation while the mountains will see the highest increases in temperature.
- As a result of changes in P, T and AET due to CC, average annual flows at the outlets of the KarMo sub-basins are projected to alter, following similar patterns as P to some extent.
- The impacts in the sub-basins at higher altitudes are relatively higher, indicating an increase in vulnerability to climate change for the high mountain regions than the flat lands in Tarai. For example, in the near future, under RCP 4.5 scenarios, the annual flow volume at the outlet of Tila is projected to change by -21.6%, at upper Karnali by -7.2%, Seti by +13.9%, Bheri by -5.4%, and Karnali-main by 0.6%.
- There is clear spatial heterogeneity in the impacts of projected climate change on an annual scale. For Chamelia, a major tributary of Mahakali on the Nepalese side, water availability under future climate is also projected to increase gradually from the baseline to near-, mid- and far-futures. An ensemble of five RCMs shows that dry-season (or pre-monsoon and winter) water availability is projected to increase at a higher rate than the average annual values.

Institutional and policy landscape in water resources management

Three aspects were studied to analyze the institutional and policy landscape for water resources governance in Nepal, and its influence on water management in Karnali and Mahakali basins: (i) policy review and institutional analysis, (ii) power mapping analysis, and (iii) in-depth case study analysis on hydropower decision-making processes at local levels. The key messages from the analysis are as follows:

- In the context of federalism, river basin planning would serve not only as a platform to coordinate cross-sectoral development activities, but also as an institutional mechanism to prevent and resolve conflicts between different key stakeholders across scales. In the past, river basin planning processes involved mainly sectoral ministries and relevant government agencies at national level, with some involvement of local authorities within particular basins. Therefore, at present, river basin planning processes need to be fine-tuned with ongoing processes of federalism.

- Conceptually, this requires the incorporation of a bottom-up approach in river basin planning processes to ensure the defined plan represents local communities' diverse development needs and aspirations. While formulating the Water Resources Policy, the Water and Energy Commission Secretariat (WECS) initiated this process through a series of consultations with local governing bodies in various basins.
- In practical terms, this bottom-up approach can work effectively if supported by systematic capacity building programs targeting the newly elected local bodies, while ensuring that they incorporate water resources management as an important cross-sectoral theme in their mandates.
- Research linking politicians and bureaucrats in water governance shows that political competitions centred on power interplay between the major political parties drive the overall performance of administrative government. Therefore, ensuring that national development planning processes (or the lack thereof) follow political agendas at individual or party level, neither incorporating the country's long-term development vision nor coinciding with local community's and the wider society's development needs and aspirations.
- Hence, the country's scattered, inconsistent national development plan as well as its overlapping and disjointed development activities should not be viewed as an indication of severe lack of governance. On the contrary, it resembles how governance structure, processes and outcomes are produced and reproduced through power relations and power interplay.

Gender and social inclusion

This study developed and applied a project-specific gender equality and social inclusion (GESI) framework for assessing the state of GESI in water institutions, policy and practice in Nepal. Mainstreaming gender and social inclusion in all work packages was core to DJB. In addition, two in-depth GESI focused empirical research, one each at the organisational and community level were conducted in order to better understand the gender dynamics in the context of water resource management. The analysis revealed that organisational policy discourses, institutional structures and professional culture towards GESI matters in order to achieve gender and social justice goals at the community level. Discourses on water should extend beyond considering water as natural and technical objects. To see water as social, closely related to hierarchy of identities including gender is imperative to achieve inclusive and sustainable development and management of water resources. As long as water management institutions do not acknowledge the social nature of water and the hegemonic masculinity of the professional culture in water governance, policy commitments towards greater gender equality will have little effect on the ground. Therefore, it is important that water institutions pay attention to their own masculine spaces, practices and attitudes to address equity and justice issues in water resources management at the ground level. The study provides the following recommendations:

- Policy discourses: Extend current framings of water as a resource to water as 'a symbol of identity, power and citizenship; move away from the engineering approach that dominates the water sector. It requires including a greater diversity of voices on water needs, experiences and subjectivities to move beyond simplistic representations of 'the Nepali woman'.

- Institutional structure: Ensure gender, ethnic, and class diversity at all levels of policymaking and implementation, allocating adequate financial and human resources for more socially just water management and creating specific incentives towards this goal, by changing performance evaluation and promotion rules.
- Professional culture: Institutionalise values that promote positive masculinities of empathy and respect within organisations. Opening safe spaces for male and female staffs to discuss opinions and experiences on doing gender can be a first step towards enhancing their skills, sensitivity and capacity to understand and address gender and social hierarchies in their daily practices.
- The research at the community level calls for investment in the social capital and capabilities of women and marginalised people with particular emphasis on women's linkages and networks, for just and effective water management.

Water source and access

Access to water is key to human survival and well-being. It is facilitated or constrained not only by the availability of water resources but also governance, and economic and social aspects. Therefore, based on socioeconomic contexts and biophysical settings, a set of techno-social interventions were designed and implemented, and their effectiveness was evaluated to draw learning and insights for local water governance and management:

- The analysis suggested that ensuring access to sustainable water resources for rural communities also requires mitigating and preventing land degradation, as the biophysical processes driving water resources are connected to land use practices.
- Recognizing the multi-functionality of agricultural land and managing agriculture as part of the larger landscape are recommended.
- Farmers can increase water productivity and profitability by adopting proven agronomic and water management practices such as collective approaches (in the case of marginal and tenant farmers); and where possible, integrated and multiple use of water (e.g., for crops, fish, livestock and domestic purposes).
- As Western Nepal is still lagging behind in terms of agricultural practices, technological interventions, capacity building, market linkages, and regular engagement and monitoring are likely to bring positive and long-lasting transformations, including up-scaling and out-scaling.

Environment

Environmental flows (E-flows) in the study basins were assessed considering hydrological, ecological and sociocultural aspects in an integrated way. Hydrology was assessed based on the well-calibrated and validated SWAT model. Ecological aspects were characterized based on sampling of macro-invertebrate as an indicator of river ecosystems. Furthermore, sociocultural water needs were characterized based on focus group discussions and key informant interviews in the basins. The results were integrated and a desktop tool to assess E-flows in Western Nepal, namely the Western Nepal E-Flows Calculator (WENEFC), was developed and shared with various stakeholders, including representatives from the PAANI program:

- The Karnali-Mohana Basin has an estimated Mean Annual Runoff (MAR) of 42,224 MCM with an annual coefficient of variation of 0.087, while the Mahakali Basin has a MAR of 25,842 MCM with an annual coefficient of variation of 0.322.
- The Environmental Management Class (EMC) C is generally considered a fair condition for a river to be maintained in and Class A is close to natural conditions. According to the Hydrological E-flows assessment, based on estimates at 111 locations using the Hydrological Method, it was observed that, in general, it is necessary to maintain E-Flows of approximately 70% of MAR to maintain a river segment in Class A condition. Furthermore, it is necessary to maintain E-Flows of approximately 30% of MAR to maintain a river segment in Class C condition.
- Results from the holistic method show that maintaining E-Flows of 70% of MAR or above would leave the river in a Class A condition, while maintaining E-Flows of at least 25% of MAR would leave the river in a Class D condition, which is not acceptable.

This is a first step in a continuous process to provide a simple user-friendly tool for rapid analysis of environmental flow requirements for Western Nepal, before major water resources development projects are initiated in this region. However, there is ample scope for improving the E-Flows calculator by extending the ecological surveys to larger segments of the Karnali-Mohana and Mahakali rivers, and conducting a series of workshops with expert groups to verify and expand the identified relationships between river flow, ecosystems, livelihoods, society and culture.

Future water development pathways

Water resources development and management present important opportunities and challenges for national governments and local communities. Effective balancing of domestic needs with development prospects, and economic growth with resource conservation requires careful and consultative planning. This study adopted three study approaches:

- The first study identified development and sectoral priorities for water management through consultative processes, and created a framework of development pathways for Western Nepal. These visions included state-led and demand-driven development, and preservation of ecosystem integrity.
- The second study contributed to the overall goal of characterizing future development by providing estimates of environmental quality valuation. The results demonstrated that even among the resource-constrained inhabitants of the Karnali and Mahakali river basins, there is significant demand for environmental conservation, demonstrating, once again, the importance of including environmental costs in any trade-off analysis.
- Finally, the third study built on two earlier studies, and developed a hydro-economic model (HEM) to simulate optimal water distribution throughout the river basins under several development scenarios. Specifically, it demonstrated how water resources could be used to meet demands in the energy, agriculture, municipal and environmental sectors. We found evidence of trade-offs between the most infrastructure-intensive development scenarios and environmental health. There were further trade-offs between agricultural production and stringent institutional withdrawal constraints from past treaties.

Abbreviations and Acronyms

ADB	Asian Development Bank
AET	Actual Evapotranspiration
BCM	Billion Cubic Meters
BS	Bikram Sambat
CBS	Central Bureau of Statistics
CC	Climate Change
CF	Climate Future
CIA	Cumulative Impact Assessment
CIDA	Canadian International Development Agency
COP	Conference of Parties
CORDEX-SA	COordinated Regional Downscaling EXperiment for South Asia
CPM-M	Communist Party of Nepal-Maoist
CPN (UML)	Unified Marxist-Leninist
CSC	Climate Service Center, Germany
CSIRO	Commonwealth Scientific and Industrial Research Organization
CV	Contingent Valuation
DDCs	District Development Committees
DEM	Digital Elevation Model
DESTEP	Decentralized Science, Technology, and Education Program
DFAT	Department of Foreign Affairs and Trade, Government of Australia
DFID	Department of International Development, UK
DHM	Department of Hydrology and Meteorology
DJB	Digo Jal Bikas
DJF	December-January-February
DLS	Department of Livestock Services
DOA	Department of Agriculture
DoED	Department of Electricity Development
DoI	Department of Irrigation
DOLIDAR	Department of Local Infrastructure Development and Agricultural Roads
DPTC	Disaster Prevention Technical Centre
DSCWM	Department of Soil Conservation and Watershed Management
DWIDM	Department of Water-Induced Disaster Management

DWNP	Department of Wildlife and National Parks
DWRC	District Water Resources Committee
DWRI	Department of Water Resources and Irrigation
DWSS	Department of Water Supply and Sanitation
E-flows	Environmental Flows
EFR	E-Flow Requirements
EIA	Environmental Impact Assessment
ELOHA	Ecological Limits of Hydrologic Alteration
EMC	Environmental Management Class
EPC	Environment Protection Council
EU	European Union
FAO	Food and Agriculture Organization, United Nations
FANUSEF	Food and Nutrition Security Program
FDC	Flow Duration Curve
FF	Far Future
FGD	Focus Group Discussion
GAMS	General Algebraic Modelling System
GEF	Global Environment Facility
GESI	Gender And Social Inclusion
GIS	Geographic Information System
GLOF	Glacial Lake Outburst Flood
GoN	Government of Nepal
GPS	Global Positioning System
GWP	Global Water Partnership
GWRDB	Groundwater Resources Development Board
ha	Hectares
HDI	Human Development Index
HEM	Hydro-Economic Model
HH	Household
Hil	Hills
HMG	His Majesty's Government
HPI	Human Poverty Index
HRU	Hydrologic Response Unit
ICTP	International Centre for Theoretical Physics
IDA	International Development Assistance

IFAD	International Fund for Agricultural Development
IFIM	In-stream Flow Incremental Methodology
IGP	Indo-Gangetic Plan
IITM	Institute of Tropical Meteorology
IMD	Indian Meteorological Department
IMTP	Irrigation Management Transfer Project
INAGEP	Innovation and Agro Entrepreneurship Program
INGO	International Non-Governmental Organization
IQR	Indicates Interquartile Range
IWMI	International Water Management Institute
IWRM	Integrated Water Resource Management
JICA	Japan International Cooperation Agency
JJAS	Jun-July-August-September
KarMo	Karnali-Mohana
KCAP	Knowledge, Capacity, Attitude, Practice
KII	Key Informant Interview
km	Kilometres
KRB	Karnali River Basin
KVWSMB	Kathmandu Valley Water Supply Management Board
LAPA	Local Adaptation Plan of Action
LFA	Local Field Assistant
LH	Latin Hypercube
LULC	Land Use/Cover
MAM	March-April-May
MAR	Mean Annual Runoff
masl	Meters above mean sea level
MCM	Million-Cubic-Meters
MF	Mid Future
MFSC	Ministry of Forests and Soil Conservation
mm	Milimeters
MnT	Mountains
MOAC	Ministry of Agriculture and Cooperatives
MOAD	Ministry of Agricultural Development
MOE	Ministry of Energy
MOFSC	Ministry of Forest and Soil Conservation

MOHC UK	Met Office Hadley Centre
MOI	Ministry of Irrigation
MoLRM	Ministry of Land Reform and Management
MoPE	The Ministry of Population and Environment
MoSTE	Ministry of Science Technology and Environment
MoU	Memorandum of Understanding
MW	Mega Watt
NAPA	Nepal Adaptation Plan of Action
NARC	Nepal Agriculture Research Council
NBCC	National Biodiversity Coordination Committee
NBU	National Biodiversity Unit
NC	National Congress
NCA	Net Command Area
NCDM	National Council for Disaster Management
NCP	Nepal Communist Party
NDMA	National Disaster Management Authority
NDWQRB	National Drinking Water Quality Regulatory Board
NEA	National Electricity Authority
NEFEJ	Nepal Forum of Environmental Journalists
NEFIN	Nepal Federation of indigenous Nationalities
NF	Near-Future
NGO	Non-Governmental Organization
NISP	Nepal Irrigation Sector Project or NISP
NMDS	Non-metric multidimensional scaling
NPC	National Planning Commission
NRs.	Nepalese Rupees
NSDRM	National Strategy for Disaster Risk Management
NSE	Nash-Sutcliffe efficiency
NWCF	Nepal Water Conservation Foundation
NWP	National Water Plan
NWRDC	National Water Resources Development Committee
NWSC	Nepal Water Supply Corporation
NWY	Net Water Yield
OAT	One-Factor-At-A-Time
ON	Ocotber-November

P	Precipitation
PAANI	Program for Aquatic Natural Resources Improvement
PBIAS	Percent Bias
PDA	Project Development Agreement
PHABSIM	Physical Habitat Stimulation Model
PPA	Power Purchase Agreement
QM	Quantile Mapping
RBM	River Basin Management
RBO	River Basin Organization
RCM	Regional Climate Models
RCP	Representative Concentration Pathways
RH	Relative Humidity
RPP	Rashtriya Prajatanra Party
RVWRMP	Rural Village Water Resources mapping Project
SAARC	South Asian Association for Regional Cooperation
SAFTA	South Asian Free Trade Agreement
SDC	Swiss Development Co-operation
SDGs	Sustainable Development Goals
SEA	Strategic Environmental Assessment
SIA	Social Impact Assessment
SMHI	Swedish Meteorological and Hydrological Institute, Sweden
SOTER	Soil and Terrain
SWAT	Soil and Water Assessment Tool
SR	Solar Radiation
T	Temperature
TiP	Tibetan Plateau
TrH	Trans-Himalayas
UKCC	Upper Karnali Concerns Committee
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNPM	United National People’s Movement
USAID	United States Agency for International Development
VADEP	Value Chain Development Program
VDCs	Village Development Committees
WECS	Water and Energy Commission Secretariat

WENEFC	Western Nepal Environmental Flows Calculator
WNEWM	Western Nepal Energy Water Model
WPs	Work Packages
WRP	Water Resources Policy
WS	Wind Speed
WTP	Willingness to Pay
WUA	Water Users Associations
WUMP	Water Use Master Plan
ºC	Degree Celcius
Δpr	Changes in annual average total precipitation
Δtmax	Changes in annual average maximum temperature

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1. Introduction

Luna Bharati

1.1. Context

The management of water cuts across multiple sectors such as agriculture, industry, sanitation, health, energy, etc. and several themes such as governance, equity and economic development. A river basin is often considered as an appropriate unit for water system analysis and management as both biophysical and human-induced processes can be traced and accounted for. Several frameworks such as Integrated Water Resources Management, the Water Energy Food nexus and Water Security have been promoting integrative and holistic approaches for basin-wide water management. However; the actual management of water, especially in Nepal, is still very fragmented and sectorial, which could possibly lead to tension and conflict as water demand and development increase.

Despite recent political and economic progress, Nepal remains a least developed country and one of the poorest countries in South Asia, with 23.8% of the population living below the poverty line. Water resources remain a particularly under-developed sector, which has been identified as a key resource for development and economic growth in Nepal (GoN-WECS 2011). Progress has been made in increasing the proportion of the population with access to improved drinking water sources and improved sanitation facilities, (85% and 62%, respectively for 2012/2013), however the extent of coverage is still low, particularly for sanitation (GoN/UNDP, 2013). Although the country has 225 billion cubic meters (BCM) of water available annually, only an estimated 15 BCM (less than 7%) has so far been utilized for economic and social purposes (GoN-WECS 2005).

Similarly, an estimated 43,000 Mega Watt (MW) as economically feasible potential for hydropower development is available in Nepal (Sadoff et al., 2013); however, the installed capacity of power plants connected to the national grid is only some 689 MW (WECS, 2010), and Nepal currently suffers from acute energy shortages. Agriculture consumes most of all water withdrawn in the country. Furthermore, over 80% of Nepal's population depends on subsistence agriculture for livelihoods (World Bank, 2013). However, only 24% of arable land is irrigated, crop productivity is significantly lower than in the rest of South Asia, and the country relies heavily on food imports from India. Women are largely responsible for agriculture but do not have the requisite social or legal status to have decision making power over land and are not targeted for the acquisition of new skills and technologies through extension services. Despite vast groundwater reserves in the Tarai, tube well development remains limited, particularly for the marginal (<0.5ha) and tenant farmers who constitute the majority of cultivators. As a result, vast tracts of land remain fallow during the winter and summer dry seasons. In this context, water resources development and management, particularly in the hydropower and agriculture sectors, represent a key building block for future of the country's economic growth and poverty reduction strategy.

Recent talks between the governments of Nepal and India on hydropower development and the interest/ investment from the private sector as well as development banks has already started the development of new hydropower projects. There are also a number of irrigation projects proposed under the new irrigation master plan, currently being drafted by the department of irrigation. Water resources planning however; is still being done in a very sector-wise manner. The existing legal frameworks contain both conceptual and operational gaps in terms of linkages between land-water-environment management policy both horizontally (between the different government agencies at each administrative level) and vertically (between the same government agencies at different administrative levels). While sustainable resource management and economic development are commonly-held policy objectives, it can be difficult to form a single, cohesive vision for regional development. Sectoral tradeoffs that require prioritization of some types of resource use over others and different institutional interests can present planning challenges. Visions for a certain development pathway can also differ between national level planners and local communities. There can be disconnections between the national and local governments on plans and priorities.

Furthermore, water resource development requires alteration of river flows for timely water supply or power generation, and therefore modification of natural ecosystems including built infrastructure. On the other hand, it is also true that the benefits that accrue from water infrastructure are themselves dependent on ecosystem services. For example, the performance (i.e. yield, reliability, resilience and vulnerability) of an irrigation canal is affected by the flow-regulating services of natural ecosystems that exist in the upstream catchment of the canal intake point. Hence, ecosystem services are integral to the functioning of built water infrastructure. Although built infrastructure enhances some ecosystem services (for example regulating and provisioning services), it adversely affects others. Services are lost when ecosystems are destroyed or damaged by the construction of dams, reservoirs, irrigation systems and canals. For example, wetlands may be drained or drowned, or seasonal patterns of river flow and groundwater may be disrupted, leading to changes in ecosystem function. The loss of natural ecosystem services, including biodiversity, is frequently overlooked or inadequately compensated. As a result, the disadvantaged people who tend to rely most heavily on these services, a group in which women are over-represented, typically bear many of the costs of development. Thus, water infrastructure development for poverty alleviation requires careful consideration of the trade-offs and complementarities between built water infrastructure and natural ecosystems

Fragmented and sectoral management can amplify inefficiencies, inequalities and can lead to degradation of ecosystems and their services and functions. In addition, global changes such as climate change or economic transformations can also lead to further stresses on the hydrological system and ecosystems and turn water allocation into a conflict-laden task. Therefore, the planning and management of water availability, access and development cannot limit itself to static biophysical analysis. Institutions, socio-economic constraints and opportunities - particularly gender and caste relations, and geo-political realities shape the impact of water management at basin/ sub-basin and national/local scales. Future challenges and opportunities linked to climate change, economic globalization, and political transitions also need to be considered. At a basin level, transboundary issues can further complicate resource management. Similarly, at the local level, increasingly fragmented landholdings, a skewed land distribution and exploitative tenure relations have reduced the incentives or capacities for farmers to invest in technologies that improve agricultural productivity.

Some of the main barriers for implementing integrated water management approaches include neglect of existing political structure and processes within and beyond the water sector (Allan, 2003), adequate inclusion of tradeoff assessments between the various objectives (Molle, 2006) and a lack of data and information necessary for planning. These criticisms recommend an explicit recognition that decisions related to water resource management are political choices (Wester et al., 2003) and to shift from unrealistic blueprint institutional arrangements to adaptive, flexible and inclusive approaches such as poly-centricity (Blomquist and Schlager, 2005, Suhardiman, 2015).

Furthermore, there is an increasing recognition of the need to allocate water for environmental purposes, besides the more traditional allocation to cities, industries and agriculture. During the planning and design stages of water resources development projects, these environmental flows should be considered explicitly alongside those of other users. These environmental water uses and requirements ought to be defined on the basis of observed direct linkages between changes in ecosystem character and the delivery of important ecological services to people (e.g. fish as food, high quality drinking water, riparian trees for house construction and recreation, etc.).

In this context, the USAID's Digo Jal Bikas (DJB) project strived to promote sustainable water resources development in Western Nepal through balancing economic growth, social justice and healthy, resilient ecosystems. The project contributes directly to IR2.3 of the USAID Nepal Country Development Cooperation Strategy (2014-18), focusing on means to increasing the resilience of targeted natural resources and consequently improving the livelihoods that are dependent on them. The geographic focus of this project is the basins and sub-basins in the Karnali and Sudurpaschim Provinces of Nepal, with a particular focus on the Karnali, Mahakali and Mohana River Basins (**Figure 1-1**).

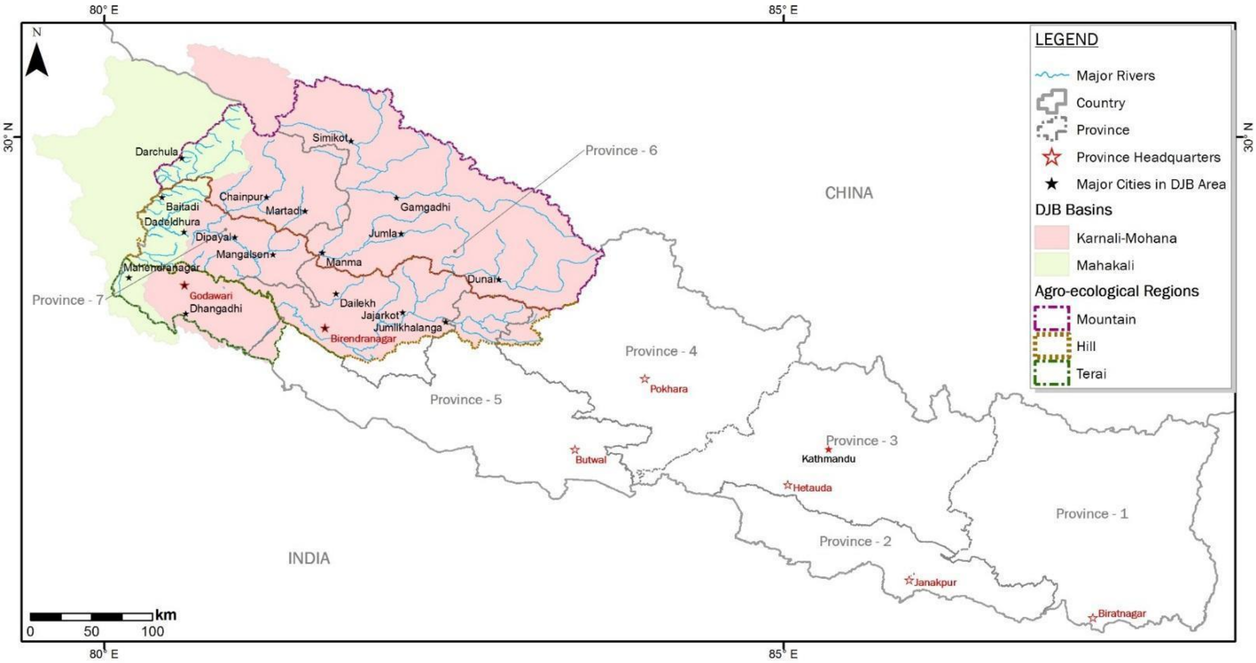

__Figure 1-1__: The study region – Karnali-Mohana and Mahakali river basins. DJB is "Digo Jal Bikas".

1.2. Project goals and objectives

The overall goal of this proposal was to promote sustainable water resources development in Western Nepal through balancing economic growth, social justice and healthy, resilient ecosystems. The geographic focus of this proposal are the basins and sub-basins within the Mid-western and Far-western Development Regions of Nepal, with a particular focus on the Karnali basin including the Mohana sub- basin in the Terai and the Mahakali basin (See **Figure 1-1**). Three objectives are proposed to achieve this goal:

i) The construction of a **sound knowledge base on the current state and use** of ecosystems and their services and the impact of climate change as well as other drivers of future change in west Nepal to identify key information and knowledge gaps. This includes a comprehensive database on the study area's natural characteristics including the river and lake network and their connectivity, groundwater aquifers, wetlands, biodiversity and protected areas, their ecosystem services, as well as all water-related physical infrastructure and modifications. This objective will help establish key knowledge and information gaps and provide key datasets that will be useable for future and diverse analyses and planning purposes.

ii) The **development and application of tools, models and approaches (including opportunities and risks) for sustainable water resources development** under current state and future scenarios at the basin and local community scale. In particular, tools will be developed to identify the water flows necessary to maintain the integrity of ecosystems and their services. This information will then be used for hydro-economical modelling at basin scale to explore water allocation under future scenarios, including climate scenarios, of different water resources development options and the resulting trade-offs. At sub-basin, watershed and local community scales approaches for improved water management and water governance will be explored.

iii) **Support for the development of integrated policy and practice guidelines on options and technologies for sustainable water infrastructure development for government and local communities.** These guidelines will be designed to promote best practice in water-related infrastructure development (e.g. hydropower, irrigation, managed aquifer recharge, water storage) at different scales, which supports local communities and protects the resilience of ecosystems and their services. The aforementioned knowledge base, tools, models and approaches will underpin these guidelines, which will be developed with input from government and community stakeholders, as well as donors and investors. The policy and practice guidelines will be formulated in collaboration with the PAANI program.

1.3. Implementation approach

The activities under the three-year project (April 2016 – March 2019) were packaged under six core Work Packages (WP) and two supporting WPs (**Table 1-1**). The WP setup and interlinkages are shown in **Figure 1-2**.

***Table 1.1**: Digo Jal Bikas (DJB) project work packages (WPs)*

Core work packages	
WP1	Basin characterization: Bio-physical, socio-economic, and hydro-climatic characterization of the basins, including analysis of institutional and policy landscape. Development of hydrological models and future climate projection tools also falls within the scope of WP1.
WP2	Environmental flow assessment and tool development: Developing a desktop tool for environmental flows (E-flows) assessment with consideration of hydrological, ecological, and socio-cultural aspects of E-flows; and then assess E-flows in the study basins using the tool.
WP3	Basin-scale development scenarios: Identify/characterize a set of basin-scale development scenarios for the study basin as potential future development pathways; develop hydro-economic model; and evaluate trade-offs and synergies between/among the various pathways.
WP4	Watershed/village water governance and management: Select suitable hamlets; analyze their biophysical, socio-economic, institutional and cultural characteristics; design a set of techno-social interventions aimed at improving water access and use; and evaluate the effectiveness of the techno-social interventions to draw learnings on water governance and management at local scale.
WP5	Gender: Mainstream GESI in WPs of DJB, develop a GESI framework to guide other WPs and in-depth empirical research on GESI.
WP6	Integrated policy and practice guidelines: Provide inputs in various policy documents that government may develop, and policy/practice guidelines that PAANI develops in the course of project implementation.
Supporting work packages	
WP7	Knowledge management and dissemination: Develop knowledge products based on findings of the research; manage and disseminate the knowledge effectively through workshops, meetings, conferences, publication international journals, op-ed in mainstream media, etc.
WP8	Project management: Ensure the project runs smoothly with monitoring and evaluation of project activities for its quality assurance and timely completion; prepare and submit regular project reports.

Furthermore, considering the need for pooling expertise ranging from river ecology and E-flows to hydrological modelling, hydro-economic modelling, climate change impact assessments, social and gender analysis to institutional policy-analysis, IWMI partnered with Kathmandu University, Duke University, and Nepal Water Conservation Foundation (NWCF) to implement this project.

In addition, a wide range of stakeholders as listed hereunder were engaged in this project, representing both next and end users of the project's products, tools and knowledge:

- Public and private sector agencies and multilateral investors who evaluate, design and implement water resources development projects and investment programs.
- National, provincial, and local level water and energy management agencies, e.g. Ministry/Department of Water Resources and Irrigation, Ministry/Department of Agriculture, Ministry of Forests and Soil Conservation, Water and Energy Commission Secretariat and the Department of Soil Conservation and Watershed Management, Ministry of Science Technology and Environment (MoSTE), Ministry of Federal Affairs and Local Development and Department of Local Infrastructure Development and Agricultural Roads (DOLIDAR), District Development Committees (DDCs) and Village Development Committees (VDCs).

- Conservation groups that want to establish environmentally sustainable water resources planning and management.
- Women and men in farmer and fisher communities that will be affected by climate change and water management decisions in the basin.

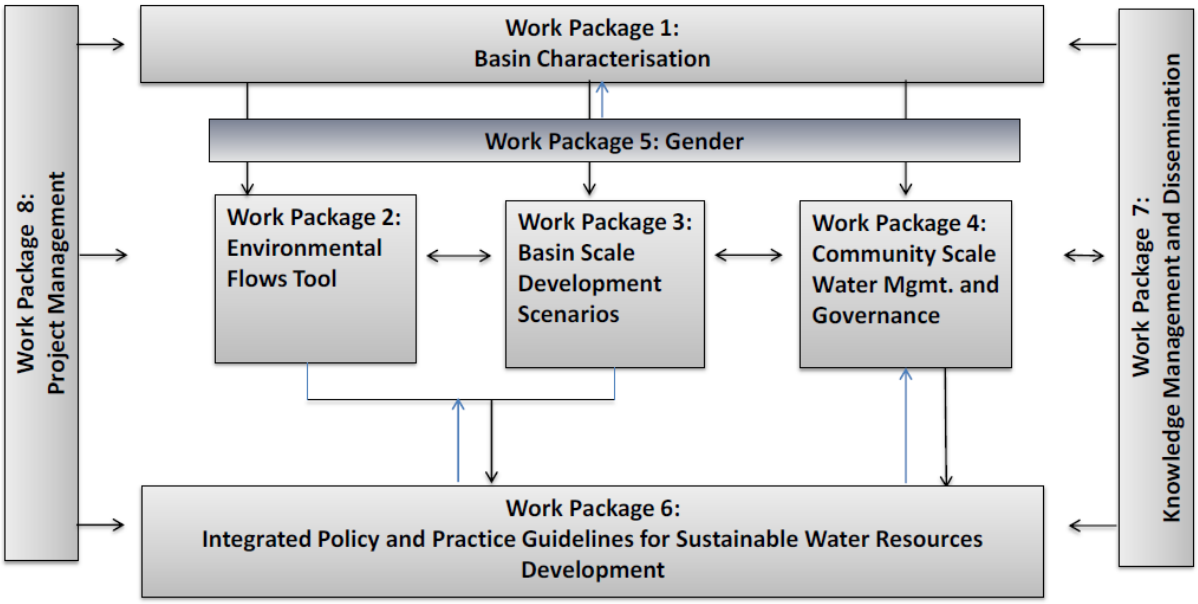

***Figure 1-2**: Setup of the various work packages (WPs) in Digo Jal Bikas (DJB) project.*

1.4. Study basins – The Karnali, Mahakali and Mohana

There are three river basins (Karnali, Mahakali, and Mohana) under the jurisdiction of the Digo Jal Bikas (DJB) project. Karnali and Mohana basins are characterized as a single unit in this study. The study basins have a large degree of heterogeneity in terms of climate, topography, geology, soils, and vegetation. Both basins are relatively pristine, as anthropogenic developments have been limited here compared to Eastern Nepal. A comparison of selected characteristics of the three study basins are provided in **Table 1-2**.

1.4.1. Karnali-Mohana Basin

The Karnali River basin lies in the western Nepal between the mountain ranges of Dhaulagiri in Nepal and Nanda Devi in Uttarkhand in India. The Karnali basin covers whole or part of 15 districts and is considered to be the least developed region of the country. Among the seventy-five districts of Nepal, Humla with the highest poverty index (HPI = 49.3) and Bajura with the least value of Human Development Index (HDI: 0.364) (GoN and UNDP, 2014) lie within the Karnali basin. Other districts of Karnali have similar conditions as low female literacy, chronic malnutrition and high poverty concentration characterize a majority of these districts. The status of access to safe drinking water as well as to irrigation is also below the national average. It is thus not surprising that the Karnali zone is very much out of the main stream of national development (Bham, 2011).

The northern part of the Karnali basin lies in the rain shadow of the Himalayas. The Karnali River Basin (KRB) starts in the High Mountains. The headwater of the Karnali River lies about 230 km North from Chisapani (mainstream Karnali River length) covering mountainous ranges with altitude more than 5,500 m up to 7,726 m. The basin includes the longest river network i.e. the Sapta Karnali River (507 km). The West Seti River and the Bheri River are the main tributaries of the Karnali River, which originate from the glaciated region of Nepal, whereas the Humla Karnali originates in Tibet (Negi, 2004).

The Mohana sub-basin is part of larger Karnali basin. The Mohana river, lying in south of the Karnali Basin, descends from Churia range, flows through Tarai plain, and meets with Karnali river at Nepal-India border. Watershed area of the Mohana delineated above the Nepal-India border is 3,730.3 km^2. The combined basin area of Karnali-Mohana (KarMo) above the Nepal-India border is 49,889 km^2. About 6.9% of the KarMo basin area lies in China. Unlike the dendritic drainage pattern of the Karnal River Basin that merge in a main river stream, Mohana comprises of a network of parallel streams that do not merge within the Nepalese borders.

***Table 1.2**: Summary of characteristics of the three study basins*

Characteristic	Karnali	Mohana	Mahakali
Originates in	Tibetan plateaus and high mountains	Nepalese Churia hills	High mountains
Basin Area[1]	46,151 km^2	3,730 km^2	17,371 km^2
Elevation Range[2]	5,500 - 7,726 masl (upstream of Chisapani)	113 – 1,928 masl	83 - 7378 masl
Location	Transboundary between China and Nepal (6.9% in China)	Nepal	Trans-boundary between India and Nepal (68% in India)
Stream Network	Dendritic	Parallel	Dendritic
Glaciers and Glacial Lakes[3]	1361 glaciers over 1740 km^2 (127.81 km^3 of ice reserve) 907 glacial lakes over 37.67 km^2		87 glaciers over 143 km^2 (10.06 km^3 of ice reserve) 16 glacial lakes over 0.38 km^2
Soil Types	21 types with Gelic Leptosol as dominant (34.2%)		18 types with Dystric Cambisols as dominant (32.5%)
LULC classes	9 classes with Forests as dominant (> $1/3^{rd}$ of the basin)		9 classes with Forests as dominant (55 %)
No. of DHM Weather Stations	36 used; but only 5 measure all climate parameters (P,T,RH,WS,SH)		7 used; but only 1 measures all five climate parameters
Hydropower Projects	127 proposed projects ranging from 0.5 -1000 MW		1 operational, 3 under-construction and 5 proposed projects ranging from 0.99 -6720 MW in the Nepalese side
Irrigation Projects	48 existing and 1 under-construction project with net command area ranging from 100-98026 ha		6 existing and 3 proposed project with net command area ranging from 170-33520 ha in the Nepalese side

[1] Basin area calculated using basin outlets placed at the Nepal-India border
[2] Elevation range as seen in ASTER GDEM V2 (NASA JPL, 2009)

[3] From Ives et al. (2010)

The Karnali basin is a biodiversity hotspot with nearly 14% of basin area under protection (WSHP, 2007). It constitutes of four national parks, one wildlife reserve, one hunting reserve and two buffer zones. The Shey Phoksundo National Park is located in the Dolpo district of the Karnali basin and is the habitat for the endangered snow leopard and blue sheep. It is also a religious Buddhist site and represents Tibetan plateau ecosystem. Rara National Park, located in the Mugu district is the smallest park consisting of a huge collection of Himalayan flora and fauna. Bardia National Park is the largest and undisturbed protected area in the basin. The park is famous for wild Asian elephants and a great number of deer species. The Karnali River supports the last potentially viable population of Ganges River dolphin, endangered Mugger Crocodile, fish-eating Gharial and the Golden Mahseer (IUCN, 2007). Other wildlife of conservation significance in the basin include Royal Bengal tiger, One Horned Rhino, Swamp deer, Back buck, Red panda, Snow leopard, and Musk deer (Shrestha, 1982).

The Karnali basin is the first basin to arouse keen interest in Nepal's vast hydropower development potential with several proposed hydropower developments by 2028 such as West Seti (750 MW) and Lohore Khola (58MW), which are storage type projects and Upper Karnali (900 MW) and Bheri Babai (48MW), which are run-of-the-river type projects. Substantial cultivable land had been identified in the Far and Mid-West development regions with future irrigation potential of 44,600ha (JICA, 1993). Six large-scale irrigation projects have been proposed in the basin, including Bheri-Babai, Chisapani multipurpose, and Rani-Jamara irrigation system. The irrigation demand is estimated to rise from 5% of the mean annual Karnali River flow at Chisapani to 11% by 2025 (Tahal Consulting Engineers, 2002) due to implementation of Bheri-Babai scheme.

The Karnali Multipurpose Project with power potential of 10,800 MW and irrigation potential of 191,000ha has been the focus of interest for the government of Nepal (Thapa, 2008). The project is proposed at Karnali gorge with a catchment area of 43,679km^2, covering nearly 30% area of Nepal (Thapa, 2008). If this irrigation project is achieved, it will result in 20% increase in the total irrigated land and proportional increase in the yield of food crops in Banke, Bardiya and Kailali, the most productive districts of Nepal (Thapa, 2008). The huge storage capacity of the project can provide water in the dry season to facilitate irrigation in the eastern parts of India, where agriculture production at present is greatly constraint by the lack of water for irrigation in the dry season. Rani Jamara Irrigation System is the largest farmers managed irrigation system in Nepal located at Kailali district. It uses water from Karnali River and has a command area of 14,000ha in 8 VDCs and 1 municipality of Kailali district (DOI, 2010).

Although thorough and aggregated impact assessments of all proposed infrastructure projects are not available, the impacts in river hydrology, riverine ecosystems, and social development as well as the national economy are likely to be huge. For example, according to the environmental assessment report of the West Seti Hydropower project, the impacts of proposed development in the Karnali basin in next 20 years are predicted to increase in dry season by 12.8% (February) and decrease in the Monsoon season by 10.1% (July) due to storage of monsoon flows (WSHP, 2007). Aquatic habitat will be fragmented by flood of river sections, downstream dewatering by the hydropower projects and Chisapani dam. But the impact is likely to be at the sub-basin scale. There will be increased pressure on forest areas due to inundation and permanent removal. Furthermore, there will be increased demand of forest resources as a result of increased population density in Terai versus increased protected area management. The Bheri-Babai project will also likely affect the protected area at the dam site as its access road is located within Bardia National Park (WSHP, 2007). The Karnali project would inundate about 339 sq.km of land and directly displace about 60,000 people (Thapa, 2008). However, the inundation area will be in the highlands where the population density and cultivable land is significantly low compared to the lowland areas (Thapa, 2008).

Currently, hydropower development on the Karnali is limited to small micro hydro schemes supported by various donors. The cumulative impacts on freshwater ecosystems and biodiversity of these and other potential small schemes are largely unknown at this time. Recent work on the Nu River in China suggests that such cumulative impacts can be comparable to single large hydropower schemes.

1.4.2. Mahakali River Basin

The Mahakali is a transboundary river basin that decends from 3,600 m at Kalapani in Nepal to 200m as it enters the Tarai plains. The river flows through Uttaranchal in India, boarders between India and Nepal and then flows down to India to eventually join the Ganges. The basin area delineated above the Nepal-India border is 17,371.3 km^2. Only 32.4% of the basin area falls within Nepalese territory. The basin has a large diversity in topography, which extends from 83 masl in south to 7,378 masl in the north. The basin has a dendritic river system with all tributaries merging at various points along the main river called Mahakali in Nepal and Sharada in India. Two important tributaries of the Mahakali River in Nepal are Chamelia and Limpiyadhura rivers. In the Nepalese side, the basin has only 87 glaciers covering 143 km^2 and 16 glacial lakes covering 0.38 km^2, of which none are considered potentially dangerous (Ives et al. 2010). The Nepal part of the Mahakali basin covers whole or part of four districts, with the human poverty index (HPI) higher than the national average (of 31.3) and the lower than the national average (of 0.458) (GoN and UNDP, 2014).

The Shukla Phanta Wildlife Reserve is located in the Kanchanpur district of Mahakali basin, covering 7% of basin area. The reserve provides prime habitat for swamp deer and is also listed as an important bird area with 15 globally threatened and 13 near-threatened bird species (Tuladhar, 2010). Likewise, the Pancheswar multipurpose project with the capacity of 6,480MW (12 units of 540 MW each) is the biggest proposed development in Mahakali River basin. According to Singh (2013), the environmental impacts of the high dam is negative with a loss of \$1.8 million worth of agricultural production, inundation of 3,850 ha of land and displacement of 22,765 people from 2,926 households (Singh, 2013). However; the income from energy generation from Pancheshwar High Dam is about \$368 million along with \$2.6 million income from open reservoir fish farming (Singh, 2013).

1.5. Structure of the report

This report is organized into eight chapters, including this introduction chapter. **Chapter 2 (Work Package 1)** focuses on biophysical characteristics of the study basins. The chapter starts with the context and need of biophysical characterization, then describes the methodology and approach used for biophysical characterization, including future climate projections, and then presents modelling results for Karnali-Mohana and Mahakali river basins. During the process of biophysical characterization, a large number of data sets, both time-series and geo-spatial, were collected and pre-processed, which all will be available in IWMI's water data portal (http://www.iwmi.cgiar.org/2018/06/water-data-portal/). Furthermore, two hydrological models for Karnali-Mohana and Mahakali have been developed. A tool for future climate projection has been developed. Finally, the chapter lists three annexes, which are primarily the journal articles either published already or under review.

Chapter 3 (Work Package 1) focuses on the institutional and policy landscape in the study basins. It first describes the importance of the topic and then describes the methods used, results, and conclusion. The results are organized under three main areas – i) river basin planning process and shaping of power struggle; ii) linking politicians and bureaucratic in water governance diagnostic; and iii) grass root forces and alliances shaping hydropower decision-making. Finally, it lists three annexes, which are the journal articles either published already or in the publication process.

Chapter 4 (Work Package 5) focuses on GESI issues in the context of the study basins. The chapter starts with contextualizing the importance GESI in water resource management and then elaborates the methodological approach adopted in this study, including gender analysis framework, and research findings. Like earlier chapters, three papers which are in the publication process are listed as Annexes.

Chapter 5 (Work Package 4) focuses on water sources and access and gives insights on design, implementation, and evaluation of a set of techno-social interventions to improve water management and governance. It starts with the approach used for selecting three hamlets as sites, followed by the socio-economic characterization of the sites, design of appropriate set of techno-social interventions, and their evaluations and learnings. It lists two papers in the process of publication as annexes.

Chapter 6 (Work Package 2) is related to the maintenance of the aquatic environment, with specific focus on environmental flows (E-flows). It elaborates the importance of E-flows and need for an integrated method for E-flows assessment that considers hydrological, ecological and socio-cultural aspects of E-flows. It then describes the methodology, description of the E-flows tool developed in this study, and then presents E-flows results for the study basins.

Chapter 7 (Work Package 3) discusses identification and evaluation of future water development pathways for the study basins. It describes methods, data, development visions and priorities, and evaluation of water development pathways by means of developing a comprehensive hydro-economic model for the Karnali-Mohana-Mahakali basins. It finally lists four related publications, either already published or in the process of publication as annexes.

The final chapter deals with conclusions, recommendations, and ways forward.

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2. Biophysical Characteristics: Current and Future

Vishnu Prasad Pandey, Sanita Dhaubanjar, Luna Bharati

2.1. Context

River basin planning requires a thorough understanding of the biophysical and hydro-climatic context of the basin. biophysical characteristics include aspects such as land use/cover (LULC), soil, topography and water resources. Spatio-temporal distribution in water resource availability is affected by changes in bio-physical and climatic characteristics of the basin. The main water balance components are precipitation, runoff, evapotranspiration, and water storage in various forms. Human activities also influence hydrological cycles through large artificial storage construction such as reservoirs, abstractions for water supply or water transfers to other areas, and by adding return flows/drainage from various uses such as irrigation areas. Changes in LULC, such as increases in agricultural areas, changes in crop systems, deforestation, or imperviousness on urbanized areas can also have significant influence in the processes of evapotranspiration, infiltration, soil water storage, and runoff. Biophysical characterization of a basin offers evidence for planning, management, and governance of water resources.

The Karnali and Mahakali basins in Western Nepal (**Figure 2-1**) account for 28% of total available water resources in Nepal (Pandey et al. 2010). Natural resources are also abundant and tourism potentials are high. With steep slopes and meandering rivers, Western Nepal offers tremendous potential for hydropower development. There are 150 identified hydropower projects of various types, including 19 storage projects, under various stages of development, with proposed installed capacity ranging from 0.5 to 6,720 megawatts (MW) (IWMI 2018). Total estimated installed capacity of all those projects is more than 21,000 MW. Implementing all of these projects will contribute to energy security and fuel economic growth for national prosperity. Despite having tremendous potential, adequate development and management of water resources has yet to gain momentum for various reasons, including lack of an adequate knowledge base on spatio-temporal distribution of water availability under current and future conditions. Evidence on hydrology and spatio-temporal distribution on water availability is useful for policy/decision-makers and other relevant stakeholders to quantify different types of water security threats; design policies and programmes; and devise strategies for better allocation, utilization, and management of freshwater resources (Sunsnik, 2010; Thapa et al., 2017) for the country's prosperity. It is therefore imperative to use state-of-the art tools, such as hydrological modelling, and assess spatio-temporal distribution of water availability under current, and multiple future time-frames using the most recent climatic scenarios.

There are several studies focusing on hydrological modelling and climate change (CC) impact assessments at local and watershed scales in Nepal (Sharma and Shakya 2006; Babel et al. 2014; Bharati et al. 2014; Dahal et al. 2016; Bajracharya et al. 2018). However, only Dhami et al. (2018) specifically focuses on the Karnali basin, and there have been no studies in Karnali-Mohana (KarMo) and Mahakali basins. Even the one study focusing on the Karnali has used a limited number of stations for calibrating the hydrological model, and has offered impacts of CC on spatio-temporal distribution of water availability. Climate change directly affects the hydrological cycle. Globally, CC is projected to impact surface and groundwater availability, affecting both the quantity and quality of future waters (UN-Water 2011; IPCC 2014). Climate change alters the timing and intensity of rainfall, temperature, and runoff; challenges coping capacities of existing infrastructures; and brings higher risk of drought and floods, which ultimately affects the hydrological cycle, locally and globally (Kundzewicz et al. 2009; Zhu and Ringler 2012). The impacts will be further aggravated by demographic, economic, environmental, social, and technological activities (UN-WWAP 2015). Understanding the extent and the significance of CC-induced alterations in the hydrological cycle and subsequent water availability is of great interest to environment and water resource managers. Several studies are being carried out at global, regional and local scales to understand water availability under CC (Christensen et al. 2004; Gosain et al. 2006; Kundzewicz et al. 2009; Zhu and Ringler 2012; Vaghefi et al. 2013; Devkota et al. 2015; Bharati et al. 2016; Trang et al. 2017; Aryal et al. 2018). However, many Nepalese basins such as KarMo and Mahakali still lack such studies.

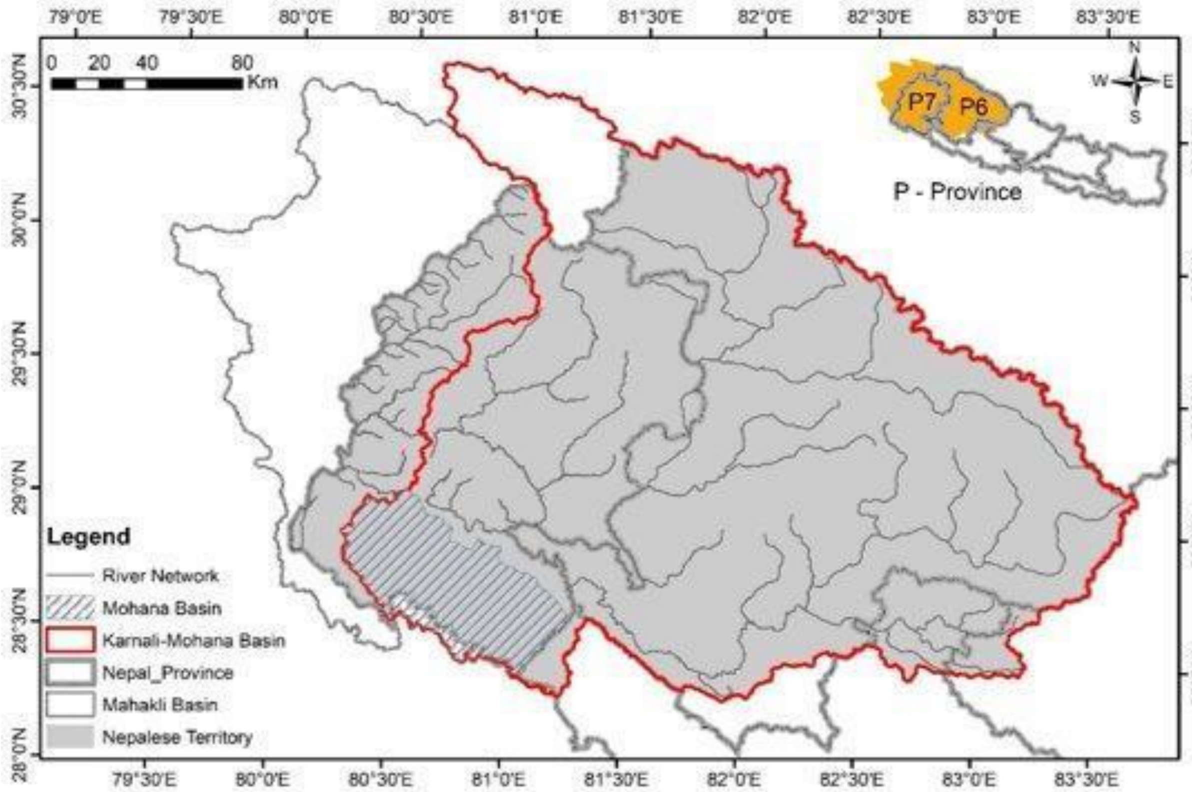

***Figure 2-1**: The Karnali, Mahakali and Mohana basins in Western Nepal*

In this backdrop, this chapter describes the biophysical characteristics of the KarMo and Mahakali rivers basins; characterizes spatio-temporal distribution in water availability; and provides information on projected future climate and associated impacts of CC on spatio-temporal distribution of water availability. Potential future climates are projected by correcting biases in 19 regional climate models (RCMs) and water availability is assessed by developing a well calibrated and validated hydrological model in Soil and Water Assessment Tool (SWAT) (Arnold et al. 1998). Other biophysical characteristics such as LULC, soil, and topography are characterized based on secondary data.

2.1. Approach

This study adopted a model-based approach to evaluate current and future bio-physical characteristics of the KarMo and Mahakali basins, and understand the spatio-temporal distribution of water availability. **Figure 2-2** depicts a flowchart of adopted methodology and **Annex 2-1** describes all the methods and data in detail. First of all, existing datasets were compiled, quality checked, and assessed for biophysical characterization of current conditions. Various geo-spatial and time-series data sets were acquired to characterize topography, soil types, LULC, hydro-climatology (please refer **Figure 2-3** for spatial coverage of the observed hydro-meteorological datasets) and development plans for water infrastructure projects in the study basins. Parallel efforts were undertaken to set up hydrological models for the two basins and prepare bias-corrected ensemble climate projections. The calibrated and validated models were forced with the projected future climatic data to simulate future hydrology. The model simulated results were analysed to assess changes in water balance components under current and future conditions and then evaluate spatio-temporal variations in the future water availability.

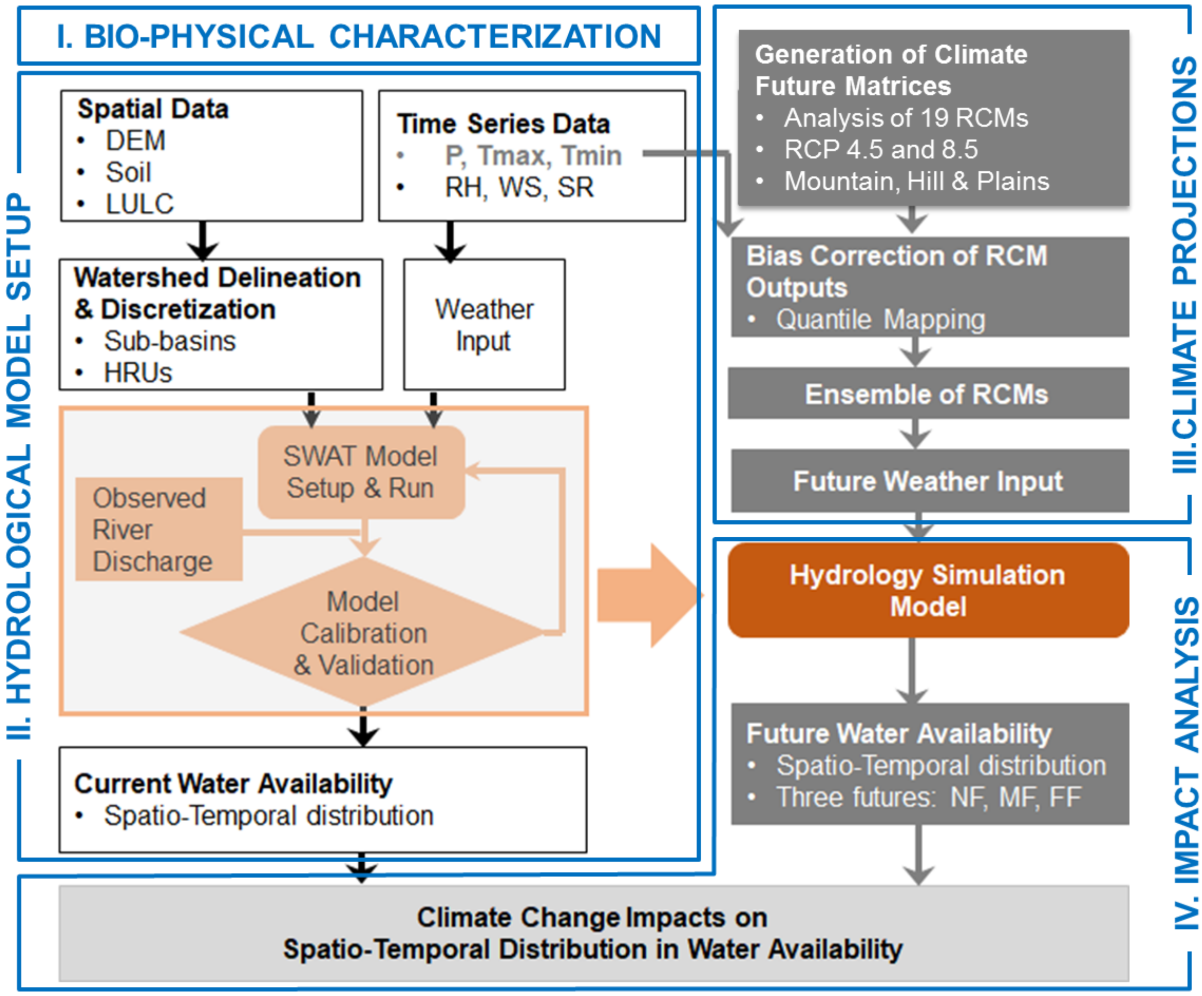

Figure 2-2*: Methodological framework for biophysical characterization of Karnali-Mohana and Mahakali basins under current and future conditions. NF, MF, and FF refer to Near-, Mid-, and Far-Futures, respectively; DEM is Digital Elevation Model, LULC is land use/cover; HRU is hydrological response unit; RH is relative humidity; WS is wind speed; SR is solar radiation; P is precipitation; T is temperature*

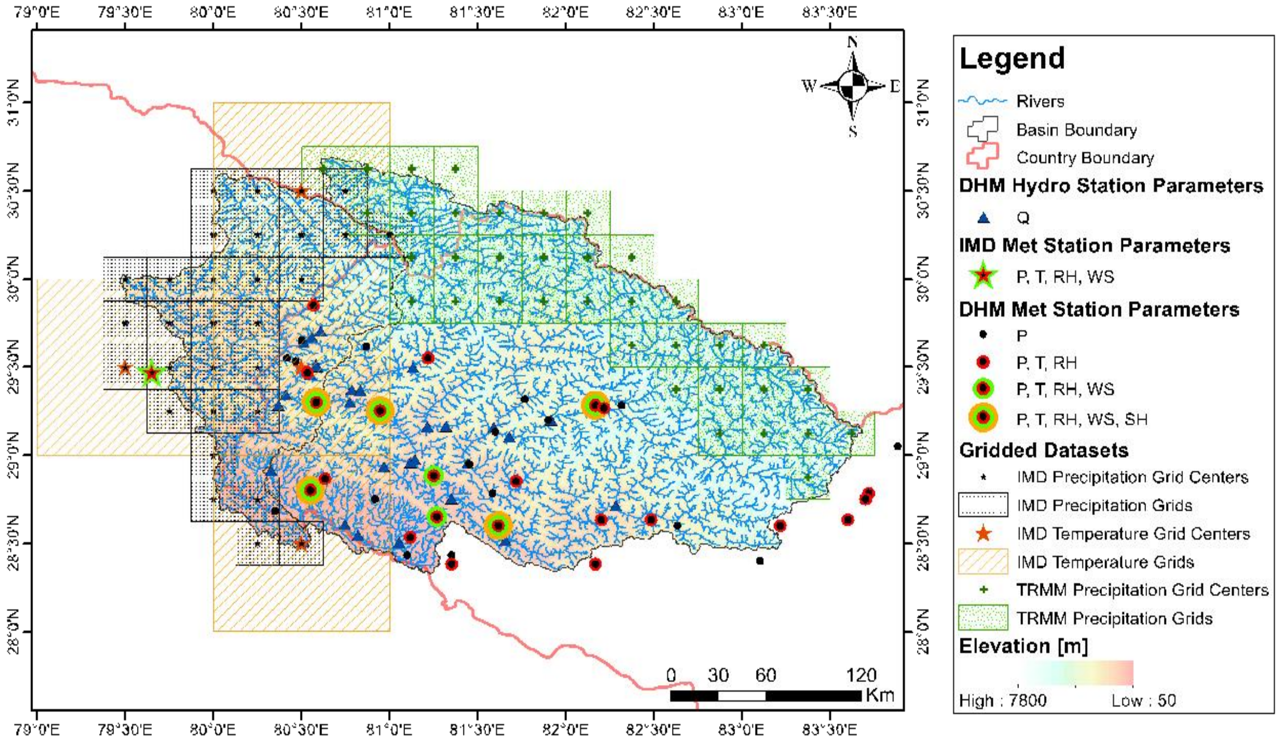

***Figure 2-3**: Spatial locations of DHM hydrological station (triangle), DHM meteorological station (circle), IMD meteorological station (star), IMD grids (Black – Precipitation and Orange – Temperature) and TRMM data grids (Green) selected after quality assessment for use in this study. Concentric circle in meteorological stations indicate the parameters (P, T, RH, WS, SH) available*

2.2. Projected Future Climate in Western Nepal

2.2.1. Climate future matrices

Figure 2-4 presents the regional changes in temperature and precipitation based on raw projections from 19 RCMs under the two representative concentration pathway (RCP) scenarios. The scatter points show mountain in blue, hill in orange and plains in green; symbols indicate the three future time-frames (near - x, mid - + and far – o). RCP 8.5 plot shows higher spatiotemporal spread than RCP 4.5. Scattered points for plains and hills are close to each other while those for the mountain are dispersed. The regions show greater variability in projections as well as diverge progressively from near to far future. Regional Δtmin and Δtmax are always positive but the values differ in magnitude and skewness across the regions. In the mountain, Δtmin and Δtmax points are higher and spread wider along the vertical axis compared to hills and plains. With minimum temperature projected to rise faster than maximum, future temperature ranges may thus be narrower with higher absolute values than in the past. Similar consistency in magnitude and direction is not found for annual Δpr over time or space. Δpr has wider spread for plain and hill than the mountain with values scattered horizontally.

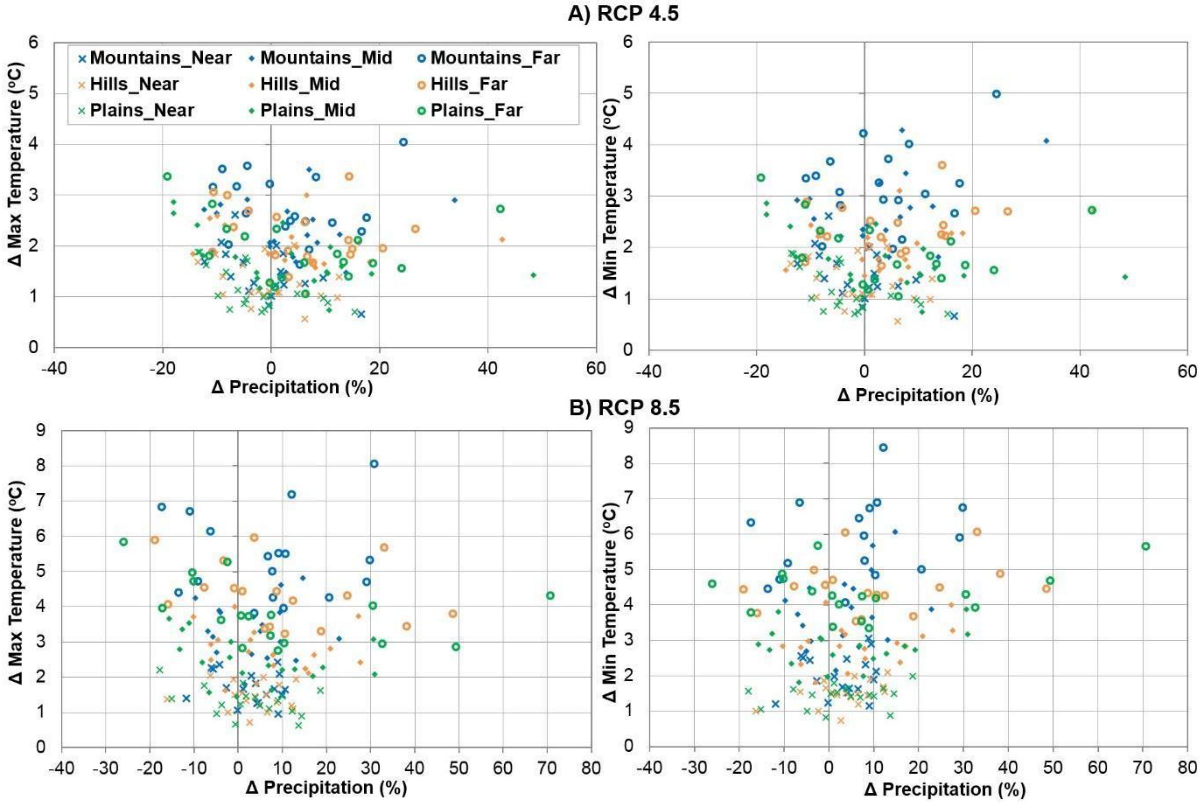

Figure 2-4*: Changes in long term 25-year average annual means from historical (1981-2005) to near (2021-2045), mid (2046-2070) and far (2071-2095) future timeframes in RCP 4.5 (top) and RCP 8.5 (bottom) scenarios. Figures on the left show percentage change in long-term average annual total precipitation versus maximum temperature, whereas on the right shows the changes in precipitation versus minimum temperature. Symbol colors distinguish the regions: blue-mountain, orange-hills and green-terai plains. Symbol shapes distinguish the timeframes: cross-near, dot-mid and circle-far futures.*

Δtmin and Δtmax for Western Nepal for RCP 4.5 ranges from 0.6 to 5.0 ºC and 0.6 to 4.0 ºC; while for RCP 8.5, Δtmin and Δtmax range from 0.7 to 9.7 ºC and 0.6 to 8.1 ºC. Five studies in literature (Christensen et al. 2013; Lutz et al. 2016; Sanjay et al. 2017a, b; Choudhary and Dimri 2018) report the annual mean temperature (Δtmean) values over South Asia and the HKH from 0.2 to 4.5 ºC and 0.3 to 7.2 ºC for RCP 4.5 and 8.5 respectively. These South Asian Δtmean ranges are comparable to the Δtmax/tmin for Western Nepal but underestimate Δtmax. Similarly, for entire Western Nepal, annual Δpr ranges from -19.2 to 48.3% for RCP 4.5 and -26.1 to 70.7% for RCP 8.5. In contrast, annual Δpr ranges for South Asia are narrower at -5.7 to 27% and -8.5 to 45% for RCP 4.5 and 8.5 scenarios based on 42 GCMs considered by Christensen et al., (2013) and 94 GCMs by Lutz et al., (2016). Values for Western Nepal are closer to seasonal precipitation changes reported by Sanjay et al., (2017a) and Choudhary and Dimri (2018) based on 10 RCMs. Naturally, our RCM-based ranges are closer to the literature ranges for RCM ensembles than GCMs. The comparison with literature also highlights the dilution of climate signal in spatiotemporal aggregation. Local changes can differ from regional and continental changes, especially for precipitation. RCMs should be considered in local studies to resolve finer microclimates within Nepal.

Due to high correlation between Δtmax and Δtmin, only Δtmax was considered for generation of the CF matrices. The number of models that fall in each of the Δpr and Δtmax classes are shown in **Annex 2-2.** Consistent with global trends, no models project a decrease in temperature and very few project dry conditions. For the mountains, model consensus is highest for "Hotter" future while for the hills and plains "Warmer" future dominates. Precipitation change in all regions predominately falls under the +/-10% "Little change" category. The number of models projecting "Little change" is nearly three times that of other Δpr classes. Redefining Δpr classes to separate smaller model projections may be considered, keeping in mind that classes should accommodate future RCM additions. The RCMs that fall under different CF matrices for two RCP scenarios and three future periods considered and region-wise means and variations of projected temperature and precipitation values are elaborated in **Annex 2-2**.

2.2.2. Bias-corrected projection

Using the CF matrices, bias-corrected multi-model ensembles of precipitation and temperature were prepared at nine meteorological stations for the 10 climate scenarios. Out of the nine stations, two (202 and 303) lie in the Mountain; four (i.e., 104, 406, 513 and 514) in the Hill; and three (i.e., 140, 187 and 225) in the Tarai plain. **Annex 2-3** presents historical long-term average seasonal total precipitation and maximum temperatures based on observed data, raw scenarios ensembles and bias-corrected ensembles. It reveals that future temperatures are higher than historical values across all seasons and stations with highest warming seen in mountain stations 202 and 303. There is no discernible trend in precipitation. The deviation of the historical raw RCM ensembles (dashed lines) from the historical observed values indicate a spatial trend in bias. Precipitation bias also shows a seasonal trend. In the mountain and hill, there is wet bias across all seasons for the majority of the scenarios. But in the plain, there is a dry bias in the monsoon (JJAS) and wet bias in winter (DJF).

Table 2-1 summarizes the range in seasonal and annual average changes seen across each region in the figure. Trends in annual Δpr and Δtmax across the various scenarios are similar for the stations in the same region. The average annual Δpr ranges from -14.1 to 16.7%, for mountain, -10.3 to 20.7% for hill and -23.8 to 16.4% for plain. Across all regions average seasonal Δpr values (-51.6 to 196.8%) are much higher and variable than annual values (-23.8 to 20.7%). Increasing trends in average annual Δtmax across the climate scenarios and stations are similar. The average annual Δtmax, ranging from 0.5 to 5.3 ^{o}C across the mountains and 0.8 to 4.5 ^{o}C across the hills and plains are well representative of seasonal changes.

Table 2.1*: Range in seasonal and annual average Δpr (%) and Δtmax (°C) values across nine meteorological stations in the three regions*

Mean Δpr [%]	DJF	MAM	JJAS	ON	Annual
Mountain (202, 303)	-45.7 to 43.2	-41.8 to 73.8	-3.1 to 22.3	-51.6 to 104	-14.1 to 16.7
Hill (104, 406, 513, 514)	-32.5 to 47.7	-29.7 to 54.5	-6.9 to 22.9	-45.7 to 196.8	-10.3 to 20.7
Tarai (209, 207, 405)	-41.1 to 62.5	-46.8 to 54.3	-21 to 14.8	-46.5 to 123.4	-23.8 to 16.4
Mean Δtmax [°C]	DJF	MAM	JJAS	ON	Annual

Mountain (202, 303)	1.1 to 8.0	0.5 to 7.0	0.4 to 4.1	0.1 to 4.2	0.5 to 5.3
Hill (104,406, 513, 514)	0.9 to 5.8	1.0 to 5.8	0.7 to 3.8	0.6 to 4.1	0.8 to 4.5
Tarai (209, 207, 405)	1.1 to 5.8C	0.6 to 5.7	0.6 to 3.4	0.5 to 4.0	0.8 to 4.5

2.3. The Karnali-Mohana Basin

2.3.1. Bio-physical and hydro-climatic characterization

The Karnali River Basin (KRB) starts in the High Mountains. The headwaters of the Karnali River lie about 230 km North from Chisapani (mainstream Karnali River length) covering an elevation of 69 m in the south to 7,726 m in the north (**Figure 2-5**). Nearly 55% of the basin is demarcated as the Mountains, 30% as the Hills and 15% as the Tarai plains. The Mohana river, lying in the south of the Karnali Basin, descends from the Churia range, flows through Terai plain and meets with the Karnali river at Nepal-India border. Watershed area of the Mohana delineated above the Nepal-India border is 3,730.3 km^2. The combined basin area of Karnali-Mohana (KarMo) above the Nepal-India border is 49,889 km^2. About 6.9% of the KarMo basin area lies in China. Major tributaries of the Karnali River are Bheri, Thuli Bheri, Seti, Mugu Karnali and Humla Karnali. Unlike the dendritic drainage pattern of the Karnali river that merges in a main river stream, Mohana comprises a network of parallel streams that do not merge within the Nepalese borders. About 1,360 glaciers cover 1,740 km^2, and 907 glacial lakes cover 37.7 km^2 of the basin (Ives et al. 2010).

For meteorological characterization, only 36 out of the 57 meteorological stations from the Department of Hydrology and Meteorology (DHM) of the Government of Nepal were selected after quality assessment for use in this study. Out of the selected stations, only five have all five parameters (P, T, RH, SH, WS), two have four parameters (i.e., no SH), and 15 have three parameters (i.e., no SH and WS) and the remaining 14 have only rainfall. Spatial variation in average annual rainfall and temperature (maximum and minimum) at selected stations is shown in **Figure 2-5**. It is clear that the north-eastern part of the basin is colder and drier with the hills and mountains creating rain-shadows on their backside. Rainfall shows a more heterogeneous pattern suggesting the presence of micro-climates induced by topography. For example, station 107 lying in the mid-hills has the highest long-term average annual total precipitation of 2,426 mm, which is much higher than rainfall seen at station 104 and 102 lying in the south, or station 202 lying along the same latitude. Station 612 in the north east has the lowest long-term average annual total precipitation at 82 mm. Stations lying at the interface between the mid-hills and the southern Tarai like 209, 405 and 206 have higher averages than stations in the Tarai or mid-hills. Temperature shows more spatial homogeneity than precipitation, with gradual decline in maximum and minimum temperatures going from south to north. Both long term average Tmin and Tmax are lowest at station 612 at -1.1 °C and 12.9 °C. Average Tmax is highest at station 417 with 31.2 °C.

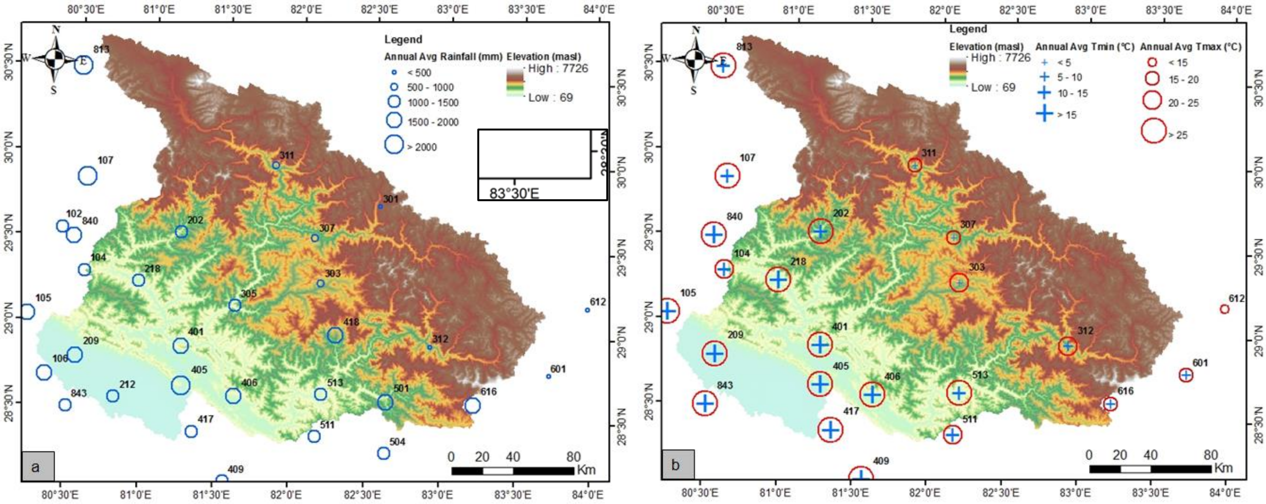

Figure 2-5: *Spatial distribution of average annual rainfall and temperature within the Karnali-Mohana River Basin – a) Accumulated Rainfall; b) Maximum and Minimum Temperatures. Avg is average; masl is meters above mean sea level. Topographical map for Karnali-Mohana (KarMo) River Basin based on ASTER GDEM (NASA JPL 2009).*

In the case of discharge, 20 out of the 22 hydrological stations within KarMo basins were selected after quality assessment. The hydrological characteristics at *Chisapani station (ID: 280; Catchment Area = 42,890 km^2),* the most downstream station in the KarMo basin is shown in **Figure 2-6**. Between 1980-2015, the daily discharge at Chisapani averaged 1375 m^3/s, with extreme daily values recorded at a minimum of 95 m^3/s and a maximum of 17900 m^3/s. The annual average daily varies between 1013-1790 m^3/s (**Figure 2-6a**) with a standard deviation of 176 m^3/s. The long-term average monthly in **Figure 2-6b** has a standard deviation of 1380 m^3/s suggesting that the intra-annual variability is stronger than the inter-annual variability. Discharge follows the monsoon strongly with flow peaking in August. The rising of the monthly hydrograph seen in April-May suggests that snow/glacier melt in the spring season provides an important contribution to the pre-monsoon flow. Strong influence of monsoon is also seen in other discharge stations upstream of Chisapani, but snowmelt contribution may not be as noticeable.

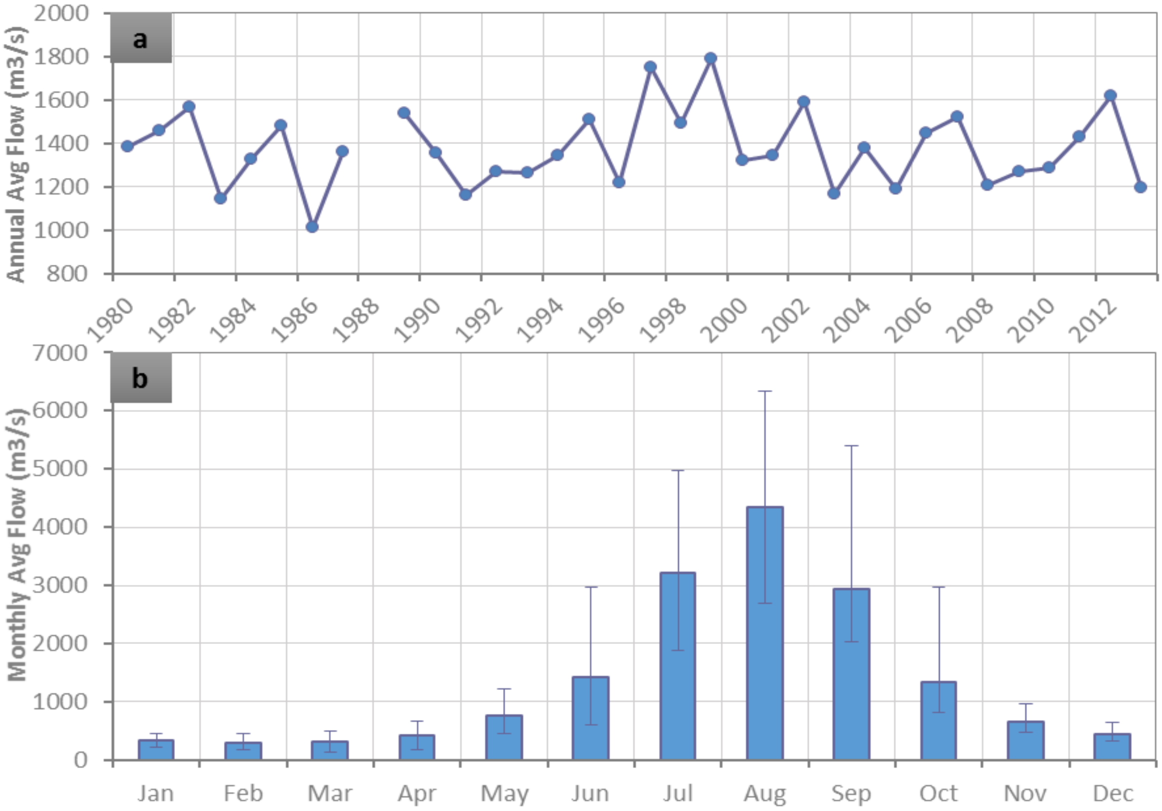

Figure 2-6: *Hydrological characteristics of the Karnali river basin at Chisapani station (ID: 280; Catchment Area = 42,890 km^2) from 1980-2015 – a) Historical trend in average annual river discharge (m^3/s); b) Long term average monthly flow (m^3/s) with error bars indicating monthly minimum and maximum values.*

There are 21 different soil types in KarMo Basin distributed as shown in **Figure 2-7**. The most dominant soil is the Gelic Leptosols (LPi) that covers nearly 34.2% of the KarMo basin. It is followed by Eutric Regosols (RGe, 20.5%), Humic Cambisols (CMu, 14.2%), Eutric Cambisols (CMe, 11.8%) and others. The LULC distribution within the KarMo River Basin was grouped into nine generic LULC types as shown in **Figure 2-8**. Forest cover is the most-dominant LULC type, constituting more than one-third of the basin area. It is followed by grassland, (19.9%), agriculture (15%), barren land (13.9%) and snow/glacier (12.7%). Agriculture is largely rainfed with only 3.1% of the basin comprised of irrigated agriculture. The dominant soils and LULC types suggest the pristine and natural conditions of the landscape in the basin that supports a rich biodiversity of flora and faunas. The basin includes four national parks: Shey Phoksundo, Rara, Bardiya and Khaptad and the Dhorpatan hunting reserve (**Figure 2-8**). Additionally, many important ramsar areas like Ramaroshan and Ghodoghodi wetlands also lie in the basin.

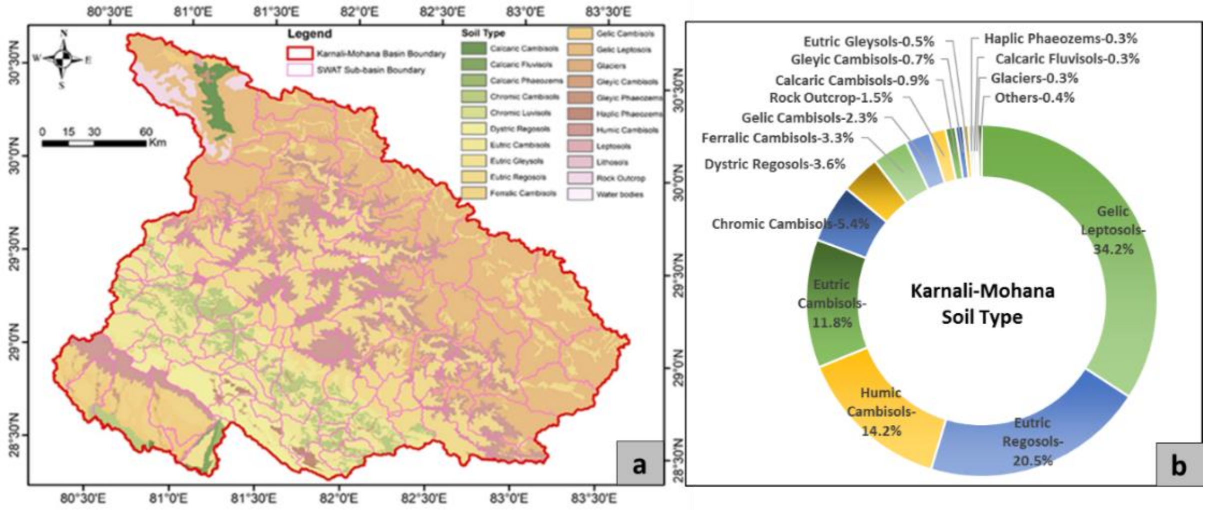

***Figure 2-7**: Soil types across Karnali-Mohana basin based on* (Dijkshoorn and Huting 2009)*. Please refer to* Pandey et al. (2020a) *for high-resolution version of the map.*

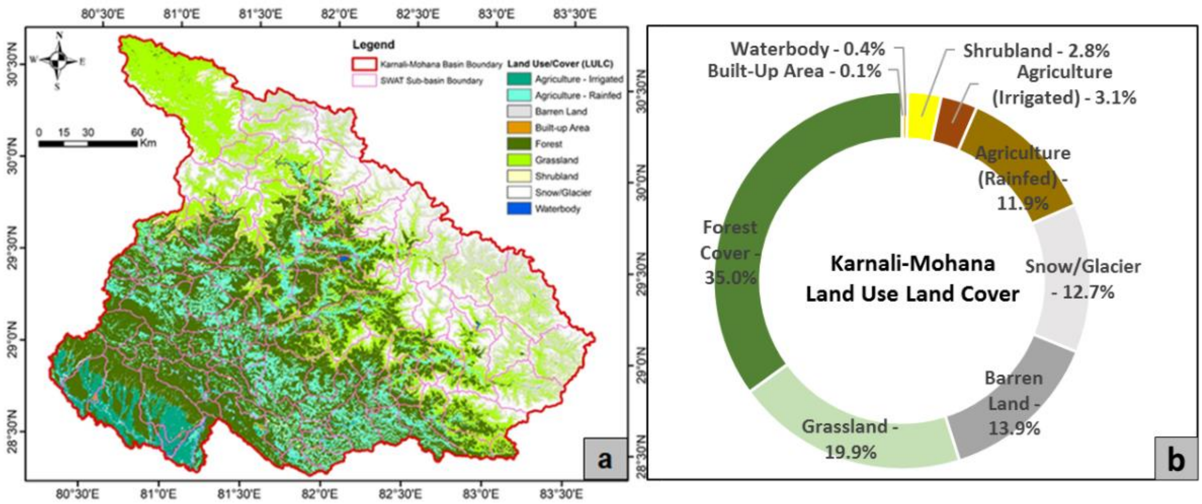

***Figure 2-8**: Land use/cover distribution within Karnali-Mohana basin based on ICIMOD (2012). Please refer to Pandey et al. (2020a) for high-resolution version of the map.*

Over 127 hydropower projects with capacity greater than 0.5 MW are also located in the KarMo basin. Out of these, 12 are under construction, 27 are planned, and the rest are proposed (**Figure 2-9a**). In terms of type, 18 out of 127 are storage type projects and the rest are run-of-the-river (RoR). The proposed installed capacities range from 0.5 to 1,003 MW. Forty-eight irrigation projects with net command area (NCA) of over 100 ha exist in throughout the basin (**Figure 2-9b**). The NCA of the identified projects varies from 100 – 98,026 ha. Out of them, only one is under construction and few are under extension while the rest are already completed. There are ample prospects for future water resource development activities in the basin. Understanding spatio-temporal distribution in water availability and implications of CC is therefore important for stakeholders across various water-use sectors.

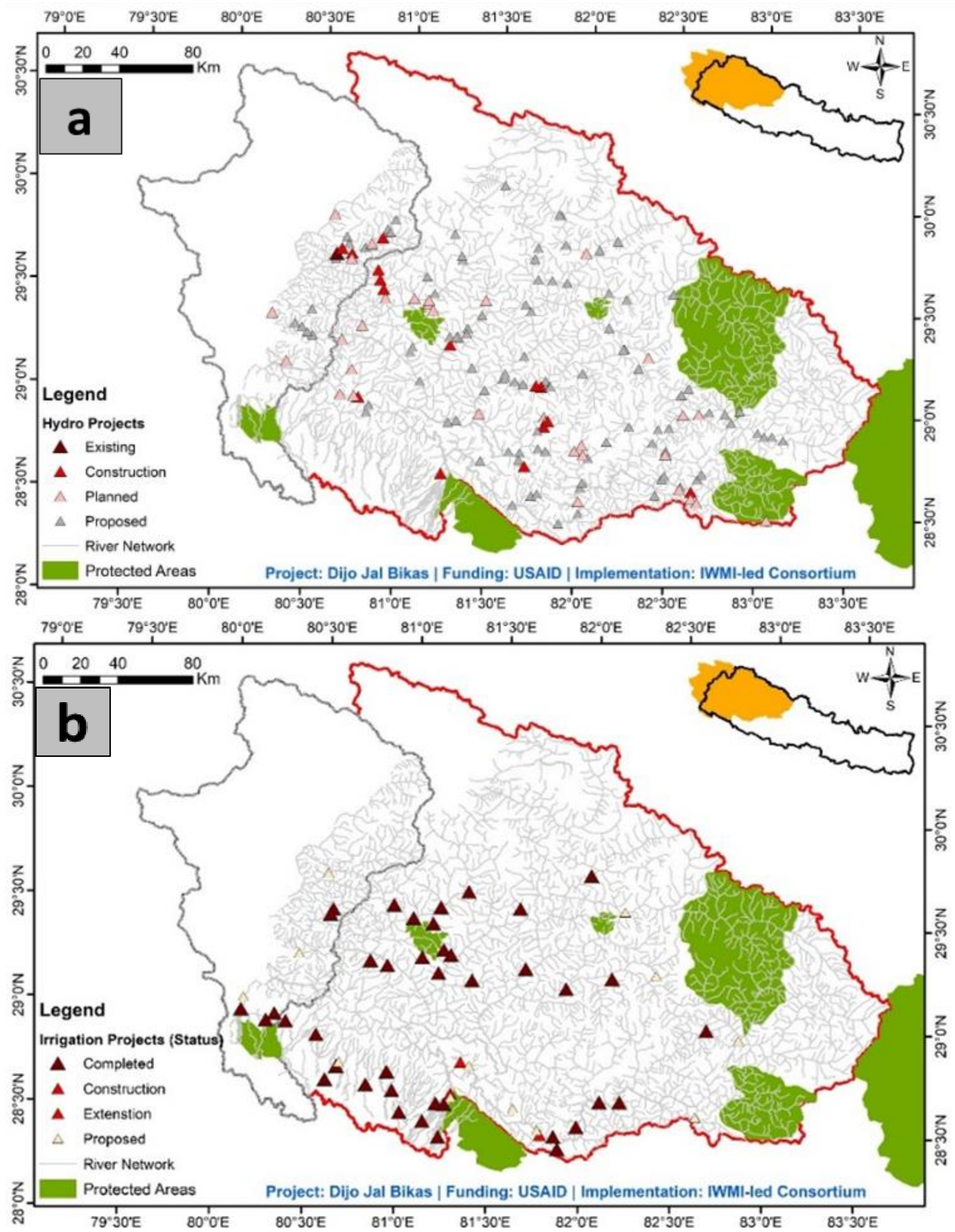

***Figure 2-9**: a) Hydropower projects and b) Irrigation projects in the Karnali-Mohana and Mahakali basins in various stages of development, alongside the protected areas in the basins.*

2.3.2. Current water availability

Current as well as future water availability were assessed by developing a hydrological model in SWAT, using the spatial and time-series datasets presented in **Section 2.4.1**. Elaborated description as well as discussion of results are provided in **Annex 2-7** (Pandey et al., 2020a). The KarMo SWAT model was calibrated and validated at 10 hydrological stations shown in **Figure 2-10**. Results from the model simulations were analysed considering spatio-temporal distribution across five major tributaries (Seti, Karnali-main, Tila, Bheri and Mohana) and five geographic divisions (of northern Trans-Himalayas (TrH), Mountains (Mnt), Hills (Hil), and southern Terai flatland, which is a part of Indo-Gangetic Plain (IGP)) of Karnali and Mohana. At each station, a summary plot, as shown in **Annex 2-4,** was prepared to evaluate hydrological model performance at daily and monthly scales by analyzing scattering of observed versus simulated points from the mean, model capability to reproduce flow duration curve (FDC), and model performance indicators. Please refer to **Annex 2-4** for the model performance as well as calibration parameters.

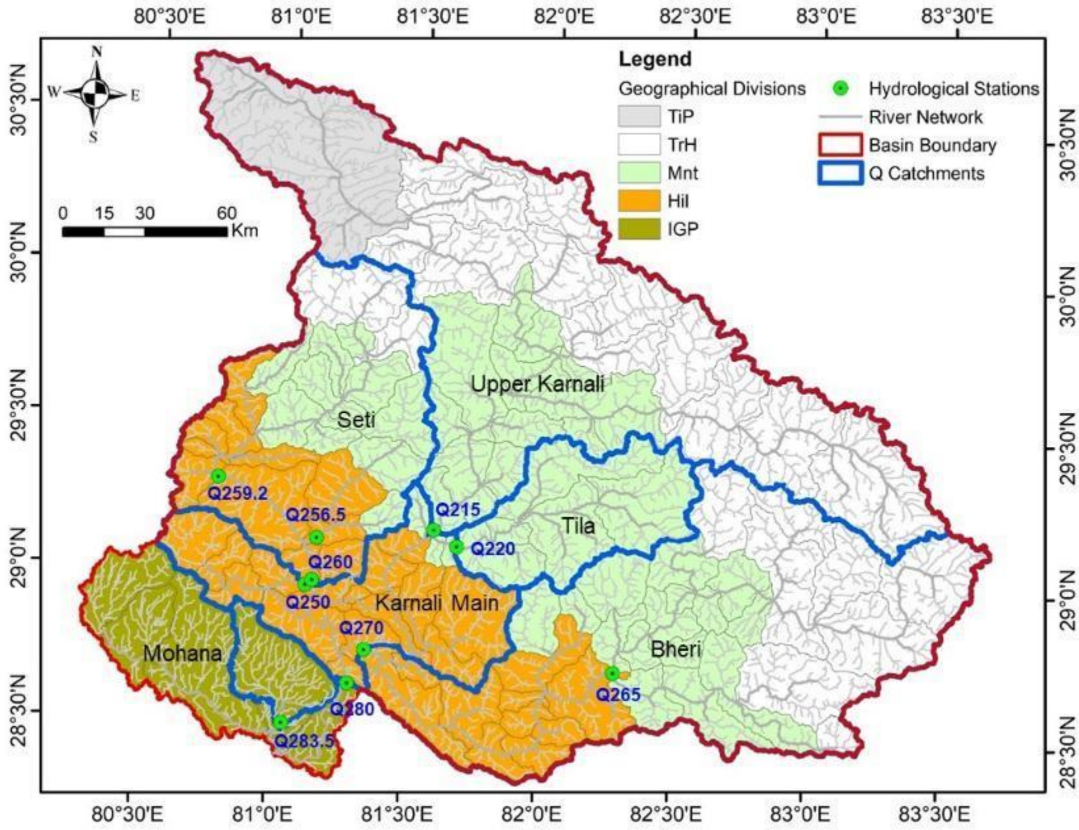

Figure 2-10*: Hydrological stations and major sub-basins in KarMo considered for development of the basin SWAT Model. Geographic divisions consider TiP - Tibetan Plateau, TrH - Trans-Himalaya, Mnt – Mountain, Hil – Hill and IGP - Indo-Gangetic Plain.*

2.3.2.1. Spatial distribution

Figure 2-11 depicts sub-basin wide distribution of major water balance components: average annual precipitation (P), actual evapotranspiration (AET) and net water yield, within the KarMo basin as simulated by the model for the baseline period (1995–2009). The net water yield refers to a combination of surface runoff, lateral flow, and groundwater flow, with deduction in transmission losses and pond abstractions (Arnold et al. 1998). The average annual P over the entire basin is 1,375 mm while net water yield is 1,004 mm. The average annual AET is 474 mm, which is about 34% of the average annual P.

The water balance components vary spatially across the sub-basins, showing similarities within the five geographical regions considered. We have merged TiP and TrH together from hydrological analysis viewpoint as there is only one sub-basin falling under TiP. The precipitation varies from less than 500mm to above 2,000 mm (**Figure 2-11**a). The Mnt (P = 1,435 mm); Hil (P = 1,625 mm), and IGP (P = 1,566 mm) regions of the basin are relatively wetter compared to the

TrH (P = 875 mm) region (**Figure 2-12**). Similarly, the average annual AET across the sub-basins varies from less than 200 mm to over 650 mm (**Figure 2-11b**). The AET values are higher in the Hil (587 mm) and IGP (553 mm) regions, compared to other two regions. Higher AET in IGP is owing owing to greater area under cultivation and proximity to the oceanfront and equator. The AET decreases as we move to the sub-basins from the southern plains to the northern Trans-Himalayan regions (**Figure 2-12**) as temperature decreases with altitude. The AET in Hil, Mnt, and TrH regions are 587 mm, 528 mm and 227 mm, respectively. The distribution pattern of AET also follows that of precipitation, which is the major source of moisture in Western Nepal.

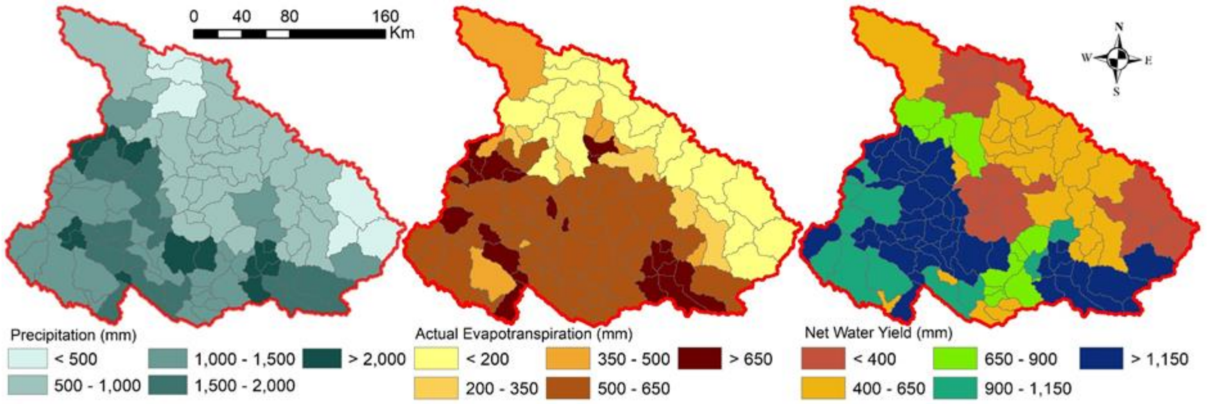

***Figure 2-11**: Spatial distribution of a) average annual precipitation (P), b) actual evapotranspiration (AET) and c) net water yield (Q) across sub-basins in Karnali-Mohana basin*

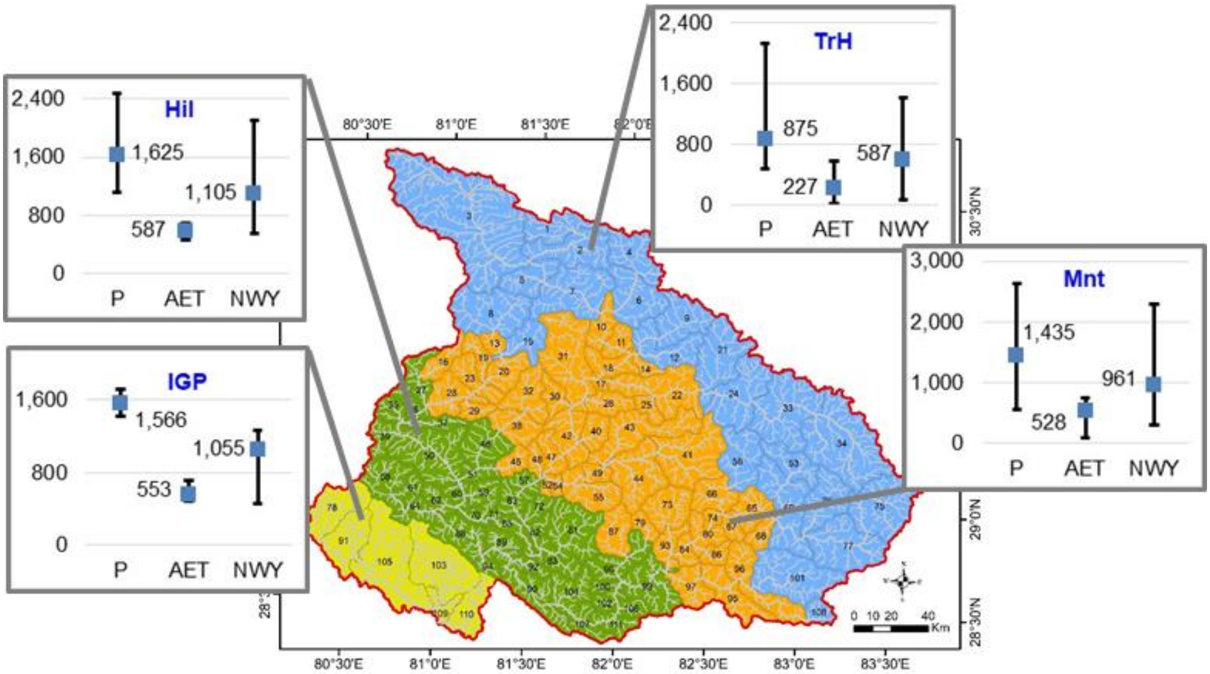

***Figure 2-12**: Spatial distribution of average annual precipitation (P), actual evapotranspiration (AET) and net water yield (Q) across geographical regions in the Karnali-Mohana basin. TrH is Trans-Himalaya; Mnt is Mountain; Hil is Hill; IGP is Indo-Gangetic Plain. Mean displayed in the figures are means. Polygons inside the regions are sub-basins used in SWAT and numbers indicate sub-basin IDs.*

Long-term average net water yield in the form of discharge at the sub-basin outlet varies across the sub-basins from 1.1 to 1,357.5 m^3/s, where sub-basin areas range from 44 to 3,183 km^2. The water yield across the KarMo sub-basins varies from less than 450 mm to above 1,150 mm (**Figure 2-11c**). In terms of geographical regions, the long-term average net water yield aggregated over the region decreases as we move up from Hil to TrH with values of 1,105 mm in Hil, 961 mm in Mnt, and 587 mm in TrH (**Figure 2-12**).

In fifty (or 45%) sub-basins, net water yield is more than 80% of P and in 101 (or 91%) sub-basins the water yield is more than half of P. The surface runoff is the dominant contributor in net water yield across most of the sub-basins, whereas the contribution of groundwater and lateral flow varies. Two-third of the sub-basins have more than one-third contribution from surface runoff and the rest from other components. In 28% of the sub-basins, contribution of surface runoff is above 50%. The groundwater contribution to the net water yield is less than one-third in 105 (or 94.6%) sub-basins and less than one-quarter in 93 (or 83.8%) sub-basins. It is to be noted that direct comparison in terms of absolute values may not provide critical insights as the sub-basin sizes vary largely from 44 to 3,183 km^2

2.3.2.2. Temporal distribution

The monthly average water balance for the baseline period shows a large temporal variation (**Figure 2-13**). Mean seasonal distribution of P in KarMo varies from 69 mm in the post-monsoon to 1,098 mm in the monsoon season. AET is related to P, land use/cover as well as temperature. Mean seasonal distribution of AET in the basin is 117 mm, 290 mm, 44 mm, and 23 mm, respectively, during pre-monsoon, monsoon, post-monsoon, and winter seasons, respectively. In case of net water yield, distribution during the four seasons are 85 mm, 654 mm, 116 mm, and 72 mm, respectively. The net water yield does not always follow the P patterns because it is also affected by rainfall intensity, soil properties, subsurface storage and land use/cover. For example, rain falling with high intensity on bare and compacted soils will produce higher runoff than longer rainfall events on deep soils and cropped areas (Bharati et al. 2014). The results still show that the monsoon is the main hydrological driver as all the water balance components (i.e. P, AET and water yield) are the highest during the monsoon.

The monsoon season (JJAS) contribution is 73%, 61%, and 71% in the average annual P, AET, and net water yield, respectively, at the KarMo outlet (**Figure 2-13**), which is comparable to values obtained by Bookhagen and Burbank (2010). As per the results from SWAT simulation, average annual flow volume at the basin outlet under the current climatic scenarios is 46,250 million-cubic-meters (MCM); 71% of which is available during JJAS. The monsoon season contribution varies across the sub-basins, from 63% at the outlet of Q220 to 68% at Q215, 71% at Q270, and 73% at Q260 (please refer to **Figure 2-10** for the station locations).

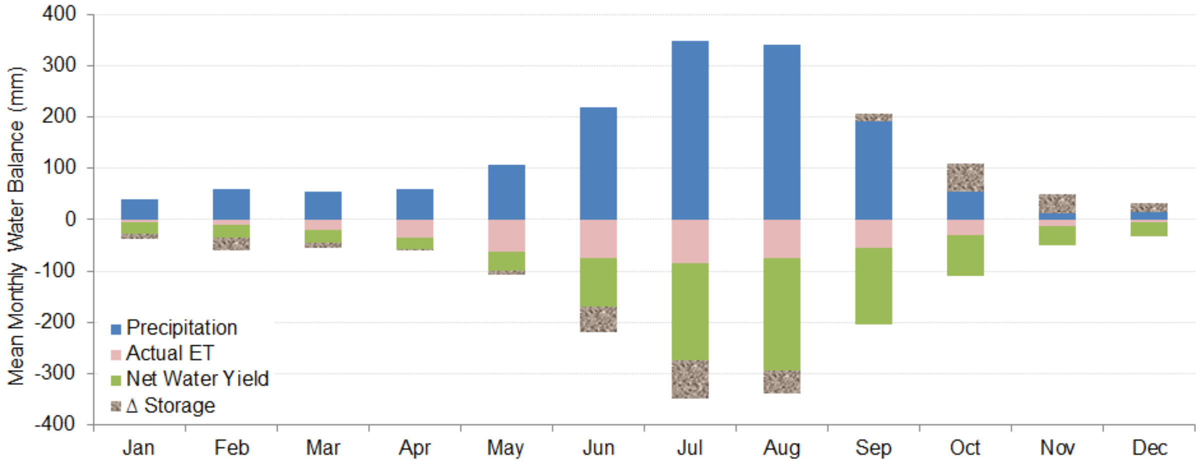

Figure 2-13*: Mean monthly (1995-2009) simulated water balance in the KarMo basin. The 'Δ storage' is a collective term including groundwater recharge, change in soil moisture storage in the vadose zone and model inaccuracies.*

2.3.3. Future water availability

Future temperature and rainfall time series projected based on an ensemble of selected RCMs for various climate future scenarios (**Section 2.3.2**) was used as input to already calibrated and validated SWAT to simulate CC impacts on future water availability. Changes in water balance components over the sub-basins as well as month/season were analyzed to understand spatio-temporal distribution of the changes under projected future climates. Output from the SWAT model was used as a baseline to compare with future scenarios. **Figure 2-14** summarizes the projected changes in average annual precipitation (green), maximum temperature (brown/yellow), and discharge (blue) for RCP 4.5 and 8.5 consensus scenarios. Trends in annual precipitation and temperature across the various scenarios are similar for the stations in the same region. The average annual precipitation ranges from -14.1 to 16.7%, for mountain, -10.3 to 20.7% for hill and -23.8 to 16.4% for plain. Average annual Δtmax increases across the climate scenarios and stations are similar. Average annual Δtmax ranging from 0.5 to 5.3 °C is highest for the mountain, with higher values for RCP 8.5 than RCP 4.5 farther in the future.

The discharge stations show varying levels of sensitivity to changes in precipitation and temperature. Specifically, station 215 in the mountain region shows higher increases with ΔQ varying from 48.2 to 63.8% while downstream station like 280 show minimal changes ranging from 01.6 to 11.6%. Maximum decline in discharge is seen in station 220 at -19.1% for the RCP4.5_NF_Consensus scenario. Stations 220, 270 and 280 appear less sensitive to climate change than others at an annual scale. Such difference in response of Q stations to Δpr may relate to the location of stations along the river. In RCP8.5_FF_HighRisk, the decline in precipitation across all meteorological stations, simulated discharge declines only in stations 220, 270 and 280, suggesting that they are rain-fed. The increasing and decreasing trends seen at station 220 and 270 across the different scenarios require further exploration of the water balance components and upstream-downstream linkages.

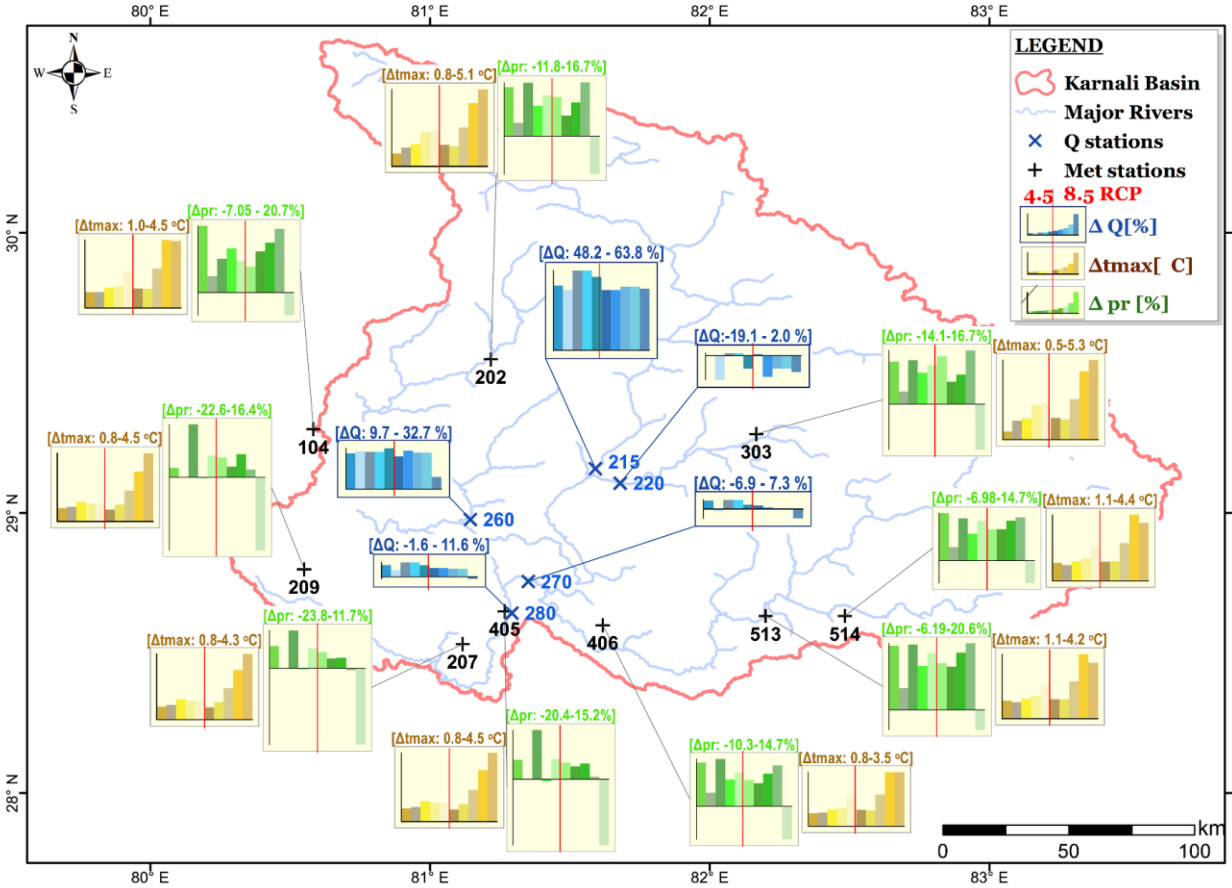

Figure 2-14: Green and brown bar charts show changes in average annual total precipitation (Δpr) and maximum temperature (Δtmax) respectively based on bias-corrected multi-RCM ensembles generated for ten climate scenarios at the nine meteorological stations. Blue bar charts show change in annual average discharge (ΔQ) at five discharge stations simulated by the SWAT model for the ten climate scenarios. Value range in each bar chart and unit is indicated above the chart. Order of climate scenarios in bar charts from left to right is: RCP4.5_NF_Low Risk, RCP4.5_NF_Consensus, RCP4.5_MF_Low Risk, RCP4.5_MF_Consensus, RCP4.5_FF_Consensus, RCP8.5_NF_Low Risk, RCP8.5_NF_Consensus, RCP8.5_MF_Consensus, RCP8.5_FF_Consensus, RCP8.5_FF_High Risk.

2.3.3.1. Spatial distribution

The sub-basin wide distribution in the change of water balance components: P, AET, and net water yield for the six consensus scenarios are presented in **Figures 2-15 to 2-17**. As seen in **Figure 2-15**, average annual P is projected to increase gradually from NF to FF. The rate of projected change, however, varies widely across the sub-basins extending beyond +/- 25% as visualized in **Figure 2-15**. Change in P as well as temperature (T) has altered AET from baseline value by -15% to 50% rates across the sub-basins as shown in **Figure 2-16**. The change in AET is more pronounced at the sub-basins in higher and middle elevations than at the lower elevations, potentially due to faster rising T in the mountains. Similar results are reported for the Koshi basin in Nepal as well (Bharati et al. 2014). The percentages of sub-basins that show increase (decrease) in precipitation under RCP4.5 are 44% (49%) in NF, 50% (46%) in MF, and 43% (47%) in FF, under both the RCP scenarios. Similarly, the sub-basins that show increase (decrease) in AET under the RCP4.5 scenarios are 74% (17%) in NF, 74% (15%) in MF, and 71% (18%) in FF.

As a result of changes in P and AET, average annual flow at outlets of the KarMo sub-basins are projected to alter as shown in **Figure 2-17**. The spatial variation in the change in average annual flow also follows similar patterns of future P, however, the variations across the sub-basins fluctuate. The impacts in the sub-basins at higher altitudes are relatively higher - perhaps due to melting of snow/glaciers as a result of changes in T and increases in ET. This indicates that high mountain regions are more vulnerable to CC than the flatlands in the lower part of the basin. For example, under RCP4.5 scenarios, the regional average net water yield in NF for IGP, Hil, Mnt, Mnt and TrH are projected to change by 8.3%, -0.2%, -2.8% and -5.6%, respectively.

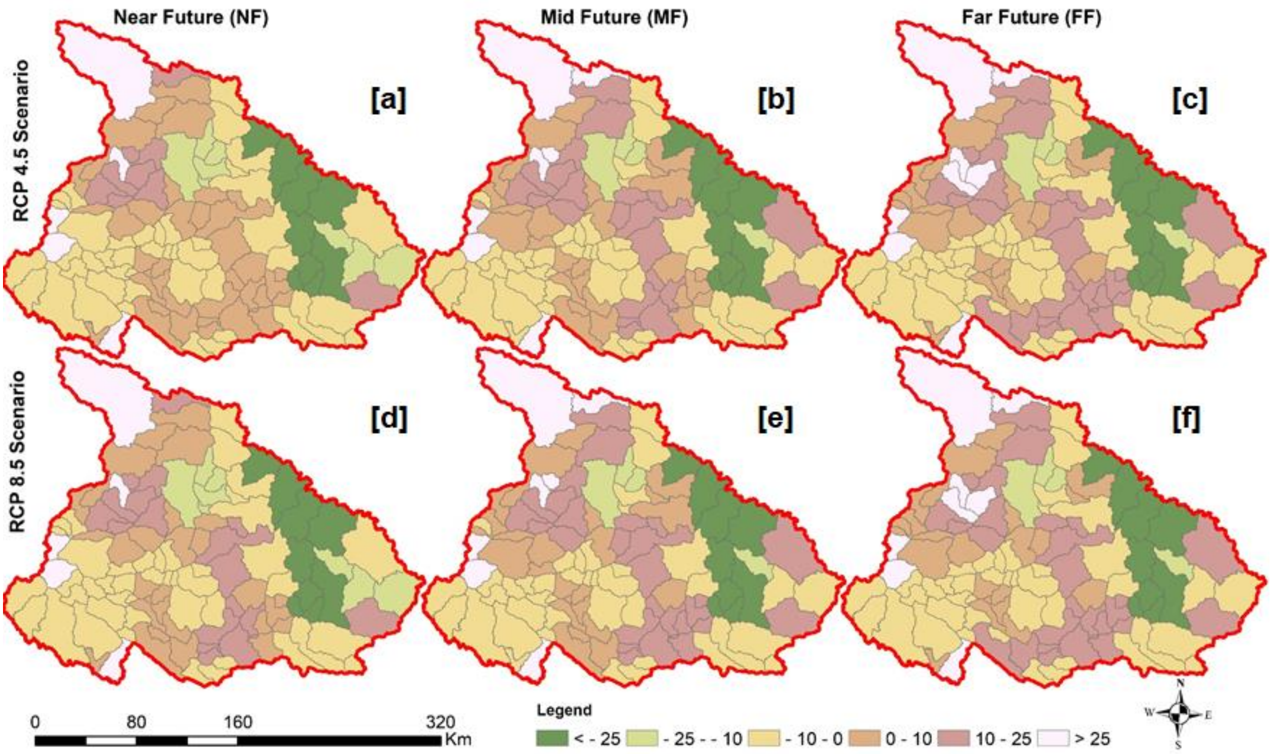

***Figure 2-15**: Change (%) in average annual precipitation w.r.t. reference period.*

2.3.3.2. Temporal distribution

The simulated changes in average annual flow as well as variation across the months at the outlets of Karnali-main and its key tributaries are tabulated in **Table 2-2**. The average annual flow volume near to the outlet of Karnali-main (before joining Mohana) [at Q280 station] for the reference period is estimated at 44,602 MCM, which in NF and MF are projected to increase by only 0.6% and 6.4% under RCP4.5 and 9% and 4.2% under RCP8.5 scenarios, respectively. The projections, however, vary across the months for different scenarios and future periods. For example, projected changes under both the scenarios in NF vary from -12.9% (June) to 25.2% (January). When moving towards mid-future, it varies from -10.6% (June) to 47.3% (April); and in the far-future it ranges from -14.9% (June) to 28.7% (January). Station Q270 and Q215 show similar trends in the change in monthly averages as Q280 where future flow volume declines in the monsoon and slight increase in the post monsoon and winter seasons.

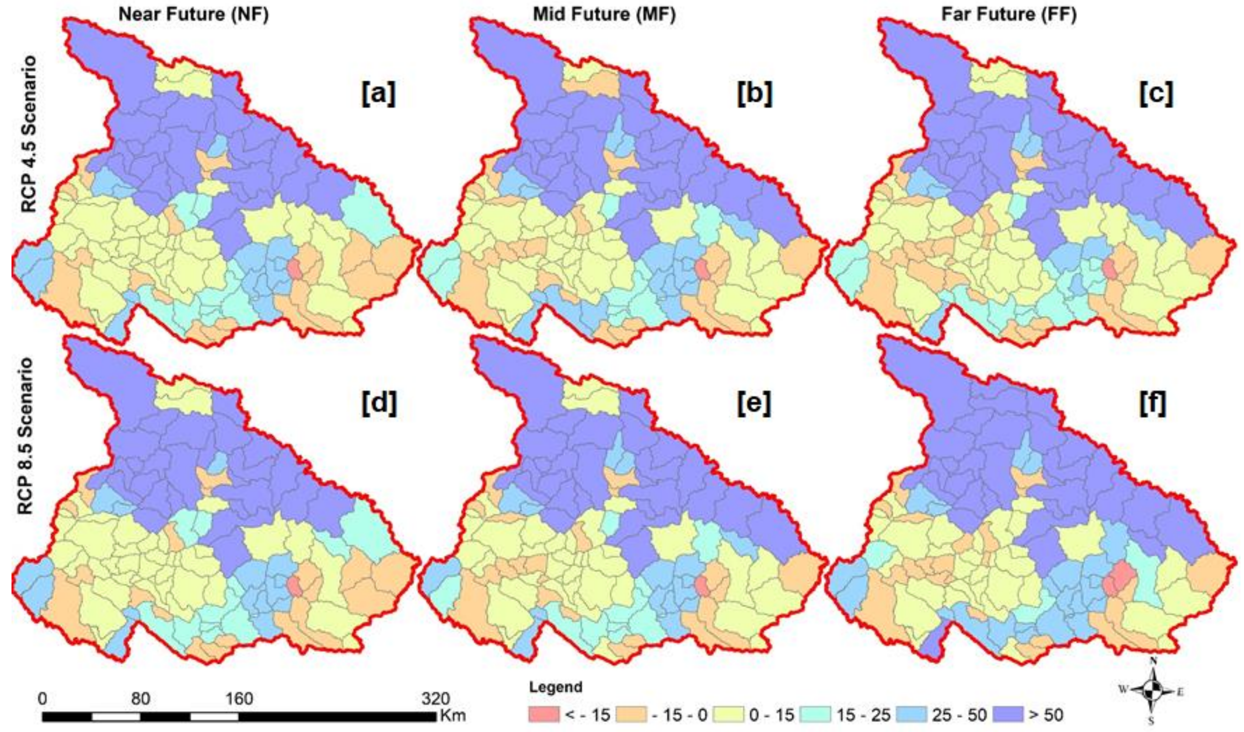

Figure 2-16: *Change (%) in average annual actual evapotranspiration w.r.t. reference period.*

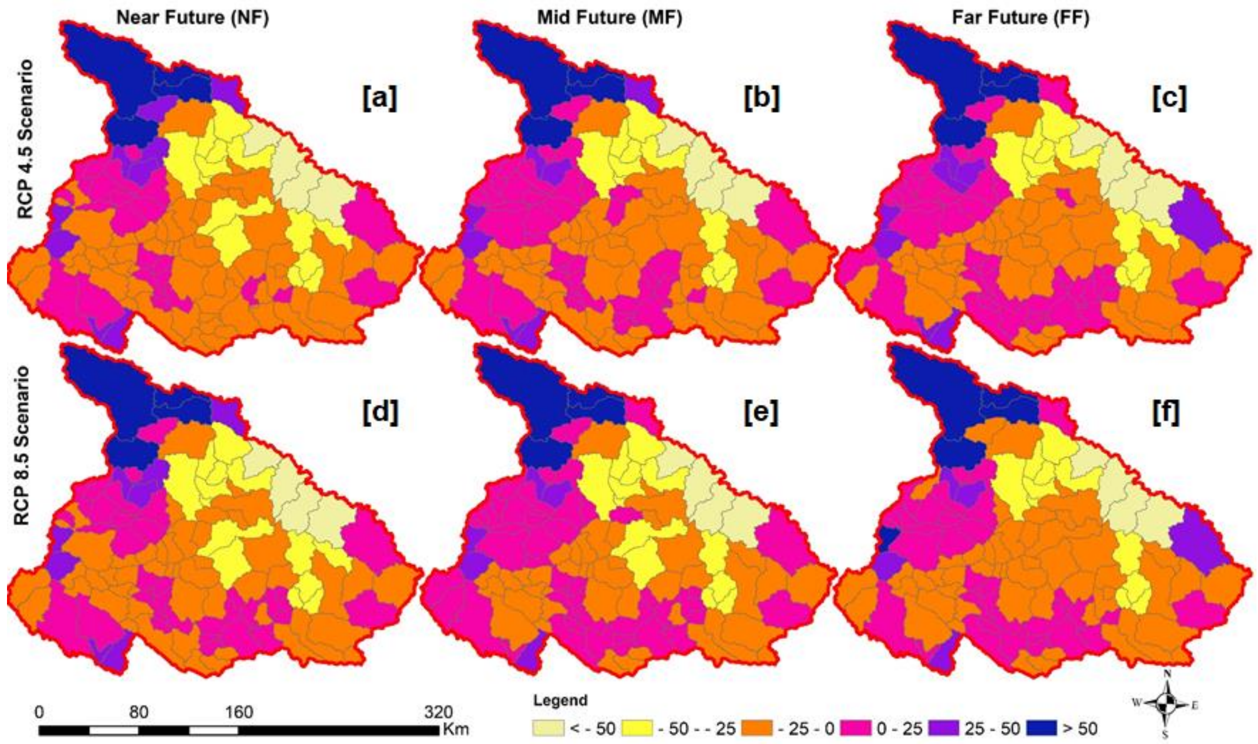

Figure 2-17: *Change (%) in average annual flows w.r.t. baseline.*

Table 2.2: *Monthly and annual average change [%] in river flow from baseline simulated at the outlets of five tributaries of Karnali under six consensus scenarios.*

	Scenarios	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Q215 [Upper Karnal]	**Baseline (m3/s)**	**83.5**	**74.7**	**80**	**124.9**	**284.6**	**445.5**	**662.9**	**750.8**	**460.4**	**221.1**	**133.4**	**100**	**285.2**
	RCP4.5-NF	20.5	12.8	21.6	43.6	-16.3	-31.2	-7	-8.3	-9.4	-3	-2.8	9.9	-7.3
	RCP4.5-MF	37	15.1	48.8	72	-6	-24.5	2.3	2.4	-7.7	0.4	9.5	58.2	2.3
	RCP4.5-FF	27.7	14.8	34.3	45	-12.1	-23.7	0.4	0	-10.3	0.6	8.9	47	-1
	RCP8.5-NF	19.9	13.7	23.6	40.8	-16.6	-30.2	-6.7	-8.2	-9.5	-2.7	-2.4	10.1	-7.2
	RCP8.5-MF	27.9	17.6	41.1	48.3	-12.3	-26.8	1.8	1.6	-9.2	-2.2	6.3	59.1	-0.3
	RCP8.5-FF	26.5	17.4	51.2	27.2	-22.9	-33.8	-3.7	-3.2	-13.8	-4.3	3.7	45.7	-5.8
Q220 [Tila Outlet]	**Baseline (m3/s)**	**18**	**15.2**	**14.7**	**18.5**	**27.1**	**40.9**	**85.7**	**126**	**98.2**	**60.1**	**32.1**	**23**	**46.6**
	RCP4.5-NF	-12.9	-22.9	-25.5	-25	-25.8	-35.1	-14.9	-17.9	-19.2	-28.1	-24.3	-24.8	-21.6
	RCP4.5-MF	24.2	6.3	30.8	33.6	21	-5.9	7.2	-13.3	-13.5	-3.4	-2.2	-14.8	-1.2
	RCP4.5-FF	-7.7	-24.8	-19.8	-22.1	-20.9	-32.1	-0.7	-5.6	-12.2	-20.7	-15	-18.1	-13.4
	RCP8.5-NF	-11.2	-20.2	-24	-20.1	-22.6	-34.3	-11.7	-16.6	-18	-25.5	-20.7	-22.5	-19.5
	RCP8.5-MF	-12.2	-21.6	-20.6	-20.7	-22.3	-31.5	-3.9	-14	-15.7	-24.5	-20.9	-21	-17.2
	RCP8.5-FF	-7.3	-26.2	-25.2	-26.5	-20.1	-29.6	2.9	-8.1	-11.4	-18.2	-14.4	-16.9	-13.2
Q260 [Seti Outlet]	**Baseline (m3/s)**	**79.3**	**76.6**	**77.7**	**89.6**	**122.4**	**260.9**	**724.5**	**871.5**	**634.8**	**249.4**	**121.1**	**95.4**	**283.6**
	RCP4.5-NF	57.3	28.9	32.5	40.5	28.2	7.9	4.5	12	4.8	18.2	29.2	35.6	13.9
	RCP4.5-MF	42.9	19.4	32.4	82.4	33	19.9	8.1	10	1.3	7.2	7.1	28	13.8
	RCP4.5-FF	46	16.7	27.2	29.8	20.5	5.7	10.8	18.1	9.6	22.2	29.8	30.3	16.1
	RCP8.5-NF	53.9	29.5	32.3	40.1	27.7	6.3	5.1	12.1	6.8	21.1	31.7	36.3	14.5
	RCP8.5-MF	41.4	20.6	29.5	33.2	22.3	8.9	9.3	17.7	7.5	23.7	30.1	30.6	16
	RCP8.5-FF	39.5	11.2	19.6	15.1	7.8	1.5	9.1	17.1	9.8	20.7	24.3	24.7	13.2
Q270 [Bheri Outlet]	**Baseline (m3/s)**	**110.4**	**97.5**	**92.8**	**106.1**	**146.8**	**279.4**	**804.9**	**1209.1**	**769.8**	**370**	**198.3**	**146.5**	**361**
	RCP4.5-NF	10	-6.1	-10.7	-19.1	-30	-26.3	-9.6	-4.1	0.4	-0.8	5.4	4.5	-5.4
	RCP4.5-MF	26.2	0.3	-6.2	-4.5	-11	1.5	1.2	0.4	1.3	4.8	18.4	16.9	3
	RCP4.5-FF	13.4	-5.6	-11.2	-16.9	-28.5	-12.5	-3.1	2.2	3	0.5	8.8	7.4	-0.7
	RCP8.5-NF	11.7	-3.9	-9.6	-18.4	-30.5	-25.7	-5	-0.3	3.3	1.2	7.9	6.7	-2.5
	RCP8.5-MF	13.5	-4.1	-10	-17.2	-28.5	-21.5	-4.2	0	4.8	2.6	9.8	7.6	-1.3
	RCP8.5-FF	11.3	-8.1	-16.4	-19.3	-28.5	-18.9	-3.6	-2.4	2.5	-0.7	6	5.6	-3.1
Q280 [Karnali-main]	**Baseline (m3/s)**	**350.7**	**301.8**	**301.3**	**428**	**791.6**	**1462.8**	**3253.3**	**4551.5**	**2960.1**	**1391.4**	**705.4**	**474**	**1414.3**
	RCP4.5-NF	25.2	7.8	10	18.3	-1.9	-12.9	-0.8	-0.1	1.5	-2.7	7.1	10.3	0.6
	RCP4.5-MF	36.1	7.8	21.5	47.3	10.8	-0.3	6.7	3.3	1.4	-1.3	13.3	19.8	6.4
	RCP4.5-FF	28.7	2.9	12	17.7	-2	-9.2	5.2	5.4	3.4	-0.1	12.2	13.5	4.2
	RCP8.5-NF	25	8.8	10.9	18.1	-2.2	-12.7	1.2	1.4	3.3	-1	9.2	11.7	1.9
	RCP8.5-MF	27	5	14.5	19.7	-1.2	-10.6	4.7	5	3.9	-0.1	11.5	15.2	4.2
	RCP8.5-FF	26.1	0.7	11.4	8.6	-8.6	-14.9	3.5	2.5	2.8	-1.5	8.8	11	1.6

2.4. The Mahakali Basin

2.4.1. Bio-physical and hydro-climatic characterization

The Mahakali is a transboundary river basin (**Figure 2-1**) originating at approximately 3,600 m at Kalapani in Nepal.It flows through Uttaranchal in India and Sudurpaschim province in Nepal, forming the border between India and Nepal, and crosses the Nepalese Tarai plains before flowing down to India where it eventually joins the Ganges. The basin has a large diversity in topography, which extends from 83 masl in the south to 7,378 masl in the north **Figure 2-18**. The basin has a dendritic river system with all tributaries merging at various points along the main river called Mahakali in Nepal and Sharada in India. The basin area delineated above the Nepal-India border is 17,371.3 km^2. Only 32.4% of the basin falls within Nepal. Two important tributaries of the Mahakali River in Nepal are Chamelia and Limpiyadhura rivers. On the Nepalese side, the basin has only 87 glaciers covering 143 km^2 and 16 glacial lakes covering 0.38 km^2, of which none are considered potentially dangerous (Ives et al. 2010).

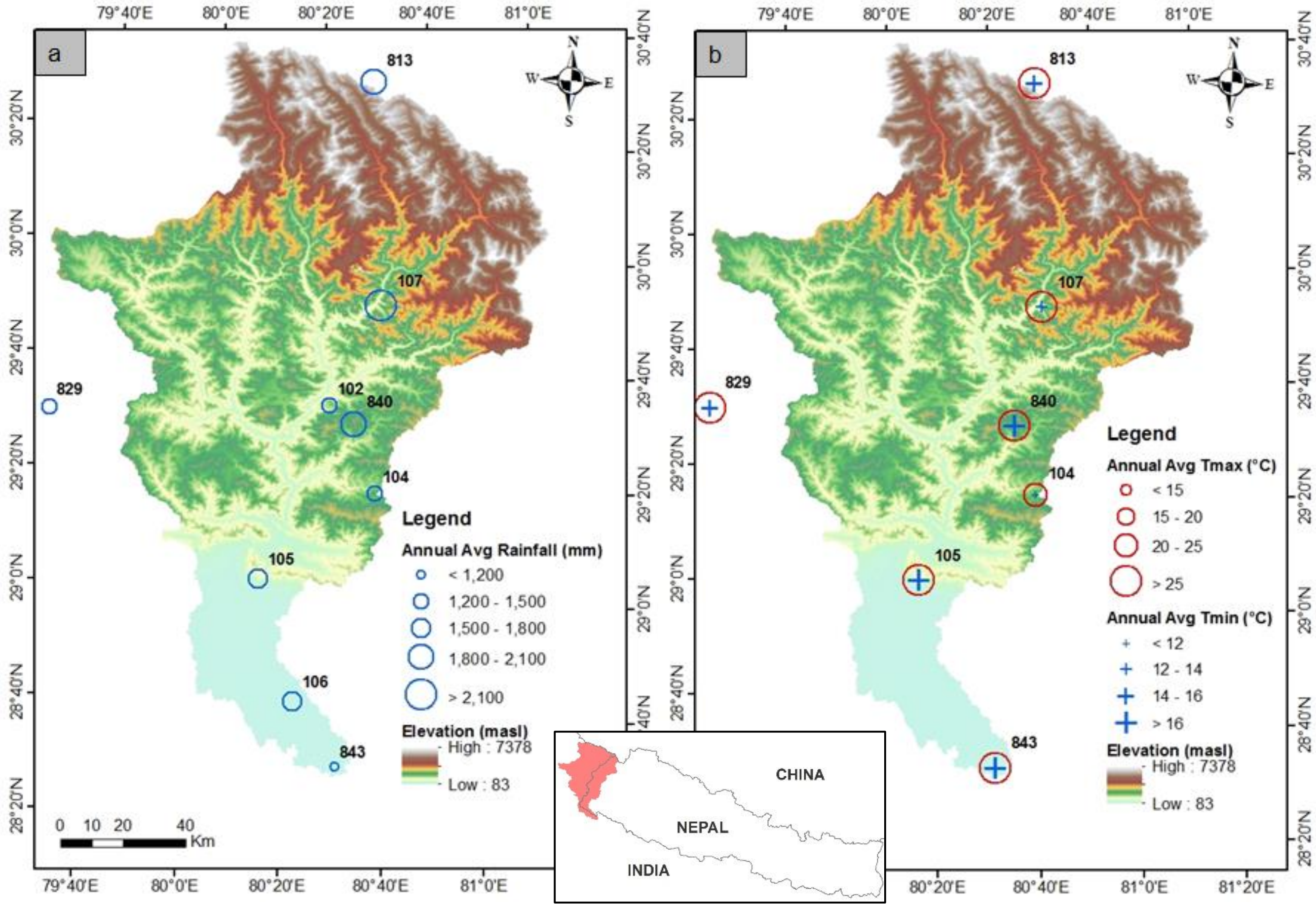

Figure 2-18: Spatial distribution of average annual a) total rainfall and b) temperature within the Mahakali Basin. Avg is average; masl is meters above mean sea level. Topographical map based on ASTER GDEM (NASA JPL 2009).

For meteorological characterization, 7 out of the 9 meteorological stations within Nepal, as shown in **Figure 2-3**, were selected after data quality assessment. Out of the selected stations, only 1 has five parameters (rainfall, temperature, relative humidity, wind speed and sunshine hours), 2 have three parameters (i.e., no wind speed and sunshine hours), and 4 have only one parameter (i.e., rainfall). Period of data availability also varies across the parameters and stations. In addition, one meteorological station, and 4 temperature and precipitation grid points from IMD where used to estimate meteorology on the Indian side of the Mahakali basin. Spatial variation in average annual rainfall and temperature (maximum and minimum) is shown in **Figure 2-18**. The strong trend of decreasing temperatures from south to north seen in Karnali is not seen as much in Mahakali. Lowest average minimum and maximum temperatures are reported for station 104 at 11.3^{o}C and 21 ^{o}C. Highest maximum temperatures are seen for station 105 at 30 ^{o}C. Rainfall appears to be higher for stations from west to east, suggesting that the mid-hills in Western Nepal are causing the rains. Highest average annual rainfall of 2,426 mm is reported at station 107 tucked in the mid-hills while the lowest rainfall of 1,131 mm is reported at IMD grid point 843. Variation in rainfall and temperature across the stations is lower for Mahakali than Karnali.

Eight hydrological stations were identified within the Nepalese side of the Mahakali basin (**Figure 2-3**). The hydrological characteristics at *Karkale Gaon station (ID: 120; Catchment Area = 1,150 km^2)* in the Chamelia river, a tributary of Mahakali basin, is shown in **Figure 2-19**. Based on observations from 1980-2013, the long-term average daily flow at the station is 56.9 m^3/s, with maximum and minimum daily values recorded at 488 m^3/s and 13.8 m^3/s. The monthly hydrograph suggests a strong influence of monsoon with flow peaking as well as showing high variability between Jun-Oct. For the winter and spring months, the flow value appears stable with very small changes shown by the error bars, indicating range in the flow values over the months. The annual average time-series in **Figure 2-19** suggests an increase in flow since 1997. The standard deviation in annual average daily is 12.3 m^3/s as compared to the monthly standard deviation of 53.51 m^3/s. Chamelia lies in the headwaters of Mahakali. A stronger variation in monthly flows caused by the monsoon may be seen further downstream. However, hydrological data for the Indian side of the basin is not publicly available.

Figure 2-20 shows the soil map for the Mahakali basin while **Figure 2-21** shows the LULC map. For both the maps, the best resolution data from separate sources were used to represent the Nepal and India side of the basin. There are 18 dominant soil types (**Figure 2-20b**). The most dominant soil is Dystric Cambisols (CMd) that covers about 32.5% while Lithosols (L) cover 25% and Eutric Cambisols (CMe) cover (12.8%). Note that the resolution of soil data for the India side is very coarse. Of the nine generic LULC types considered in this study, forest is the most-dominant LULC type, which covers 54% of the basin. It is followed by rainfed-agriculture (14.8%), grassland (11.6%), and snow/glacier (10.8%) cover. It is clear from the map in **Figure 2-21a** that rainfed agriculture is dominant in the Nepal side of the basin. In addition, irrigated agriculture dominates the southern part of the basin where irrigation canals exist on both the Indian and Nepalese sides.

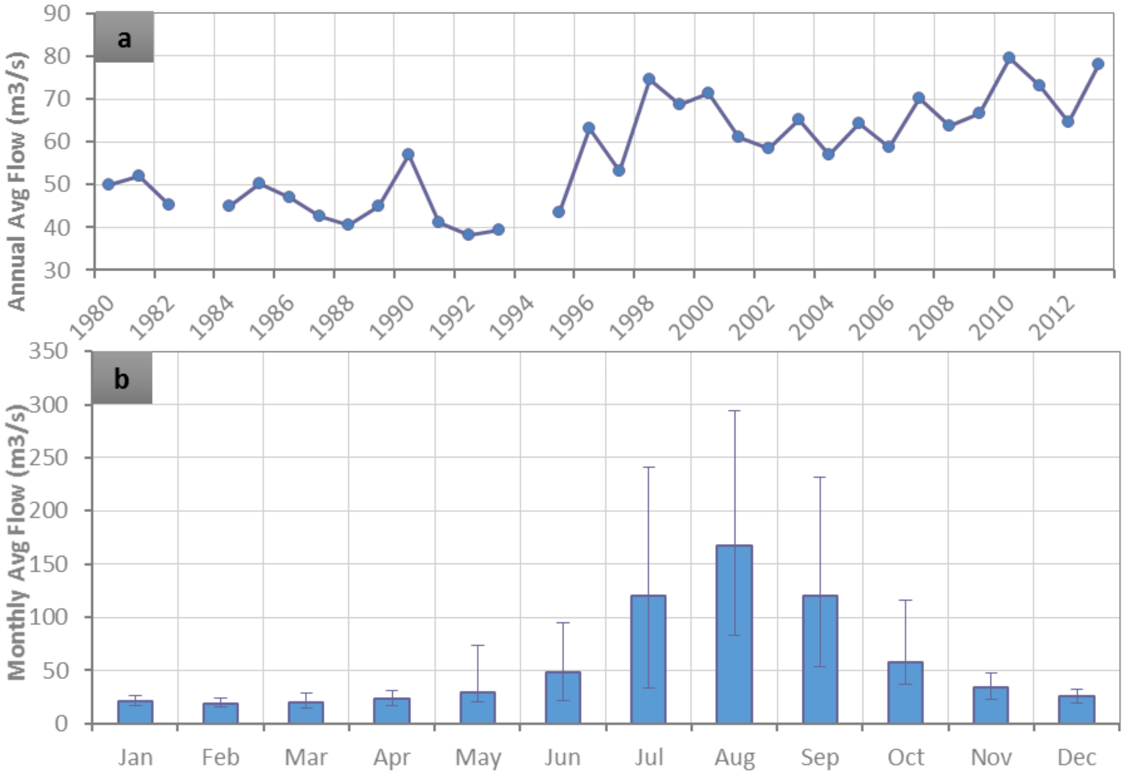

***Figure 2-19**: Hydrological characteristics of the Chamelia river (tributary of Mahakali Basin) at Karkale Gaon station (ID = 120; Catchment area = 1,150 km^2) from 1980-2013. – a) Historical trend in average annual river discharge (m^3/s); b) Long-term average monthly flow (m^3/s) with error bars indicating monthly minimum and maximum values.*

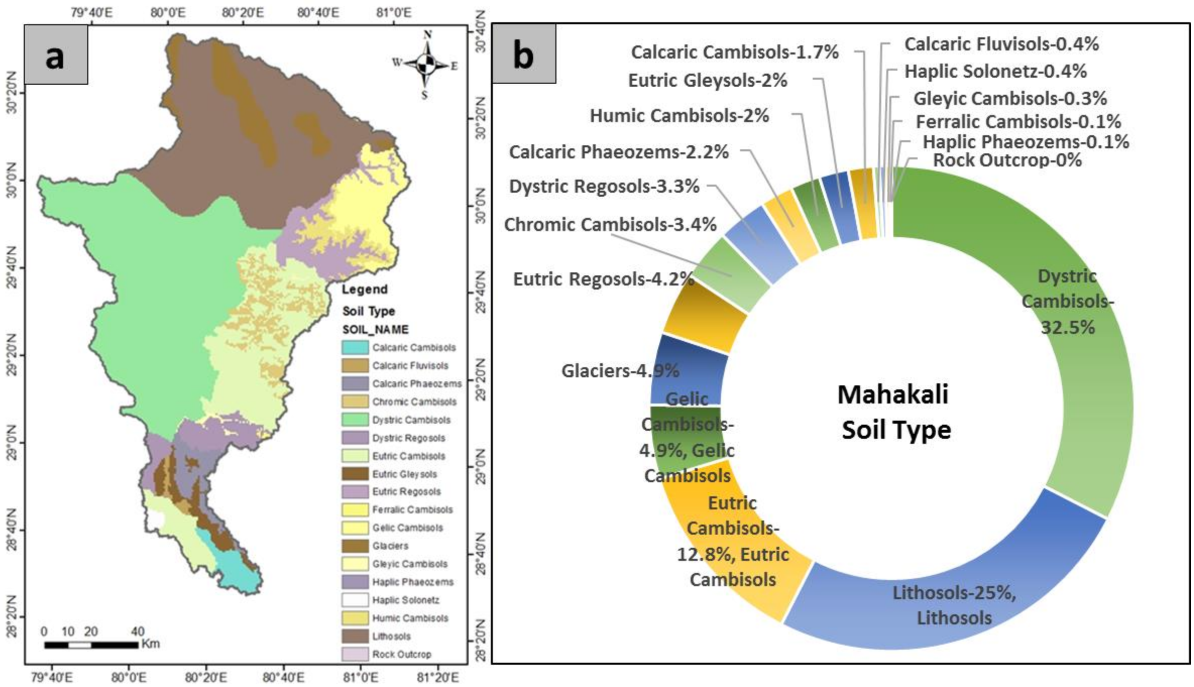

***Figure 2-20**: Soil types across Mahakali basin based on SOTER database (ISRIC World Soil Information 2009) for Nepal and Digital Soil Map of the World (FAO 2007) for India. Please refer to Pandey et al. (2019) for high-resolution version of the map.*

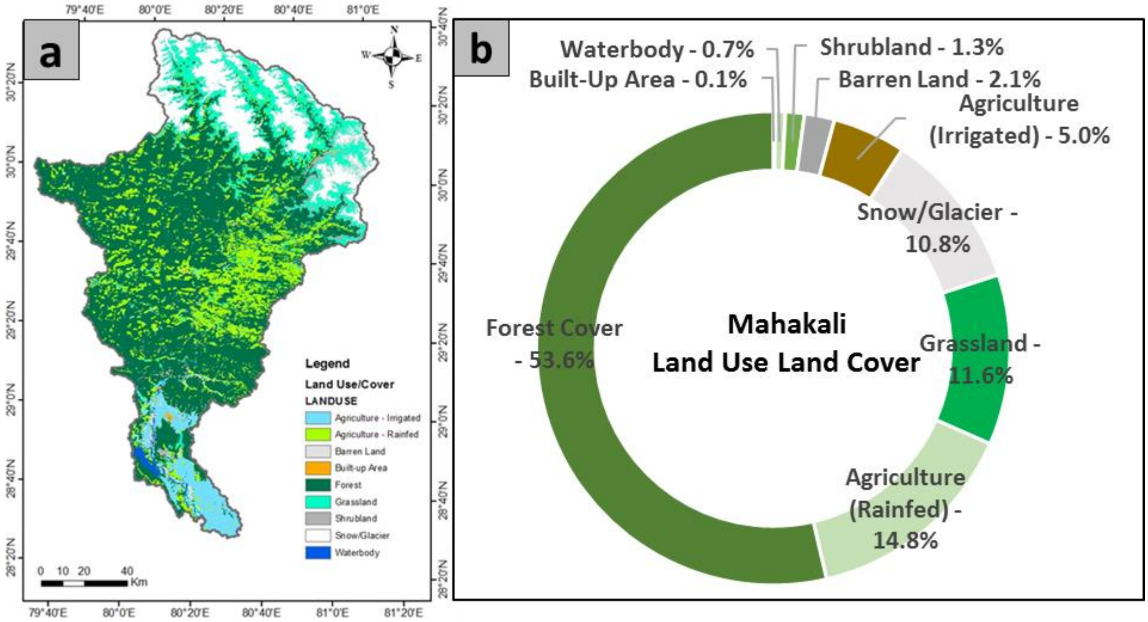

***Figure 2-21**: Land use/cover distribution of Mahakali, within Nepal basin based on ICIMOD (2012) and within India based on ESA (2016). Please refer to* Pandey et al. (2019) *for a high-resolution version of the map.*

There are nine irrigation projects and 23 hydropower projects at various stages of development in the Nepalese side of the Mahakali basin (**Figure 2-9**). The net command area (NCA) of the irrigation projects ranges from 170 – 33,520 ha and six out of nine projects are already completed. The installed capacity of the hydropower projects ranges from 0.99 to 6,720 MW, and two out of the 23 projects are in operation. More specifically, the Chamelia sub-basin has 14 hydropower projects in various stages of development, with individual capacity ranging from 1 to 40 MW, and a total capacity of 214 MW; 56.5 MW are either operational or under construction. Irrigation and hydropower projects in the Indian side have not been considered here.

2.4.2. Current water availability

A well calibrated and validated SWAT hydrological model was developed using the spatial and time-series datasets presented in **Section 2.5.1** to assess current as well as future water availability and spatio-temporal distribution. Only a third of the Mahakali basin falls in Nepal with the remaining area in India. Hydrological data from the Indian side of Mahakali was not accessible at the time of the study. Owing to this limitation in hydrological data for Mahakali, a SWAT model was calibrated only for Chamelia, the largest tributary of Mahakali within Nepalese borders with a catchment area of 1,603 km^2. Please refer **Figure 2-22** for the location and associated details of the Chamelia basin and **Annex 2-6** for the model performance during calibration and validation. Elaborated description as well as discussion of results are provided in **Annex 2-6** (Pandey et al., 2019).

The water availability analysis in the chapter, therefore, presents results only for the Chamelia watershed. Following sub-chapters present and discuss water availability based on the model simulated time-series, with a focus on spatio-temporal distribution across sub-basins of the Chamelia.

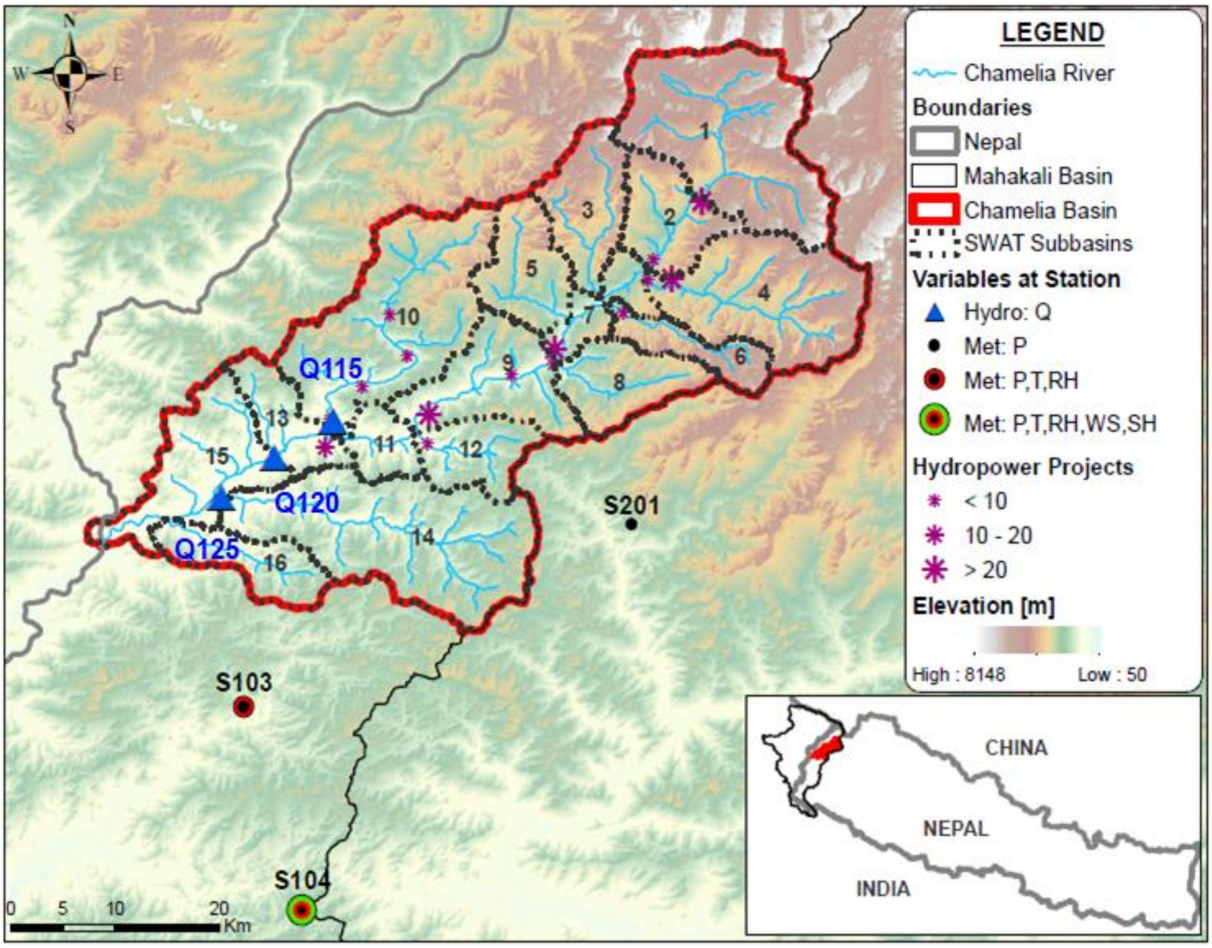

***Figure 2-22**: SWAT sub-watersheds and model calibration stations along with the elevation map for Chamelia watershed in Mahakali basin.*

2.4.2.1. Spatial distribution

Figure 2-23 shows the water balance at the 16 sub-basins in Chamelia as simulated by the calibrated and validated SWAT model. Four major hydrological components were considered for the analysis – P, AET, net water yield and the change in storage (Δ storage). Annual average precipitation, actual ET and net water yield of the basin at Q120 station for the simulation period (2001-2013) are 2,469 mm, 381 mm and 1,946 mm respectively. The values, however, vary within each sub-basin (#14 in **Figure 2-23**). There is spatial heterogeneity in all the water balance components. Net water yield or streamflow shows a minimum value of 589 mm in sub-basin 16 near the outlet of the watershed and a maximum of 2,152 mm in sub-basin #6, a tributary near the headwaters of the watershed (see **Figure 2-22** for sub-basin locations). Net water yield is greater than actual ET in most of the sub-basins upstream, represented by low sub-basin numbers. Low ET is reasonable as these sub-basins lie at higher elevations with low temperature. Also as ET depends largely on precipitation, LULC and temperature, it was estimated higher in forested areas. In case of actual ET, sub-basin #1 has the minimum value of 9 mm and sub-basin #11 has the highest value of 766 mm.

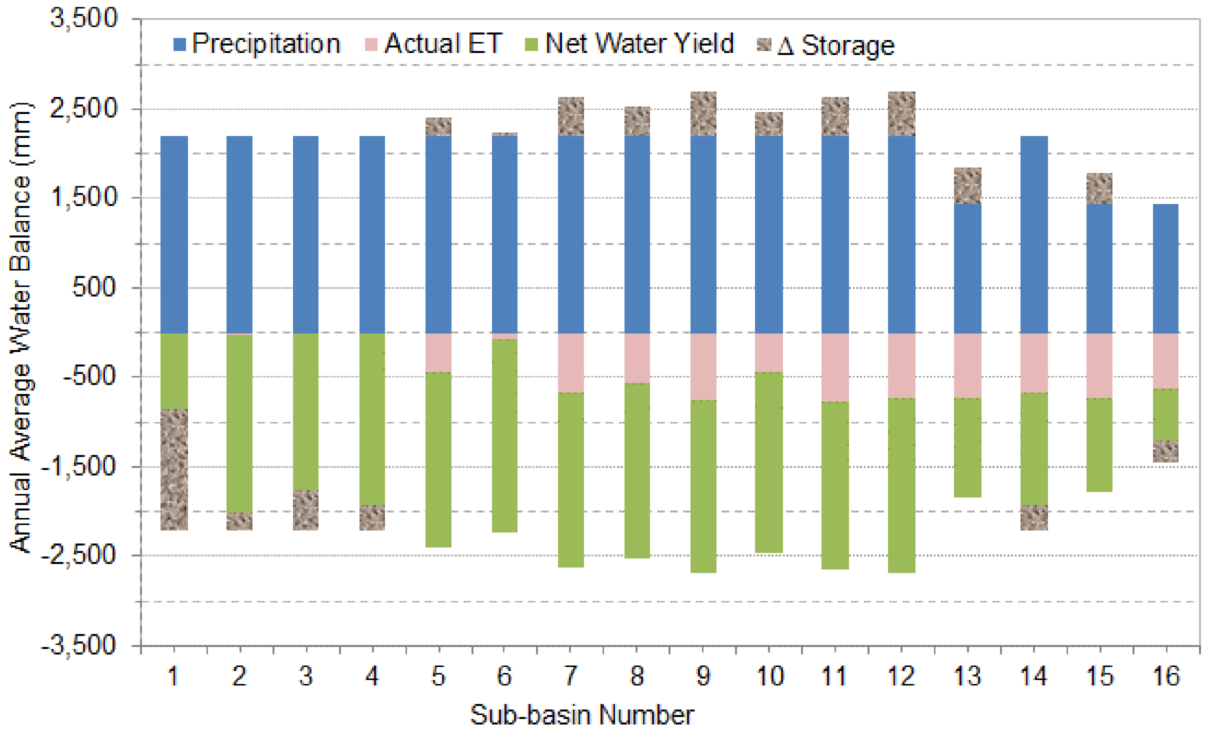

Figure 2-23*: Sub-basin wise long-term annual average water balance from SWAT model simulations (2001-2013) in Chamelia. See* ***Figure 2-22*** *for location of sub-basin within the watershed, small numbers represent upstream basins. ET is evapotranspiration.*

Precipitation contributes to storage only in upstream basins in steep terrain while in downstream basins, storage contributes to baseflow. This indicates that aquifer recharge is largely happening in the hills. Furthermore, watersheds with more snow cover in upstream showed lower contribution of baseflow than other watersheds, which is consistent with literature (e.g., Hasan and Pradhanang, 2017). On the other hand, watersheds in the downstream shows more contribution from baseflow, which is likely due to interflow of water infiltrated from upstream. These findings indicate that the hydrological characteristics simulated by the model are reasonable.

2.4.2.2. Temporal distribution

Figure 2-24 shows temporal variation in the water balance components in the Chamelia watershed. Net water yield and actual ET are highest in the monsoon season and lowest in the dry season, as expected. Δ storage is negative in monsoon with -134.5 mm in July (the wettest month) indicating recharge, and positive in the dry season with 43.5 mm in December indicating groundwater contribution to streamflow. The relatively large value of the Δ storage in monsoon season could be attributed to high groundwater recharge, which yields to high groundwater contribution to streamflow during the dry periods.

2.4.3. Future water balance

Bias corrected precipitation and min/max temperature projections were prepared at the three selected meteorological stations based on raw projections extracted from five RCMs. Projections were prepared for two RCPs (4.5 and RCP8.5) and three future timeframes: near future (NF, 2021

– 2045), mid-future (MF, 2046-2070), and far-future (FF, 2071-2095). At station 103, ensemble of bias-corrected RCM projections showed that maximum temperature under RCP4.5 (RCP8.5) scenario for near-, mid-, and far-futures is projected to increase from the baseline by 0.9°C (1.1°C), 1.4°C (2.1°C), and 1.6°C (3.4°C), respectively. Minimum temperature for the same scenarios and future periods are projected to increase by 0.9°C (1.2°C), 1.6°C (2.5°C), and 2.0°C (3.9°C), respectively. Average annual precipitation under RCP4.5 (RCP8.5) scenario for near-, mid-, and far-futures are projected to increase by 10% (11%), 10% (15%), and 13% (15%), respectively. Based on the five RCMs considered, there is a high consensus for increase in temperature but higher uncertainty with respect to precipitation. Such trends suggest that the RCMs show consensus that future change will likely increase the amount of winter rain (from westerlies) and extend the duration.

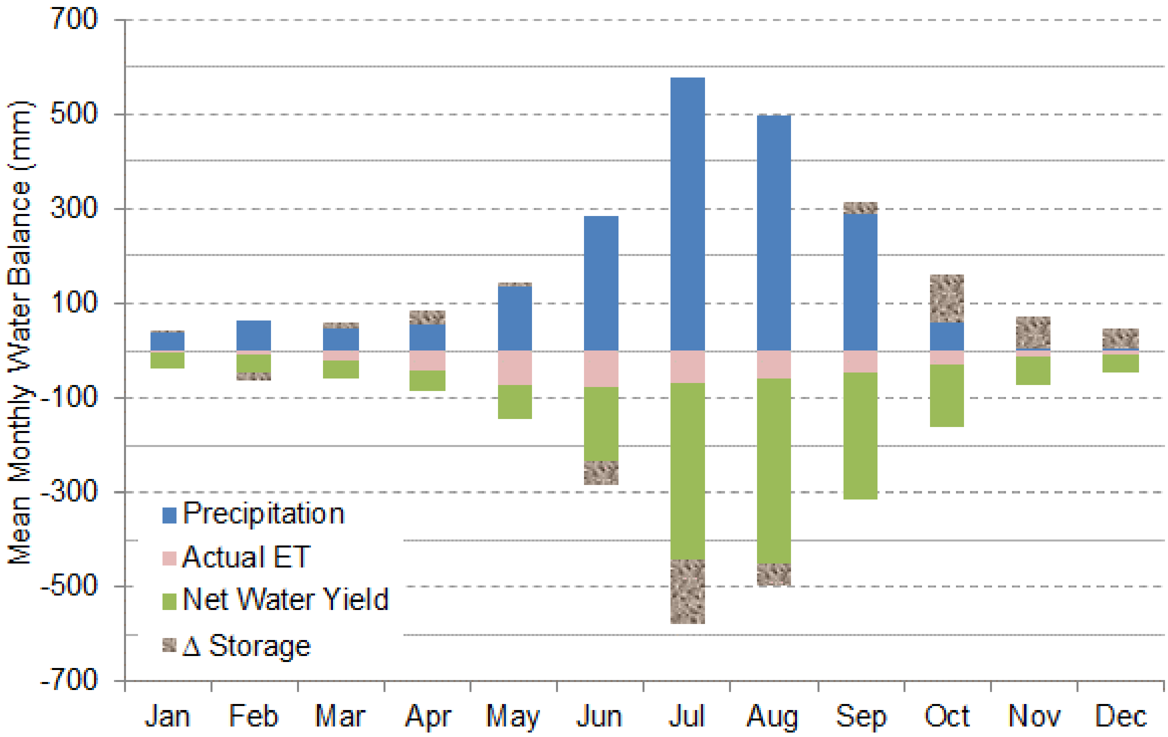

***Figure 2-24**: Mean monthly water balance from model simulation (2001-2013) in the Chamelia watershed. ET is evapotranspiration.*

Change in water balance components under the projected changes in future temperature and precipitation were simulated using the calibrated and validated SWAT model, and analysed at annual as well as seasonal scales. The SWAT output for current hydrology was considered as the reference baseline to estimate changes in the water balance components for future scenarios. The projected range of streamflow change for the future periods, scenarios, and RCMs are shown in **Figure 2-25**. The projected change in streamflow for an ensemble of five RCMs shows increasing trend for annual as well as seasonal values, for all future periods considered, and for all scenarios. For all the seasons except pre-monsoon (i.e., MAM), individual RCMs project increase in future streamflow with means and medians lying above zero. Similar to projected precipitation in, REMO streamflow projections are relatively dry while ICHEC_RCA4 projections are wetter than other RCMs. ICHEC_RCA4 also has the widest range of stream flows.

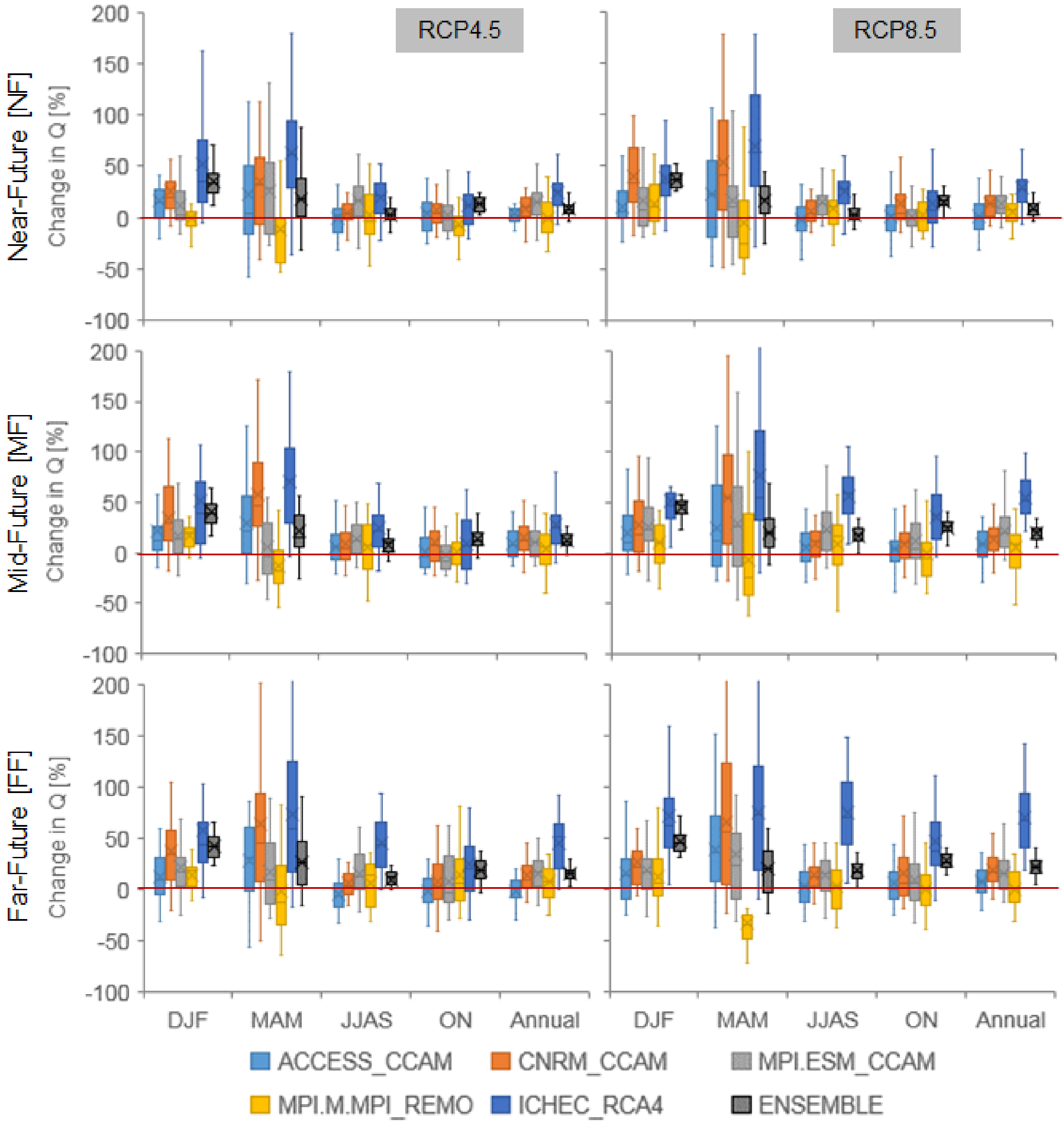

***Figure 2-25**: Range of projected change (%) in simulated streamflow for future periods, scenarios, and RCMs in the Chamelia watershed. Each box represents range in one RCM where whiskers indicate max and min values excluding the outliers, line markers indicate the median and x marker indicate the mean of change in annual total precipitation projected for each future timeframe.*

Average annual streamflow is projected to increase gradually from NF towards MF under both RCPs (**Figure 2-26**). For RCP4.5, the annual values are projected to increase by 8.2% in NF, 12.2% in MF, and 15.0% in FF. Similar increase was also reported for other watersheds in Nepal (e.g., Immerzeel et al. 2012; Bhattarai and Regmi 2016). The projected increasing trend is consistent across all the seasons. However, the increase in streamflow is highest in winter (DJF), followed by pre-monsoon (MAM), post-monsoon (ON), and then monsoon (JJAS) seasons. Considering RCP4.5 scenarios, the projected increase in winter season (DJF) flow is 34% in NF, 40% in MF, and 42% in FF. In addition, uncertainties in the simulate flow are shown with a grey band indicating minimum-maximum range in projections as well as average of the 5 RCMs for each period future timeframe. For long-term average flow, historical as well as projected flows for all the seasons lie within the mix-max band. The bandwidth is wider during high-flow season and gradually decreases during low flow seasons. The wider bandwidth is reasonable given monsoon induced natural variability in streams. Similar trends can be seen in the historical and projected FDC shown in the third row of **Figure 2-26**.

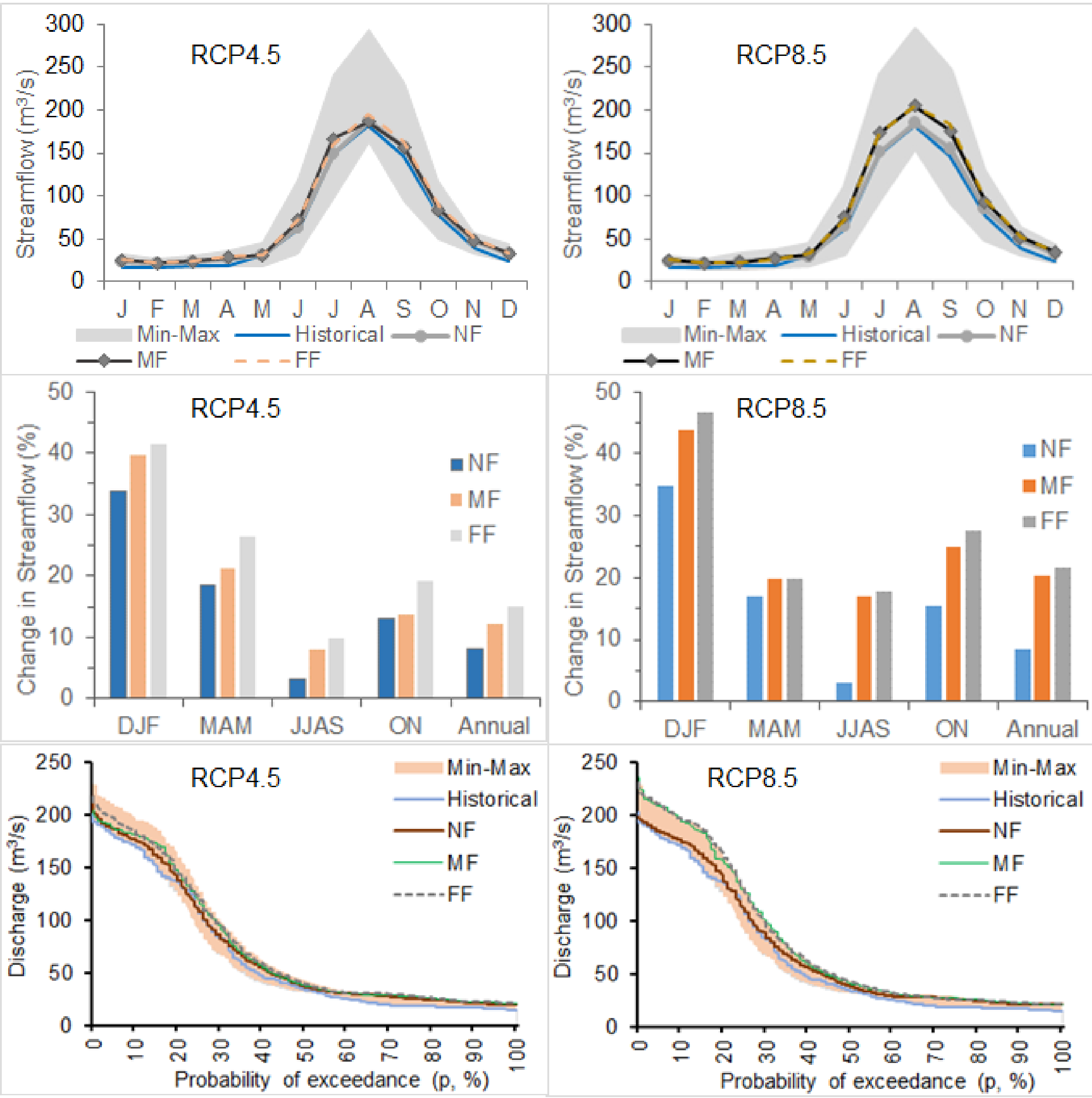

***Figure 2-26**: Change in simulated streamflow at Q120 station based on climate projections for 5 RCMs for RCP4.5 (left) and RCP8.5 (right) scenarios. The first, second and third rows show monthly hydrograph, change in streamflow from baseline, and flow duration curve (FDC), respectively. NF, MF and FF refer to Near-, Mid- and Far-Futures, respectively; Min-Max refer to a band of variation for the months.*

2.5. Conclusions

Western Nepal has a huge potential for water resources development with the majority of the Karnali and Mahakali basins covered by forests and many hydropower and irrigation projects in the planning phase. Relatively pristine nature of water resources in these basins can support regional development and national progress through investments in hydropower, irrigation, and biodiversity conservation. Planning for a sustainable and climate-resilient pathway for such development requires a thorough understanding of the existing state of water availability and ways it may change in the future. We undertake an intensive bio-physical characterization of the Karnali, Mohana and Mahakali basins to provide a benchmark on water resources available in the basin under current and future climate. Starting with collation and analysis of existing datasets on basin topography, soil, land use/cover (LULC), hydro-meteorology and development agendas, we take a model-based approach to project future climate and simulate current and future water balance in Western Nepal.

Based on the projections of 19 different CORDEX-SA RCMs, 18 climate future (CF) matrices and 10 plausible CF scenarios for RCP 4.5 and 8.5 were generated. These represent the first comprehensive RCM selection framework developed for Western Nepal for generating application-specific climate projections for long-term water resources planning. The spatiotemporal variability in future climate across three regions (mountain, hill and plains) of Western Nepal have been characterized based on changes in total precipitation (Δpr) and maximum temperature (Δtmax) for bias-corrected ensemble projections generated using the CF matrices compared to historical baselines. The 10 plausible climate scenarios identified from the CF matrices suggest that high-risk scenarios, with drier and warmer climates, are more likely to occur in the plains than in the mountain. Across nine stations in Western Nepal, the bias-corrected Δpr project highest values and spread for the post-monsoon season (JJAS), especially in the hills, indicating a potential shift in rainfall pattern with prolonged current monsoon and sporadic intense rain events likely even in drier months. Average seasonal Δpr values (-51.6 to 196.8%) are much higher and variable than annual values (-23.8 to 20.7%). The average annual Δtmax, ranging around 0.5-5.3°C across the mountains and 0.8 to 4.5°C across the hills and plains are well representative of seasonal changes. Based on raw and bias-corrected RCM projections for RCP 4.5 and 8.5, it can be concluded that further in the future, the hills and plains may see the most fluctuation in precipitation while the mountains see the highest increases in temperature. Spatial variation in temperature is projected to be narrower, but absolute values for minimum and maximum temperature may increase. The lack of definite direction in precipitation change will be a key challenge in the management of climate risks.

Two SWAT models were developed to simulate hydrological regime in the Karnali-Mohana (KarMo) and Mahakali basins and to assess the changes in future water availability. The multi-parameter and multi-site calibration approach for calibration and validation was used for model development to ensure better representation of hydro-meteorological variability within the sub-basins. The KarMo model was validated at 10 hydrological stations while the Chamelia model in the Mahakali basin was validated at three hydrological stations. The model was iteratively calibrated using manual and automated methods for visual inspection of hydrological pattern as well as model performance evaluation using statistical indicators for average flows and biases.

Both models show reasonable performance in terms of capturing hydrological patterns including flow duration curves and statistical properties of the observed daily and monthly time-series. The KarMo model is most reliable for station Q280 and Q270 while the Chamelia model is most reliable for station Q120.

Model simulations were used to characterize spatio-temporal distribution in current water availability. The annual average precipitation (P) of the KarMo basin is estimated at 1,375 mm and actual evapotranspiration (AET) is 34% (approximately) of the P, but with a large spatio-temporal heterogeneity. The P across the sub-basins vary from less than 500 mm to above 2,000 mm. The mountain, hill, and terai (a part of Indo-Gangetic Plain) regions are relatively wetter compared to the trans-Himalayan region. The AET on the other hand varies from less than 200 mm to over 650 mm, which decreases as we move to the sub-basins from the southern plains to the northern Trans-Himalayan regions. Average annual flow volume at the basin outlet under the baseline scenario is 46,250 million-cubic-meters (MCM), and the discharge at the sub-basin outlets vary from 1.1 to 1,357.5 m^3/s. Majority of P in most of the sub-basins flow out as river discharge (or net water yield). The surface runoff has the dominant contribution in discharge across most of the sub-basins whereas contribution of groundwater and later flow varies. In terms of seasons, P varies from 68 mm (post-monsoon) to 1,098 mm (monsoon), AET from 23 mm (winter) to 290 mm (monsoon), and NWY from 72 mm (winter) to 654 mm (monsoon). The monsoon season (JJAS) contribution is 73%, 61%, and 71% in the average annual P, AET, and NWY, respectively at the KarMo outlet. In contrast, in Chamelia sub-basin, above the Q120 hydrological station, current water balance components P, AET, and discharge are 2,469 mm, 381 mm and 1,946 mm, respectively. There is large temporal variation in the water balance components in the Chamelia watershed. Net water yield and AET are highest in the monsoon season and lowest in the dry season.

The impacts of projected change in climate to spatio-temporal distribution of water availability was assessed by forcing the calibrated/validated SWAT model with bias-corrected ensemble climate projections based on the CF framework. As a result of changes in P, T and AET, average annual flow at outlets of the KarMo sub-basins are projected to alter, however in general, following similar patterns as P. The impacts in the sub-basins at higher altitudes are relatively higher, indicating higher vulnerability to CC in the high mountain regions of the basin than the flat lands in the Tarai. For example, in NF under RCP4.5 scenarios, the annual flow volume at the outlet of Tila is projected to change by -21.6%, at upper Karnali by -7.2%, Seti by +13.9%, Bheri by -5.4%, and Karnali-main by 0.6%. It clearly reflects the spatial-heterogeneity in the impacts of projected CC on an annual scale. In addition, projected alterations also vary across the seasons. Taking the case of RCP4.5 and NF again, it alters from -35.1% (June) to -11.2% (January) in Tila, -31.2% (June) to 43.6% (April) in upper Karnali, 4.5% (July) to 57.3% (January) in Seti, -30.5% (May) to 11.7% (January) in Bheri, and -12.9% (June) to 25.2% (January) in Karnali-Main. For Chamelia, water availability in the changed future climate is also projected to increase gradually from baseline to near-, mid-, and far-futures. An ensemble of five RCMs shows dry season (or pre-monsoon and winter) water availability is projected to increase at a higher rate than the average annual values, which would be beneficial for water resources infrastructure projects.

A thorough understanding of the spatio-temporal variation in future climate and water availability is essential to build climate-resilient communities and ecosystems. It is demonstrated that CF framework provides a systematic basis to create plausible future scenario ensembles for a robust scenario-based assessment of the impact of climate change. The subsequent quantification of the spatiotemporal variation in water balance components using SWAT modeling provides an extensive knowledge base to help plan for water allocation across various competing usage under the water-energy-food nexus. The finding of this biophysical characterization of Western Nepal provides valuable information for water resource planners and managers for developing location-specific strategies within the Karnali, Mohana and Mahakali basins for sustainable utilization of water resources for the country's prosperity under the uncertainty raised by climate change. As local, provincial and federal governments push for large infrastructure projects in Western Nepal under the new federal system, the robust characterization of current and future water availability will be imperative to help decision makers identify and negotiate climate-resilient development pathways across the three tiers of governance.

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2.7. Annexes

Annex 2-1: Description of methodology for bio-physical characterization

Annex 2-2: Advance Climate Future matrix visuals for the western Nepal

Annex 2-3: Evaluation of RCM biases across seasons and regions in the Western Nepal.

Annex 2-4: Evaluation of hydrological model performance for the Karnali-Mohana (KarMo) basin.

Annex 2-5: Evaluation of hydrological model performance for the Mahakali basin.

Annex 2-6: Pandey V.P., Dhaubanjar S., Bharati L., Thapa B.R. (2019a). Hydrological response of Chamelia watershed in Mahakali Basin to climate change. Science of the Total Environment, 650: 365-383. (https://www.sciencedirect.com/science/article/pii/S0048969718334892)

Annex 2-7:

a) Pandey V.P., Dhaubanjar S., Bharati L., Thapa B.R. (2020a). Spatio-temporal distribution of water availability in Karnali-Mohana Basin, Western Nepal: Hydrological model development using multi-site calibration approach (Part A). Journal of Hydrology: Regional Studies, In Press.

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3. Institutional and Policy Landscape in Water Resources Management

Diana Suhardiman, Ram Bastakoti, Emma Karki

3.1. Context

Over the past decades, Nepal has undergone a rapid period of political reform as it has transitioned from a government led by a monarchy towards a democratically elected federal government. Driven by the political move towards federalism, to place greater decision-making authority to local governing bodies, this period has been characterised by rapid policy and institutional change across scales as well as power struggles between major political parties, government agencies, civil society organizations, and local communities competing for decision-making across scales.

Understanding and documenting these changes, and how they are driven by the wider political context and state transformation processes are key for identifying potential entry points for more productive, sustainable, and just water resources management. The policy review and institutional analysis of Nepal's water resources management is comprised of three interrelated key elements:

i) the central positioning of river basin planning processes;
ii) power mapping analysis to highlight the political aspect in water governance; and
iii) the role of grass roots actors and processes in shaping water governance outcome in general, and with regard to hydropower development in particular.

Over the past two decades, the idea of river basin planning has gained a lot of traction in shaping developing country governments' water resources management policies. Rooted in the concept of Integrated Water Resources Management (IWRM) (Biswas, 2008; Merrey, 2008; Molle, 2008), major international donors such as the World Bank and the Asian Development Bank (ADB) and international organizations such as the Global Water Partnership (GWP) have promoted river basin management as the flagship of water programs worldwide (Biswas, 2008; Chikozho, 2008; Dombrowsky, 2008; McDonnell, 2008; Saravanan et al., 2008). Amidst the fragmented sectoral decision-making landscape, and driven by the need to better coordinate water resources management due to the increasing competition for water resources, basin-wide approaches have been widely presented as a welcome aim or vision (Butterworth et al., 2010). With strong advocacy and funding support from international donors, it has become a mainstream approach in water resources planning and management globally (UNEP, 2012; UN-Water, 2008; Van der Zaag, 2005). In Nepal, the idea of river basin planning was first initiated by Canadian International Development Agency (CIDA) (Suhardiman et al., 2015) and later also supported by other international donors including the ADB, United States Agency for International Development (USAID), and Department of Foreign Affairs and Trade (DFAT) of the Government of Australia.

Scholars have criticized the idea of integrated river basin planning for its neglect of political structure and processes within and beyond the water sector (Allan, 2003; Blomquist & Schlager, 2005; Gyawali et al., 2006; Wester et al., 2003, Venot et al., 2011). Warner et al. (2008) point out that river basin boundaries and institutional arrangements are not natural but matters of choice and contestation. Or, as stated by Blomquist and Schlager (2005, p. 102): *"The watershed does not resolve fundamental political questions about where the boundaries should be drawn, how participation should be structured, and how and to whom decision makers within a watershed are accountable."* Drawing institutional boundaries is indeed a political act: *"Boundaries that define the reach of management activities determine who and what matters"* (p. 105). These criticisms highlight the need to recognize that decisions related to water resource management are political choices (Wester et al., 2003).

Water governance scholars have also discussed the political aspects in water governance, while unpacking the conceptual weaknesses in integrated water resources management and river basin planning approaches (Allan, 2003; Biswas, 2004; Blomquist and Schlager, 2005; Gyawali et al., 2006; Molle, 2009a; Varis et al., 2008; Wester et al., 2003). They have shown that water governance structure, processes and outcomes are contested and embedded in ' the political choices and interests of key actors and institutions (Cohen and Bakker, 2014; Warner et al., 2008; Wester et al., 2003). Public administration scholars have discussed politician-bureaucrat relationships and their positioning as power holders in their respective political and bureaucratic domains (Mosse, 2004; Quarles van Ufford, 1988; Niskanen, 1971). They have also shown how bureaucratic decisions are linked to political decisions, thus implying that water resources development and management decisions cannot be discussed in isolation from the wider political constellation. Public administration scholars have discussed politician-bureaucrat relationships and their positioning as power holders in their respective political and bureaucratic domains (Mosse, 2004; Quarles van Ufford, 1988; Niskanen, 1971). They have also shown how bureaucratic decisions are linked to political decisions, thus implying that water resources development and management decisions cannot be discussed in isolation from the wider political constellation.

Building on these works, we conducted a policy review and institutional analysis to give an overview of the state of knowledge in the basin, from the perspective of policy and institutions governing water and other natural resources to identify challenges and opportunities that exist in the current frameworks and their implications for water governance for Karnali and Mahakali basins in particular. We describe and analyze the sectoral decision-making set up at national level and its implications for water resources management to identify potential entry points for change towards sustainable, just and productive water resources management. In doing so we: i) position river basin planning as a function of power, contested territorial boundary, and arena of power struggles (Molle, 2009a; Warner et al., 2008); ii) bring to light the close interlinkages between bureaucratic and political competition, how the two work in tandem through politician-bureaucrat relations, while indirectly shaping water governance decisions and outcomes; and iii) highlight the role of spatial alliances shaping hydropower decision-making processes at grass roots level.

3.2. Methodology

The study combines three elements of policy review and institutional analysis; power mapping analysis; and an in-depth case study analysis on hydropower decision-making processes at grass roots level. First, we reviewed existing policies and legal frameworks relating to land-water-environment management in Nepal in general and for Karnali and Mahakali basin in particular. The review described and analyzed the sectoral decision-making set up at national level and its implications for water resources management. **Table 3-1** gives an overview of the reviewed policies and legal frameworks. The objectives of this policy review and institutional analysis are as follows:

- to give an overview of the state of knowledge in the basin, from the perspective of policy and institutions governing water and other natural resources;
- to identify challenges and opportunities which exist in the current policy, legal and organizational frameworks and their implications for water governance; and
- to identify potential entry points for change towards sustainable, just and productive water resources management.

During the review process, we discovered that land-water-environment management is not consistently defined legally. The existing legal frameworks resemble both conceptual and operational gaps in terms of land-water-environment management policy both horizontally (between the different government agencies at each administrative level) and vertically (between the same government agencies at different administrative levels). Our response to this inconsistency and policy gaps is that they exist not without reasons. So, rather than saying that there is a gap that needs to be filled, our approach is focused on trying to understand why this gap exists in the first place. To answer this question, we look at the rationale behind policy formulation, key assumptions behind this rationale, targeted policy outcome, and key indicators to measure this outcome.

Second, we brought to light the sectoral decision-making set up at national level. We identified the agency responsible for the role/task defined in the legal frameworks and look for possible complementarity, overlapping and/or gaps and how this affects each agency's actual involvement vis-à-vis their formal role and decision-making authority. This institutional mapping focused on looking at the organizational structure of the relevant sector ministries, their tasks and formal mandate, and whether the current institutional set-up is conducive in enabling them to exercise their role effectively and how these influence what the project is trying to achieve.

Table 3.1: *National policy documents of Nepal*

Policy Cluster	Documents
Water	Water Resources Act (2049/1992)
	Water Resources Strategy (2002)
	National Water Plan (2005)
	Draft Water Resources Policy (2016)
Agriculture	Agriculture Development Strategy (2014)
	Nepal Agriculture Perspective Plan (1995)
	Irrigation Policy (2003; 2013)
	Ground Water Utilization and Conservation Act (2013)
	Climate Change Adaptation and Disaster Risk Management in Agriculture: Priority Framework for Action (2011-2020)
Energy	Hydropower Development Policy (2001; 1992)
Environment	Environment Protection Act (1996)
	Environment Protection Rules (1997)
	National Wetlands Policy (2012)
	Soil and Watershed Conservation Act (1982)
	National Biodiversity Strategy (2002)
	National Biodiversity Strategy and Action Plan (2014-2020)
	Forest Act (1993)
	Forest Regulation (1995)
Climate change and Disaster Risk Management	National Adaptation Plan for Action (NAPA) (2010)
	Local Adaptation Plan for Action (LAPA) (2011)
	National Strategy for Disaster Risk management (2009)

State governance and decentralization	Local Self-Governance Act (1999)
	Constitution of Nepal 2015 (2072)
Transboundary	Treaty between His Majesty's Government of Nepal and the Government of India concerning the Integrated Development of the Mahakali Barrage including Sarada Barrage, Tanakpur Barrage and Pancheshwar Project (1996)
	Agreement between His Majesty's Government of Nepal and the Government of India on the Gandak irrigation and power project (1975)
	Revised Agreement between His Majesty's Government of Nepal and the Government of India on the Kosi Project (1975)

This institutional mapping includes: 1) Water and Energy Commission Secretariat (WECS); 2) National Water Resources Development Committee (NWRDC) (in relation to international water treaties); 3) National Planning Commission (NPC); 4) Kathmandu Valley Water Supply Management Board (KVWSM B) (IWRM planning and coordination); 5) Department of Water Supply and Sanitation (DWSS); 6) National Drinking Water Quality Regulatory Board (NDWQRB); 7) Nepal Water Supply Corporation (NWSC) (urban water supply, sewerage, and planning); 8) Department of Water Resources and Irrigation (DWRI, the then Department of Irrigation (DOI)); 9) Groundwater Resources Development Board (GWRDB); 10) Nepal Electricity Authority (NEA); 11) Rural Electrification Office/Board (rural electrification); 12) Electricity Regulatory Board (electricity and tariff regulation); 13) MOPE (environmental policy, approvals and regulation); 14) Department of Soil Conservation and Watershed Management (DSCWM) (watershed management); 15) Department of Wildlife and National Parks (DWNP) (aquatic ecosystem management); 16) Department of Water-Induced Disaster Management (DWIDM) (water induced disasters investigation, research and planning); 17) Department of Hydrology and Meteorology (DHM) (information and warning system); 18) District Water Resource Committees (DWRCs) (licensing of water use and conflict resolution); 19) Department of Energy Development (DoED) (promotion and licensing of private sector hydropower).

In addition to the above institutional analysis, we looked at how sectoral ministries and private sector actors are involved (directly and indirectly) in water resources development planning and management (e.g. hydropower development project operation), in terms of policy procedures to be followed, documents to be approved, agreement to be made, and related activities to be conducted in the field. Our research methods include secondary data analysis (legal documents and policy reports); key informant analysis and semi-structured interviews with government officials from relevant ministries in Kathmandu as well as local authorities in our study area. Our key informant analysis also incorporates how international donor agencies, civil society groups and academics perceive water resources management in Nepal in general, and pertaining to basin planning in particular, amidst ongoing move to federalisms and within the broader context of state transformation processes.

Next, we looked at how both politicians and bureaucrats shape water governance decision making through their relations and interactions. While looking at power dynamics shaping these interactions, we focus on three elements: 1) how politician and bureaucrat strategically navigate through their relations, and how the latter drives the country's development planning, or the lack thereof; 2) how political competition correlates with practice of sectoral egoism between different government ministries; and 3) lessons learned for shaping future water governance approaches following federalism.

To understand how politicians and bureaucrats navigate their way through their interactions and how these drive the country's development planning processes, we conducted in-depth semi-structured interviews with key stakeholders from relevant government ministries at national level as well as representatives from major political parties. We included representatives from prominent international donors in our interviews, to learn from their views and insights on politician-bureaucrat relations based on their experience from relevant development programmes that they have been promoting. Furthermore, we interviewed representatives from civil society organizations to learn more about how they view the ongoing state transformation processes to a federal structure, and how these are partly shaped by politicians-bureaucrat relations. The interview respondents include 16 government officials from various government ministries, seven (7) political party representatives, three (3) international donor representatives, and five (5) civil society organizations. Selected participants are high ranking officials with decision-making power in their respective agency and are considered experts in the field of water resource management at national level. While the number of interview respondents is not large enough to be representative, their valuable insights on various strategies they applied to navigate through political and bureaucratic competition enable us to gain good understanding in unpacking politician-bureaucrat relations, and how these shape the country's development planning processes in general and with regard to water resources management in particular. Similarly, their views and perceptions on ongoing political and policy changes, amidst federalism, serve as a good starting point to come up with lessons learned for future water governance approaches following federalism.

For each interview, we conducted a power mapping exercise, wherein each respondent was asked to rank relevant stakeholders in the water resource management arena. Here, one shared and explained the rationales behind the specific rankings, in relation to how one viewed his/her own power position. The ranking was conducted to understand the source of power for each key stakeholder (e.g., access to decision-making, access to development funds), and how they gain and sustain their power through various means and strategies (e.g. formal and informal channels of communication, close/distant relations with specific actors and institutions). For example, while a minister affiliated with the ruling political party would view the National Planning Commission (NPC) as a powerful actor, a minister affiliated with the opposition party might view the latter as unimportant. This is mainly because NPC serves mainly as an advisory body loyal to the Prime Minister, and thus the ruling political party. Similarly, a minister might not view the NPC as important, institutionally, but would rely mainly on his/her personal relations with certain NPC member(s). We also link this priority ranking and power mapping with how interview respondents perceive current challenges in water governance, and how these challenges are linked to ongoing state transformation processes and the prevailing political fragmentation. Interviews were transcribed word-for-word. Each transcription was coded using predefined nodes, including nodes defined by the first author before the interviews, and new nodes for information that emerged during the interviews. The coding process was done manually and designed in line with the requirement of NVIVO tool.

Finally, we conducted an in-depth case study research (Burawoy, 1991; Yin, 1994) from January to June 2018, looking at how power dynamics is shaping and reshaping hydropower decision-making processes in Nepal, while focusing on the Upper Karnali hydropower project in particular. We focused on two elements: 1) how spatial politics shape strategic alliances formation in hydropower decision making; and 2) how these alliances shape the views of the local community on the planned hydropower project, and vice versa.

To understand how the local community perceives the planned hydropower project, we conducted a series of focus group discussions with various Upper Karnali Concerns Committee (UKCC) members and villagers from 8 villages along the Karnali River, followed by in-depth semi-structured interviews with 5 UKCC members and 15 farmers. UKCC was formed by the hydropower company as a means to establish better line of communication between the company and the villagers. We gathered information on how UKCC members and villagers perceive the planned hydropower project, how their different perceptions are linked to their relationship with the hydropower company, and how such relationship partly derives from the spatial location of their respective villages. As part of this field research, we interviewed the company representative in Kathmandu. Placing the information and insights into the wider context of water governance in Nepal, we link our field data collection with an institutional analysis of hydropower decision making at national level. As part of this institutional analysis, we conducted a series of in-depth interviews with 8 government officials from various sector ministries, 7 political party representatives, as well as 9 representatives from donor agencies, international organizations and civil society groups. We complemented this institutional analysis with a policy review on the hydropower sector, looking at various policies and regulations (e.g., licensing system, cross-border power trade agreement, power purchase agreement).

3.3. Results and Discussion

3.3.1. Review of policy and legal framework

In this section we reviewed the different policies and legal frameworks, while classifying them into different cluster: 1) water; 2) agriculture; 3) energy; 4) environment; 5) climate change; and 6) federalism.

3.3.1.1. Policy Cluster 1: Water

Water Resources Act (2049/1992)

The Act distinguishes between two different types of water use 1) those that do not need any license (including for drinking water, irrigation, local transport); and 2) those that intend to survey or utilize water resources, in which a license needs to be obtained. Despite the distinction, it is unclear how the licensing criteria/process is linked with actual use of water, especially with regard to the local population's access to water resources. How this licensing process is linked with processes of formulation Water Use Master Plan in particular, and with regard to actual water use rights in general, remains opaque. Similarly, while the Act highlights the importance of forming Water Users Associations (WUAs) as autonomous, corporate body, the question remains as to whether WUAs will be consulted during licensing processes for hydropower dam construction upstream of the irrigation systems, and/or have a say on how the dam might impact their irrigation water supply.

While the Act does not specifically mention hydropower development, the linkage between the rationale behind licensing and hydropower development is most apparent in the following Water Resources Strategy (2002) and National Water Plan (2005).

Water Resources Strategy Nepal (WECS 2002)

The strategy highlights the need to ensure every Nepali citizen's basic needs for water (e.g. drinking, cooking, sanitation). Bringing to light the country's water resources development potential for irrigation and hydropower (food and energy), it positions water resources management as a means for economic development. In its implementation, the Water Resources Strategy would be guided by the National Water Plan, which is to be prepared by WECS in close collaboration with relevant government agencies and other key stakeholders, including the wider public. In parallel to this preparation, a comprehensive Water Resources Policy would also be formulated.

The need for comprehensive water resources policy, integrated river basin planning, water pricing and cost recovery, as well as power system planning and the need to encourage private investment for hydropower development are highlighted as some of the key issues that need to be addressed. In terms of water use, the strategy distinguishes it into three water sector issues: 1) water supply and sanitation; 2) irrigation; 3) hydropower, while also incorporating the environmental, information, and socio-economic, legal-institutional issues.

While the Strategy urged the need that water resources management and development are to be undertaken in a holistic, systematic manner, relying on Integrated Water Resources Management (IWRM), it also emphasized on the need to decentralize water delivery services. While holistic and systematic IWRM might require a certain degree of centralized planning, the question remains as to how such planning can be fine-tuned with local communities' development needs and aspirations towards more decentralized water delivery services. Similarly, while combining top-down and bottom-up approaches would require a lot of fine-tunings and consultations, the Strategy does not outline any mechanism or procedure to be followed to ensure sustainable and just water resources management.

The Strategy embodies both social and economic development principles. For example, it highlights the need for water resources development to significantly contribute to national economic output and reduce poverty and unemployment as well as to share project benefits more equally through, for instance, better compensation and rehabilitation measures in case of resettlement. The question remains as to how to balance it? What are the benefit-sharing mechanisms available at present? How does the notion of benefit share shape the overall hydropower development decision-making processes and procedures in Nepal?

Institutionally, the Strategy includes the following government agencies: 1) WECS; 2) NWRDC (in relation to international water treaties); 3) National Planning Commission; 4) KVWSMB (IWRM planning and coordination); 5) DWSS; 6) NDWQRB; 7) NWSC (urban water supply, sewerage, and planning); 8) DWRI (the then DOI); 9) GWRDB; 10) NEA; 11) Rural Electrification Office/Board (rural electrification); 12) Electricity Regulatory Board (electricity and tariff regulation); 13) MOPE (environmental policy, approvals and regulation); 14) DSCWM (watershed management); 15) DWNP (aquatic ecosystem management); 16) DWIDM (water induced disasters investigation, research and planning); 17) Department of Hydrology and Meteorology (DHM) (information and warning system); 18) DWRCs (licensing of water use and conflict resolution); 19) Department of Energy Development (DoED) (promotion and licensing of private sector hydropower).

In terms of institutional change, the Strategy mentioned the need to 1) elevate status and mandate of WECs as the central planning and coordinating agency in water resources; 2) restructure NEA to operate more efficiently and in a compatible manner with private operators; 3) restructure existing tariff commission into a full regulatory body for power sector; and 4) transfer the mandate for urban water supply from NWSC to municipalities and/or private operators. It also urges the need to establish a permanent WECS? Board and for WECS to liaise more closely with the NPC.

As outlined in the Strategy, following the NWP formulation in 2005, WECS developed a draft Water Resources Policy (WRP). This policy sets forth the need for institutional change by outlining the institutional frameworks that need to be developed towards the realization of IWRM. However, the WRP was never approved, because of objection by the Ministry of Energy's (MoE). The WRP was drafted notably to give legal backup to WECS to review and approve sectoral ministries' development plans and activities. MoE resisted the idea because it would result in a new control mechanism (in terms of technical audit), which would stand above the sectoral ministries' decision-making authority. Moreover, stated in the draft WRP was also WECS's proposal to change the membership status of the WEC from appointment only to full-time recruited staff. WEC members are mainly high-level officials representing various sectoral ministries.

Officially, there are 11 ministries represented in WEC, and they are supposed to meet regularly. In practice, however, the meetings with representatives from the other sectoral ministries happen irregularly. WECS's functioning is shaped mainly by MoE, which plays a crucial role as the chair of WEC. The NWP initially proposed that "WECS will be transformed to WEC, operating full time with a permanent office and with the provision of chief commissioner and commissioners, who will be full-time office bearers" (HMG (His Majesty's Government), 2005, p. 62). This provision, if implemented under the WRP drafted by WECS, would have indirectly resulted in the replacement of all WEC current members (representing the sectoral ministries) and in the loss of control of sectoral ministries over WECS. Obviously, the propositions to give WECS formal decision-making authority to review and approve sectoral planning, combined with the change in the modality of WEC membership/staffing, gave enough reasons for the MoE to halt the WRP promulgation process. MoE (which chairs WEC today) thought that agreeing to the proposal would result in MoE's losing control of WEC.

This illustrates the structural challenge to materialize and implement the WRS, centering on the positioning of WECS as the envisioned regulatory and coordination body in water resources management. While such positioning does make sense from the basin planning perspective, the question remains as to how WECS can get the needed buy in from different sectoral ministries. As long as sectoral ministries do not see the importance of WECS for basin wide planning, they will never comply with and follow WECS' decision, and continue to direct the overall water resources management relying mainly on sectoral development plans and targets. Moreover, taking into account how sectoral ministries could view WECS coordinating/regulating role as imposition to their sectoral mandate, this raises the question as to why they should support the shaping of WECS as regulatory/coordination body in the first place. Put differently, what are the main incentives for sectoral ministries to support the overall process of institutional reform, especially if the reform will only reduce their power? To what extent and in which way can the development interests of the sectoral ministries be translated as an integral part of the reform?

Further, the Strategy stated that the general level of financial commitment that will be required to realize the targeted outputs (see Table 7.1 and Figure 7.1 of the Strategy) and that priorities for specific projects and investment plans will be set out in the NWP. While most investment will be needed for hydropower development, this investment will come mainly from commercial loans and private sector developers, and thus not directly through the government's budget. In addition, the Strategy did not clarify as to whether hydropower investments would include costs for compensation and resettlement measures, how such measures will be arranged through government regulation or companies' codes of conduct, and how these are linked to the notion of benefit sharing in hydropower development. At present, WECS is drafting a new Water Resources Policy. Unlike before, acting as the WECS leading officials are the former DG of Ministry of Water Resources and a former high official of Ministry of Energy.

National Water Plan Nepal (WECS 2005)

The National Water Plan (NWP) was formulated by WECS in close collaboration with relevant government agencies (mostly acting as consultants for the different sector and sub-sector) with financial support from the Canadian International Development Agency (CIDA) and the World Bank (the latter through the Nepal Irrigation Sector Project or NISP).

The Plan highlights the importance of the Karnali and the Mahakali river, as the country's major river systems along with the Koshi and the Narayani river. While hydropower is presented as one of the development priorities, the Plan also mentions the regional ramifications of the high dam projects. As stated in the Plan (2005:6): *"The high dam projects identified, which store large volumes of monsoon flood and generate huge electric power, will essentially have regional ramifications. The bone of contention in these projects seem to be the Indian viewpoint that sees such projects as strictly bilateral issues and undermines the issue of downstream benefits in terms of irrigation as well as flood. It is yet to be seen how India intends to address the issue of cost sharing regarding the proposed 'river-linking project', which eventually will involve building storage dams in Nepal".* This highlights the transboundary element in water resources management especially pertaining to how the proposed hydropower development would broaden and increase the complexity of cross-borders water issues, incorporating not only water use/allocation aspect, but also environmental impact assessment, flood control, irrigation, among others, as induced by the plan to build large storage dams.

Like the Strategy, the Plan highlights the need for IWRM and river basin management (RBM). Here, the IWRM is defined as (2005: 7): *"a process that promotes the coordinated development and management of water, land and related resources to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystem".* It highlights the need to manage and develop water resources at the scale of a basin, instead of individual projects.

The Plan further elaborates on the different sub-sectoral plans as follow: 1) Water induced disasters; 2) Environmental action plan on watersheds management and aquatic ecosystems; 3) Water supply, sanitation, and hygiene; 4) Irrigation for agriculture; 5) Hydropower development; and 6) Industries, tourism, fisheries and navigational use. In turn, each sub-sectoral plan listed its envisaged targets for 2007, 2017 and 2027, as well as action programmes that will be taken forward in each of the defined periods. For example, for hydropower sub-sector plan, it targets up to 700 MW power generation by 2007, 2,035 MW in 2017 and up to 4,000 MW in 2027. Similarly, the water induced disasters sub-sector plan intended for potential disaster zones to be identified by 2007, infrastructures for mitigating predictable disasters to be put in place in twenty districts and warning systems established across the whole country by 2017, and socio-economic losses reduced to levels experienced in other developed countries by 2027. Furthermore, the sub-sector plan also outlines action programmes to achieve the defined targets. For hydropower, this includes programme to develop cost-effective micro, small and medium hydropower, a separate programme on rural electrification, as well as a programme to improve power system planning. For water induced disaster these programmes include: risk/vulnerability mapping and zoning, disaster networking and information system improvement, and community level disaster preparedness programme, among others.

Despite the plan's elaborate content on the current status, targets, and action programmes, it lacks a clear institutional arrangement in terms of the government agency in charge of leading the program formulation and implementation, as well as for undertaking specific program activities. It is unclear as to whether the program formulation will be done at sectoral ministry level, with guidance from WECS, or the other way around, led by WECS with close consultation and collaboration with the respective, relevant sectoral ministries. For example, while hydropower development falls within the mandate and responsibility of Ministry of Energy, the boundary is not so clear cut with regard to other sub-sector plans. Also, bearing in mind the close interlinkages between the sub-sectoral plans, cross-sectoral coordination is in theory inevitable, if we are to strive for basin wide holistic water resources management planning. This reflects the problem of sectoral, bureaucratic fragmentation, and that basin wide planning is not a neutral, a-political measure. On the contrary, the idea for basin planning will involve negotiation and power struggles between the different sectoral ministries, WECS as the envisioned regulatory/coordinating body, and other key stakeholders (e.g. private developers, civil society groups, national universities).

Furthermore, while the Plan later mentioned the need for institutional reform, it does not show a clear guideline as to how such reform will take place, under what preconditions, based on what common agreements, etc. Moreover, centering mainly on how the WECS could play a greater role in water resources management and development planning in the country, it lacks clear guidelines on how WECS can get buy in from sectoral ministries and local government agencies (e.g. District Development Committees (DDCs) and Village Development Committees (VDCs)) while formulating and carrying out the envisioned reform. For instance, while the proposed governance structure does link WECS with district government and local level organizations, the question remains as to how the linkage will be effective amidst sectoral fragmentation at national level. For example, as basin planning will be initiated at national level by WECS and in consultation with relevant sectoral ministries, the question remains as to how such planning can be translated into district and local level, especially in the case when sectoral ministries do not comply with the plan. Similarly, while the proposed governance structure to implement NWP relies on WECS, government agencies (sectoral ministries and others) at district level, and local level organizations, the question remains as to how this structure will change following recent discussion on State Federalism. As Federalism would mean that the national government would have to channel their decision making authority to the Federal State, this in theory does not only add an extra institutional/governance layer, but also creates a more complex institutional framework in terms of organizational linkages and overall coordination.

Thus, the question at stake is not so much on how to make the most comprehensive and clear water resources management and development plan, but also on how to materialize such plan within the existing institutional, legal, and political set up. This highlights the need to 1) better understand the ongoing process of state transformation, especially pertaining to the idea of state federalism, how this is linked to the overall notion of state centralization and decentralization, and how it will change the existing power structure and power relationships; and 2) better understand how sectoral ministries and other government agencies perceive the idea of basin planning, how these perceptions are linked to their roles and mandates in sector development, and how it in turns influence the space for institutional reform.

The plan has a separate section on regional cooperation framework. As stated in the plan: "Nepal has entered into five bilateral treaties with India, viz. (a) exchange of letters relating to the Sharada Barrage in 1920; (b) the Kosi agreement of 1954 and the revised one of 1966; (c) the Gandak agreement of 1959 and the subsequent review by an exchange of note in 1964; (d) the Mahakali treaty of 1996; and (e) the joint commission agreement of 1987". At present, riparian countries relationships are geared towards benefit sharing from water resources development, especially in relation to hydropower, irrigation, and flood control. For example, the plan stated that the South Asian Free Trade Agreement (SAFTA) was reached at the 12th SAARC Summit in Islamabad, Pakistan in January 2004, which further enabled potential regional cooperation in power trade and benefit sharing. While Nepal and India have reached an agreement for power exchange (up to 150MW), limited power transmission lines is a challenge. Nepal also views the development of regional grid concept to be essential to link its hydropower potential with Bangladesh, Bhutan, and India. While power trade agreement with India is set as one of the targets that needs to be achieved in 2007, to what extent has this been really achieved, apart from the agreement on power exchange (50-150MW)? Similarly, while the plan emphasizes the need for regional cooperation, it is unclear as to how this will be linked to bilateral agreements on power transfer and other water related issues (e.g. floods and irrigation).

Water Resources Policy (draft 2016)

In 2016, WECS drafted the Water Resources Policy. At the time of writing, the policy is not yet issued. While the draft policy sets the directions for water resources management in Nepal through it different objectives, it is not clear from the document alone as to how these different objectives will be prioritized, and interlinked with each other. As it stands now, the document states the first four objectives are to: i) formulate transparent statutory on water sharing arrangement; ii) guide/prepare legal and institutional structures; iii) develop necessary infrastructure; and iv) develop and manage water resources database and information system, with each objective linked to specific strategies on how to achieve the objective. Nonetheless, the document does not elaborate on how the process and procedure of operationalizing these objectives will take place. For instance, the formulation of statutory water sharing arrangement cannot be done without proper backup from database development and integration. Similarly, the formulation of statutory water sharing arrangements cannot be based on existing data base alone, without incorporating the existing institutional set up and challenges. What will be the basic rationale for infrastructure development and how this rationale is linked to other objectives need to be clarified.

While the draft document incorporated the proposed institutional structure for water resources development and management (e.g. river basin organization), the question remains as to whether this structure has been agreed upon among the different government agencies (MoI, MoE, NEA, etc). While the proposed structure can serve as a starting point for cross-sectoral discussions, the question remains as to what benefit different sectoral ministries would get by agreeing with it. Nonetheless, it is pertinent to draft how the role of River Basin Organization (RBO) is envisioned in relation to furthering various government agencies' role in water resources management across scales. Similarly, it will be good to document the various government agencies' view on RBO and how they can contribute to its effective application**.**

The documents hardly elaborate on the issue of financial source in general and with regard to policy implementation in particular. This is a very important driving force, and will very much define the overall effectiveness/actual significance of the proposed policy elements (e.g. RBO formation, formation of regulatory body, licensing, etc). For instance, for WECS to be able to make meaningful decisions on the licensing of infrastructure projects, it needs to be able to stop any proposed projects, if they do not meet the required standard. In order to do this, WECS needs to somehow be connected to the financial system related to water resources projects. Similarly, who will fund the overall process of RBO formation, river basin planning formulation, and how this is linked to the overall funding process of large infrastructure development?

Still related to the previous point on financial source for policy implementation, while hydropower development is centrally positioned in the draft water resources policy, the document hardly elaborates on institutional and funding mechanisms in hydropower development such as how the GON would shape/negotiate the Project Development Agreement with foreign/national investors, as well as Power Purchase Agreements between the different public-private entities. Such mechanisms and arrangements need to be clarified beforehand as they will also have strong implications on the overall river basin planning and the Master Plan development (e.g. managing peaking demand in hydropower dam operation is closely linked to how the power purchase agreement is defined in the first place). In addition, the document states that the Centre will be responsible for feasibility study of identified hydropower projects. More elaborate explanation needs to be made in relation to which government agencies at the central government level will be responsible for each stage of hydropower development (e.g. feasibility study, MoU, PDA, PPA, EIA/SIA, CIA/SEA).

On local communities' representation in river basin planning/RBO, the draft policy mentioned that the river basin planning formulation process will incorporate local communities. It would be good to maybe set a quota in terms of percentage (or number) of local communities that need to be consulted for the river basin planning formulation, while also taking into account their location in the basin e.g. upstream/downstream of proposed dam projects. Alternatively, WUMP can serve as a potential starting point for grass-roots river basin planning, to the extent possible. Moreover, it is important to emphasize on the need to focus on marginalized groups (e.g. by gender, ethnicity and socio-economic assets) and how national infrastructure development projects and policy should be defined and implemented in a way that minimizes negative impacts on these groups, while optimizing all the benefits (including indirect) they can get in terms of revenue redistribution.

3.3.1.2. Policy Cluster 2: Agriculture

Agricultural Development Strategy (MoAD, 2014) and Nepal Agriculture Perspective Plan (1995)

The strategy aims to guide the development of agricultural sector over the next 20 years. Formulated by the Ministry of Agricultural Development (MoAD) with support from various donors (ADB, IFAD, EU, SDC, JICA, DANIDA, USAID, DFID, among others), it aims to improve food and nutrition security, reduce poverty, promote agricultural trade competitiveness, increase income and strengthen farmers' rights. Through its different flagship programs such as Food and Nutrition Security Program (FANUSEP), Decentralized Science, Technology, and Education Program (DESTEP), Value Chain Development Program (VADEP), Innovation and Agro Entrepreneurship Program (INAGEP), the strategy positions farmers, cooperatives and private sector as the key stakeholders in these programs. As stated in the strategy (MoAD, 2014: 33): *"The overall objectives of APP were as follow: 1) accelerate the growth rate in agriculture through increased factor productivity; 2) alleviate poverty and achieve significant improvement in the standard of living through accelerated growth and expanded employment opportunities; 3) transform agriculture from subsistence to commercial orientation through diversification and realization of comparative advantage; 4) expand opportunities for overall economic transformation by fulfilling the preconditions of agricultural development; and 5) identify immediate, short term, and long term strategies for implementation, and provide clear guidelines for preparing future periodic plans and programs."* While these objectives are defined based on how the government envisions the role of agricultural development for the country, the question remains as to what extent these plans are linked to water availability assessment in the different Master Plans (for hydropower and irrigation).

The strategy also includes mechanisms established for gender equality and social and geographic inclusion (GESI) as well as specific programs to strengthen Water User Associations (WUAs), market infrastructure, value chains, crop diversification, technology transfer, infrastructure rehabilitation, among others. The plan was prepared by Agricultural Projects Services Centre in Kathmandu and John Mellor Associates based in Washington DC, part of ADB TA no. 1854. The plan was prepared for the National Planning Commission and set up key issues that later are elaborated in the Agriculture Development Strategy (2014).

Irrigation Policy (2003; 2013)

The Policy highlights the need to develop the storage type of irrigation systems to ensure water availability for year round irrigation. This is in line with WRS. It classifies irrigation systems into: 1) major project/system as having more than 1,000 ha of irrigated area in the hills and 5,000 ha in the Terai and Inner Terai; 2) large project/system as having between 500 to 1,000 ha of irrigated area in the hills and between 2,000 and 5,000 ha in the Terai and Inner Terai: 3) medium project/system as having 25 to 500 ha of irrigated area in the hills and between 200 and 2,000 in the Terai and Inner Terai; 4) small project/system as having less than 25 ha of irrigated area in the hills and less than 200 ha in Terai and Inner terai; and 5) traditional irrigation system as system constructed and managed by farmers.

It highlights the role of Water Users Associations in irrigation system management, but does not elaborate further on how they are linked to main system management and basin level planning approaches.

Ground Water Utilization and Conservation Act (2013)

This Act aims to make arrangements for the optimum utilization, development, operation, conservation and management of the groundwater available in Nepal. As per the provision made in this Act, the Government of Nepal may issue order to prohibit and control the utilization of groundwater in specific areas of Nepal. While utilizing groundwater priority order shall, in general, be followed as: domestic uses, irrigation and agricultural uses, industrial enterprises and mining uses, and other uses. The Act suggested establishment of a Groundwater Development and Conservation Authority for the optimum utilization, development, operation, conservation and management of the ground water and also to make groundwater pollution free by preventing environmental and other hazardous effect. It is unclear, however, as to how the contribution of groundwater to irrigation will be regulated and monitored, especially in relation to domestic use. The same applies for groundwater use for mining and industrial purposes.

Climate Change Adaptation and Disaster Risk Management in Agriculture: Priority Framework for Action (2011-2020)

The framework focuses on climate change adaptation and disaster risk management in agriculture as outlined in the Nepal Adaptation Plan of Action (NAPA) and the National Strategy for Disaster Risk Management (NSDRM). Institutionally, strengthening climate change and disaster risk management units in the Ministry of Agriculture and Cooperatives (MoAC), Department of Agriculture (DoA), Department of Livestock Services (DLS) and Nepal Agriculture Research Council (NARC) are some of the defined priorities. While climate change policy measures have t highlighted the need to strengthen the agricultural sector's resilience, the question remains as to whether this effort is linked with water resources assessment (e.g. flow regimes change due to climate variability, GLOF, etc.) and its potential impacts to agricultural development plans both in relation to climate adaptation and more broadly.

3.3.1.3. Policy Cluster 3: Energy

Hydropower Development Policy (MoWR, 2001) and Hydropower Development Policy (2049)

Both policies view hydropower development as a means to generate low cost electricity for home consumption including rural electrification as well as for export. While both cover the different financial aspects to develop hydropower plant/dam, including royalty fee, income tax exemption rule, customs duty levy, selling rate of electricity, they are less comprehensive and clear with regard to socio-environmental aspect. For example, while the need for resettlement and compensation was mentioned in both policies, they do not specify on these. Both policies do not mention the need to develop these as a separate policy either. While EIA is included in the Environment Protection Act (1997) and Environment Protection Rules (1997) both documents do not specify on the role of the EIA in the overall decision-making process for hydropower development. Placing this within the context of basin planning, there is also a need to include Cumulative Impact Assessment (CIA) and Strategic Environmental Assessment (SEA) to get an overview of the overall impacts of proposed development plans (both for hydropower and irrigation). In addition, while the policy mentioned the need to establish a Rural Electrification Fund, it is unclear how such a fund will be set up (e.g. source of fund, funding mechanisms, distributional aspects, etc.).

Both policies lack a clear general guideline on hydropower decision making in Nepal. For example, while the policy mentioned Ministry of Water Resources as the responsible government agency to provide license to hydropower dam developers, it does not further specify as to which criteria dam developers need to fulfil to get this license. Similarly, little information is available with regard to how the licensing systems and process will be linked to sectoral ministries development planning, and the overall basin planning, in relation to the different master plans for hydropower and irrigation developed later. No reference was made with regard to the stepwise procedure in hydropower decision making (e.g. license approval, feasibility study, EIA review, SIA review, power purchase agreement, RAP, etc.), which government agencies will be in charge to approve each step, based on what rationale, or how local communities will be consulted about the planned development (e.g. by whom, how).

Neither policy mentions the issue of land concession. It is unclear as to how land concession will be linked to livelihood options for local communities, and how the latter will be compensated when the concession is granted. Moreover, while both policies mentioned the idea of benefit sharing in hydropower development, they do not specify the types of benefit sharing mechanisms that might be suitable for specific projects. For example, it remains unclear how such mechanisms can be hindered/supported by existing institutional set-ups and legal frameworks, whether local communities would have a say in designing proposed benefit sharing scheme, and in what way is it different from resettlement and compensation mechanisms.

Last but not least, while the importance of electricity export is reflected in both policies, they do not refer to any bilateral agreements with other countries in the basin. For example, while transboundary water treaties do exist, they do not include hydropower development planning, and its implications for the riparian countries involved. As some of the treaties were signed so long time ago (back in the 1920s), it needs to be updated with the current development trajectories of the basin.

3.3.1.4. Policy Cluster 4: Environment

Environment Protection Act (1996) and Environment Protection Rules (1997)

The Act highlights the need to carry out initial environment examination or Environmental Impact Assessment (EIA) for each development proposal submitted to the government. It also prohibits any proposal implementation without the EIA approval. Institutionally, however, it is unclear as who is be responsible for reviewing and approving the EIA. Technically, this should be the mandate of the Ministry of Science, Technology and Environment (MoSTE). In practice, however, there is a tendency to give each sectoral ministry the responsibility to approve the EIA, in relation to their proposed development plans. In some cases, sectoral ministries could also put pressure on MoSTE to approve the EIA. This highlights the issue of conflict of interest in EIA review, when the government agency reviewing the EIA is also in charge of the proposed development. Here, rather than acted as a third party, the EIA review can be done to rubber stamp the proposed development projects (e.g. hydropower/irrigation dam). Nonetheless, in case any forest land is affected by the proposed development, sectoral ministries would have to get approval from MoSTE/Department of Forestry.

Similarly, while the Act describes the role of Environment Inspector, it is unclear as to whether this EI reports to a particular ministry in charge for EIA. Its line of command and source of funds are not clarified in the Act. Moreover, while the Act included the need to establish Environment Protection Fund as an alternative financial mechanism, it does not specify as to how such a Fund would be set up or operationalized etc. In addition, while the Act mentioned that Village Development Committee would play an important role in conveying EIA and compensation claims, it is unclear to which government ministries the VDC had to submit the application.

As regards compensation, the Rules outline the procedural step to claim and get compensation through, for instance, submitting the application to the concerned Chief District Officer. Nevertheless, this rule applies compensation mechanisms mainly at individual basis, based on individual household's assessment? of actual loss, and thus is not linked with the overall idea of Resettlement Action Plan (RAP) and Compensation and Grievance Mechanism. In case of hydropower, the pertinent question is whether RAP and Compensation will then be incorporated as part of hydropower development planning.

The Act and Rules emphasize on the need to prevent and control pollution, but do not mention the need to prevent any potential impact from changing flow regimes (e.g. hydropower dam construction and its peaking electricity demand).

National Wetlands Policy (2003)

Nepal has shown its commitment to wetlands conservation by signing the Ramsar Treaty 1971. The policy's main objective is to involve local people in wetlands management to conserve its biodiversity. While the policy highlights the need to protect wetlands, and has come up with a step-by-step participatory approach on how to promote awareness as well as to manage invasive species, institutionally, it suffers some of the earlier described problems, both in terms of appointing government agency in charge for the task, and how this appointment relates to sectoral ministries' development plans and strategies.

Soil and Watershed Conservation Act (1982)

The Act highlights the need to conserve soil and watershed, but lacking a clear direction as to how this should/could be done in an effective way, involving which government ministries, relying on which ministerial budget/alternative budget, and how this is related to other sectoral ministries development plan and strategies.

Nepal Biodiversity Strategy (2002) and National Biodiversity Strategy and Action Plan (MFSC, 2014-2020)

The Strategy (2002) is an output of the Biodiversity Conservation Project of the Ministry of Forests and Soil Conservation (MFSC), supported by the Global Environment Facility (GEF) and the UNDP. The strategies (2002; 2014) comprehensively describe Nepal's biodiversity and its significance, existing mechanisms for conserving biodiversity, major threats and their root causes, strategies to conserve biodiversity and the different key stakeholders' role. However, they are hardly linked with the country's sectoral development strategies and plan (e.g. hydropower, irrigation, road infrastructure). For example, while it includes a wide range of strategies to conserve biodiversity, ranging from landscape planning approach, to protected areas establishment, to increasing conservation awareness, these strategies are described and discussed in isolation from other ministries' sectoral development plans, not only pertaining to agriculture development, but also for hydropower and irrigation, within the context of water resources management. Furthermore, while it incorporates forests, rangelands, and a wide range of ecosystems, it hardly mentioned water resources in relation to biodiversity.

Institutionally, Nepal is equipped with the Committee on Natural Resources and Environment, which has existed since July 1991 though was dormant for most of the time, and the Environment Protection Council (EPC), first established in 1992, but only active for the first two years after its formation. While the role and responsibility of both EPC and the Committee are clearly defined under the Environment Protection Act (1996), the Act does not give them full decision-making authority. As stated in the strategy (2002: 37): *"The Environment Protection Act (1996) recognized the EPC and provided for its establishment as a statutory body. However, the Act does not provide for the composition, powers, and functions of the EPC, which has therefore remained under the chairmanship of the Prime Minister, with seven independent experts as members. The Environment Protection Regulations (1997) are also silent on the role of the EPC. In the absence of such guidance under the Act and Regulations, it is hard to determine whether the EPC would be an appropriate institution for developing policies and legislation and overseeing their implementation as well as those of various programs".* Similarly, while the Local Self-Governance Act (1998) requires both the District Development Committees (DDC) and Village Development Committees (VDC) to formulate and implement plans for biodiversity conservation and environmental protection, no practical measures have been taken to integrate conservation activities into district level decision making.

Both the EPA and EPR have made Initial Environmental Examinations or Environmental Impact Assessments mandatory for development proposals involving forests, industry, roads, tourism, drinking water, solid waste management and agriculture. Nevertheless, it is unclear as to whether the EIA and IEE process is embedded into hydropower decision-making processes in particular, and infrastructure development in general. Similarly, it is unclear as to whether the Ministry of Population and Environment (MoPE) is consulted and/or has any role/say in hydropower decision-making process and other infrastructure development processes.

Institutionally, the Strategy stated that: "A National Biodiversity Coordination Committee (NBCC) will be established, composed of one senior level representative from each of the relevant government ministries, the private sector, civil society and major donors, with 12-15 members in total. The Ministry of Forest and Soil Conservation (MoFSC) will chair the NBCC. The NBCC task is to develop policies and provide institutional, political, and operational guidance for the implementation of the Strategy. It is also equipped with the National Biodiversity Unit (NBU) under the Environment Division of the MoFSC, in charge for policy implementation.

Forest Act (1993) and Forest Regulation (1995)

The Act accounts for all forest values, including environmental services and biodiversity, as well as production of timber and other products. The provision relating to protected forests, community forests and leasehold forests will have long term impact on the conservation and sustainable use of components of biological resources. Section 23 empowers the government to delineate any part of a national forest that has a special environmental, scientific or cultural importance as a protected forest. The government is entitled to grant any part of a national forest for the following purposes: 1) as a leasehold forest for raw materials required by industries; 2) to plant trees and increase the production of forest products for sale or use; and 3) for tourism or agroforestry in a manner conducive to the conservation and development of forests.

The Act states the different procedural steps with regard to the provisions relating to the different types of forests (e.g. government managed forest, protected forest, community forest, leasehold forest, religious forest, private forest). It also demarcates the boundaries of national forest by the District Forest Officer. Yet, it is unclear how this demarcation and provision are linked to the development plans and targets of other sector ministries. For example, to what extent and in which way would hydropower development plan site selection take into account the scope and location of protected forest and community forest in the same area? How is the latter incorporated and/or linked with the overall development of hydropower and irrigation master plans?

The Act and Regulation highlight the important role of User Groups in managing community forest. While the User Group is centrally positioned in community forest management, it is unclear as to whether the Group can

influence hydropower dam decision making, in case it will impact their community forest. The linkage of the Group to existing hydropower/mining/irrigation decision making (e.g. EIA review, compensation assessment) is questionable, especially those pertaining to large infrastructure development.

3.3.1.5. Policy Cluster 5: Climate change and disaster risk management

National Adaptation Plans for Action (NAPA)

Institutionally, Nepal has Climate Change Council as a high-level inter-ministerial coordination body chaired by the Prime Minister, and with MoSTE functioning as the Council Secretariat. Formed in 2009, prior to COP 15, the Council's task is to provide high-level policy and strategic oversight, coordinate financial and technical support to climate related programs and projects, as well as to ensure that Nepal benefits from climate related international negotiations and decisions. It comprises of 25 members, including 11 ministers and 8 technical experts nominated by the government. Relevant ministries involved in the Council include MoPIT, MoI, MoE, MoAC, among others. In terms of climate adaptation, the Council positions these ministries' role mainly to develop potential projects that specifically respond to climate issues (e.g. early warning systems for Glacial Lake Outburst Floods (GLOFs), more resilient crops, greater storage capacity for water supplies), as part of their sectoral development programs.

MoSTE is the designated focal point and lead ministry to implement the provisions of the UNFCCC and coordinate the implementation of climate adaptation activities across sectors and donor agencies. Institutionally, this reveals how Nepal government positions climate adaptation as a broader issue pertaining to environmental challenges, beyond water resources management. Administratively, MoSTE comprises of four divisions: 1) Climate Change Management; 2) Science and Technology Promotion; 3) Planning and Evaluation; and 4) Administration. In total, there are 12 sub-divisions within the ministry, three of which are within the Climate Change Management division. These include: 1) Climate change; 2) Sustainable Development and Adaptation; and 3) Clean Development Mechanism. While the current institutional structure shows Nepal's comprehensive approach to climate adaptation, in practice, MoSTE has little presence outside its administrative headquarter in Kathmandu, and was working on how to increase its organizational capacity so that it could coordinate and implement climate adaptation at sub-national level. The Division of Hydrology and Meteorology under MoSTE collects and disseminates hydrological and meteorological information for water resources, agriculture, energy, and other development activities. Yet, it is unclear how this information is conveyed to or being used as a starting point for policy discussion.

Local Adaptation Plans for Action (LAPA) (MoSTE, 2011)

Aiming to integrate climate change resilience into local to national development planning processes and outcomes, the LAPA is governed by the following principles: 1) bottom-up planning; 2) inclusive planning; 3) responsiveness; and 4) flexibility. Formulated just after the National Adaptation Plans for Action was formulated in 2010, the LAPA positions the VDC and the municipality as the governance unit for integrating climate change resilience into national and local development plan and activities.

While LAPA formulation could in theory, bridge national and local development needs and aspirations, in practice, centralized climate funds do not always allow key stakeholders to develop bottom-up planning for climate adaptation. On the contrary, financial planning and allocation for adaptation appears to suffer from a disconnect between a NAPA-driven top down approach on the one hand, and a more bottom-up process envisaged by the Local Adaptation Program for Action plans (LAPAs) and Development Plans. From the 124 projects planned at the local level only 12 have been implemented (Karanjit et. al, 2014). One of the reasons for poor implementation could be because only 11.4% of the total climate budget was in fact allocated to local governments as of FY 2013/2014 (Karanjit et. al, 2014). This is despite the 80% target set for local level climate financing. Other reasons for the discrepancy between local implemented projects and planned projects could be that the formal and actual funds distribution differed significantly due to transparency issue (Regmi et al. 2014). For example, it is unclear whether the remaining 88.6% of total climate budget is used at national level and for what type of activities. The current centralized finance governing structure has resulted in a large disconnect between the DDC and the VDC. For instance, after sanitation, disaster risk reduction and climate change considerations, only 1% of the allocated annual budget of local bodies VDCs? is directed towards gender equity and social inclusion (Karanjit et. al, 2014).

The disconnect between the national and local governments regarding priorities of climate change budget allocation is one of the biggest hindrances to effective climate change financing in Nepal. For example, while agriculture and irrigation development are considered top priorities by local government, both activities are poorly funded (Oxfam, 2014), resulting in increased vulnerability for climate change. Moreover, despite the NAPA explicitly stating energy, water and public health as a priority for climate adaptation, Nepal lacks any funding related directly to climate adaptation for the respective sectors.

National Strategy for Disaster Risk Management (2009)

Prior to the formulation of NAPA and LAPA, the National Strategy for Disaster Risk Management aims to reduce risk from natural disasters through an integrated, cross-sectoral approach. Institutionally, it highlights the need to establish the National Council for Disaster Management (NCDM), chaired by the Prime Minister, with National Disaster Management Authority (NDMA) as its Secretariat.

3.3.1.6. Policy Cluster 6: State Governance and Decentralization

Local Self Governance Act (1999)

The Local Self Governance Act institutionalizes the process of development by enhancing the participation of all the people including the ethnic communities, indigenous people and down-trodden as well as socially and economically backward groups in bringing out social equality in mobilizing and allocating means for the development of their own region and in the balanced and equal distribution of the fruits of development. This Act facilitated formation of local bodies for the development of the local self-governance system in a manner that they are able to make decisions on matters affecting the day-to-day needs and lives of the people, by developing local leadership. Local bodies should be capable of bearing responsibility, the Act provides such responsibility and power at the local level as is necessary to formulate and carry out plans.

3.3.2. Institutional analysis and sectoral decision making set up

This section analyzes overall decision-making set up and processes with regard to water resources development and management in Nepal. It gives an overview of decision-making landscapes in the Nepal water sector and identifies the relevant government agencies in charge for land-water-environment management. The overall analysis includes each agency's formal mandate, responsibility, tasks and actual role in shaping water resources development and management. The institutional analysis covered following government agencies:

1. National Planning Commission
2. Ministry of Energy

    a. Water and Energy Commission Secretariat
    b. Department of Electricity Development
    c. Nepal Electricity Authority
3. Ministry of Irrigation
    a. Department of Irrigation
    b. Department of Water-Induced Disaster Management
    c. Ground Water Resources Development Board
4. Ministry of Water Supply and Sanitation
5. Ministry of Agricultural Development
6. Ministry of Land Reform and Management
7. Ministry of Forests and Soil Conservation
8. Ministry of Population and Environment

3.3.2.1. National Planning Commission (NPC)

The Planning Commission was first created in Nepal in 1956. It was soon renamed in accordance with the Yojana Mandal Act of 1957. Following the introduction of the party-less Panchayat system in 1961, the National Planning Council was formed under the then king. In 1963, the Council was dissolved and a new planning body, with an identical name, was constituted under the Chairman of the Council of Ministers. All the Ministers became ex-officio members of the Council; and the Ministry of Economic Affairs was renamed the Ministry of Economic Planning. In 1968, all tasks related to development budget and foreign aid hitherto carried out by the Ministry of Economic Planning were assigned to the Ministry of Finance. The National Planning Council then morphed into the National Planning Commission (NPC) under the Chairmanship of the Prime Minister. A 1972 study on the functions and responsibilities of the central planning agency resulted in the reconstitution of the NPC. After the historic restoration of multiparty democracy in 1990, the newly elected government reconstituted the NPC again with the Prime Minister as Chair, a full-time Vice-Chairman, five Members, and a Member-Secretary. The current organization and functions of the NPC draw on the Executive Order issued by the cabinet in 2010.

Formal mandate

The National Planning Commission (NPC) is the apex advisory body of the Government of Nepal for formulating a national vision, periodic plans and policies for development.

Tasks and responsibilities

The NPC assesses resource needs, identifies sources of funding, and allocates budget for socio-economic development. It serves as a central agency for monitoring and evaluating development plans, policies and programs. The NPC also serves as an intellectual hub for the exchange of new development ideas and proposals from scholars, private sector, civil society, and development partners.

Organizational structure

The organography of NPC is shown in **Figure 3-1**. NPC is headed by the Prime Minister of Nepal. At present, the NPC has one full-time Vice-Chairman (rank par with Cabinet Minister), eight members (rank par with Assistant Minister), and one Member-Secretary who also heads a fully staffed secretariat. The Chief Secretary and the Finance Secretary are ex-officio members of the Commission. The national statistical organization of Nepal, the Central Bureau of Statistics (CBS), functions as a specialized entity of the NPC Secretariat, headed by a Director-General. The Secretariat consists of six functional Divisions each headed by a Joint-Secretary: i) Economic Management; ii) Social Development; iii) Infrastructure Development; iv) Agriculture and Rural Development; v) Monitoring and Evaluation; and vi) Administration. Each Division is further divided into Sections headed by an Under-Secretary.

Organogram of NPC

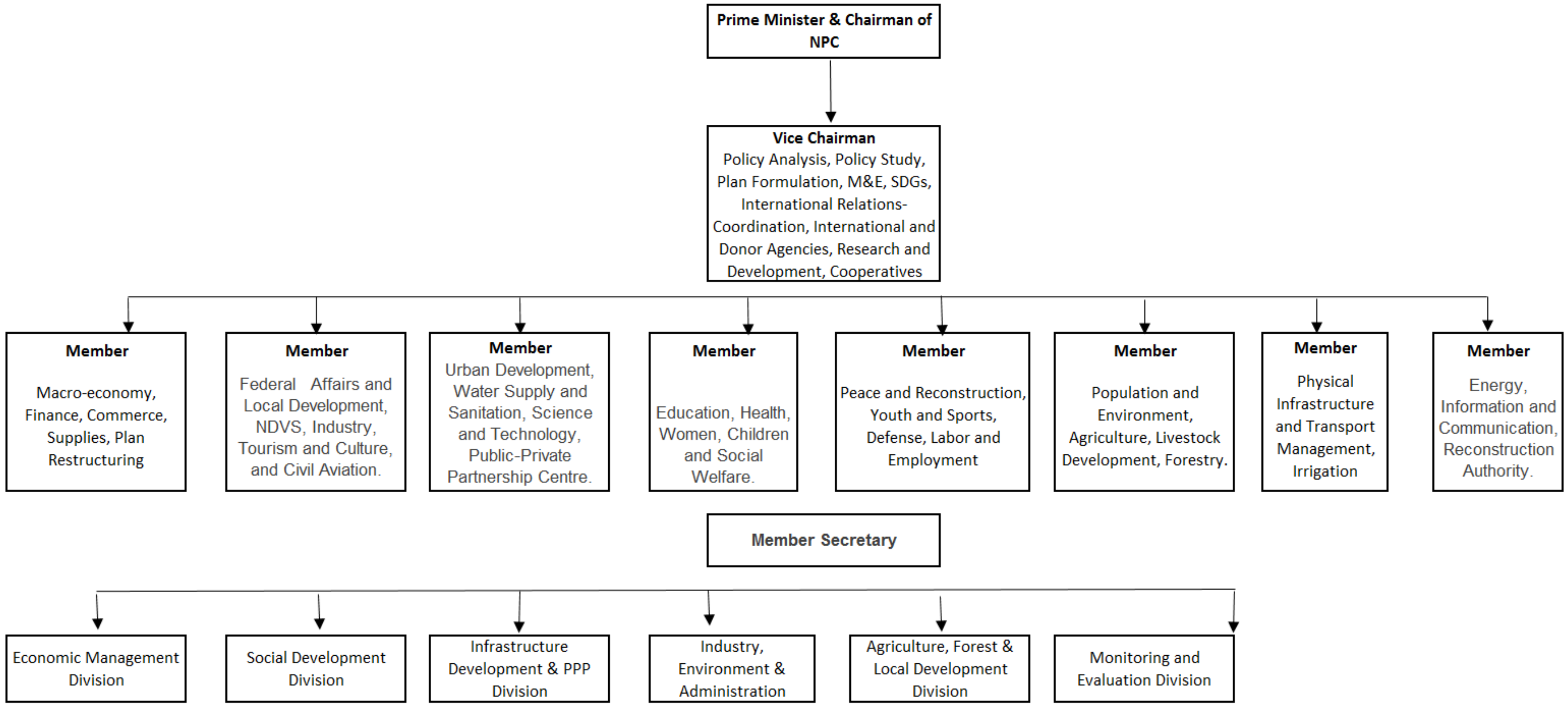

***Figure 3-1**: Organogram of Nepal Planning Commission (NPC)*

3.3.2.2. Ministry of Energy (MoE)

Ministry of Energy was formally established in 2066 (BS) [2009 AD]. It was previously part of the Ministry of Water Resources.

Formal mandate

Nepal has immense potential to generate hydropower due to abundant water resources availability. The main mandate of the Ministry of Energy is to manage the production of energy for the expansion of industrial and economic activities.

Tasks and responsibilities

Ministry of Energy is responsible for utilization and management of water resources for power generation. As per the Work Division (Second Amendment) Rules, 2066 of Government of Nepal, this ministry has been entrusted with the following tasks:

- Development of policies, plan and implementation for conservation, regulation and utilization of energy.
- Conduct survey, research and feasibility study of energy and its utilization.
- Construction, operation and maintenance and promotion of multipurpose electricity project.
- Development of Human Resources and their capacity building.
- Study, research, feasibility study, construction, operation, maintenance and development of energy development and electricity development projects.
- Matters related to energy and electricity and companies and corporations related to energy and electricity.
- Promotion of private parties in electricity development.
- Matters related to national and international level seminars, workshops and contacts.
- Matters related to bilateral and multilateral dialogues, agreements and understandings regarding energy and electricity.
- Matters related to tax.
- Coordination of institutions related to electricity.

Organizational structure

As depicted in **Figure 3-2**, Ministry of Energy is led by Minister for Energy. Secretary of the Ministry is the main official and he/she is supported by technical and non-technical staff of different ranks. The Ministry of Energy has four divisions: (i) Planning and Program Division; (ii) Policy and Foreign Coordination Division; (iii) Administration Division; and (iv) Legal Division. The Ministry includes Department of Electricity Development (DOED). This Ministry also includes 2 key organizations: Water and Energy Commission Secretariat (WECS) and Nepal Electricity Authority (NEA).

Organogram of MoE

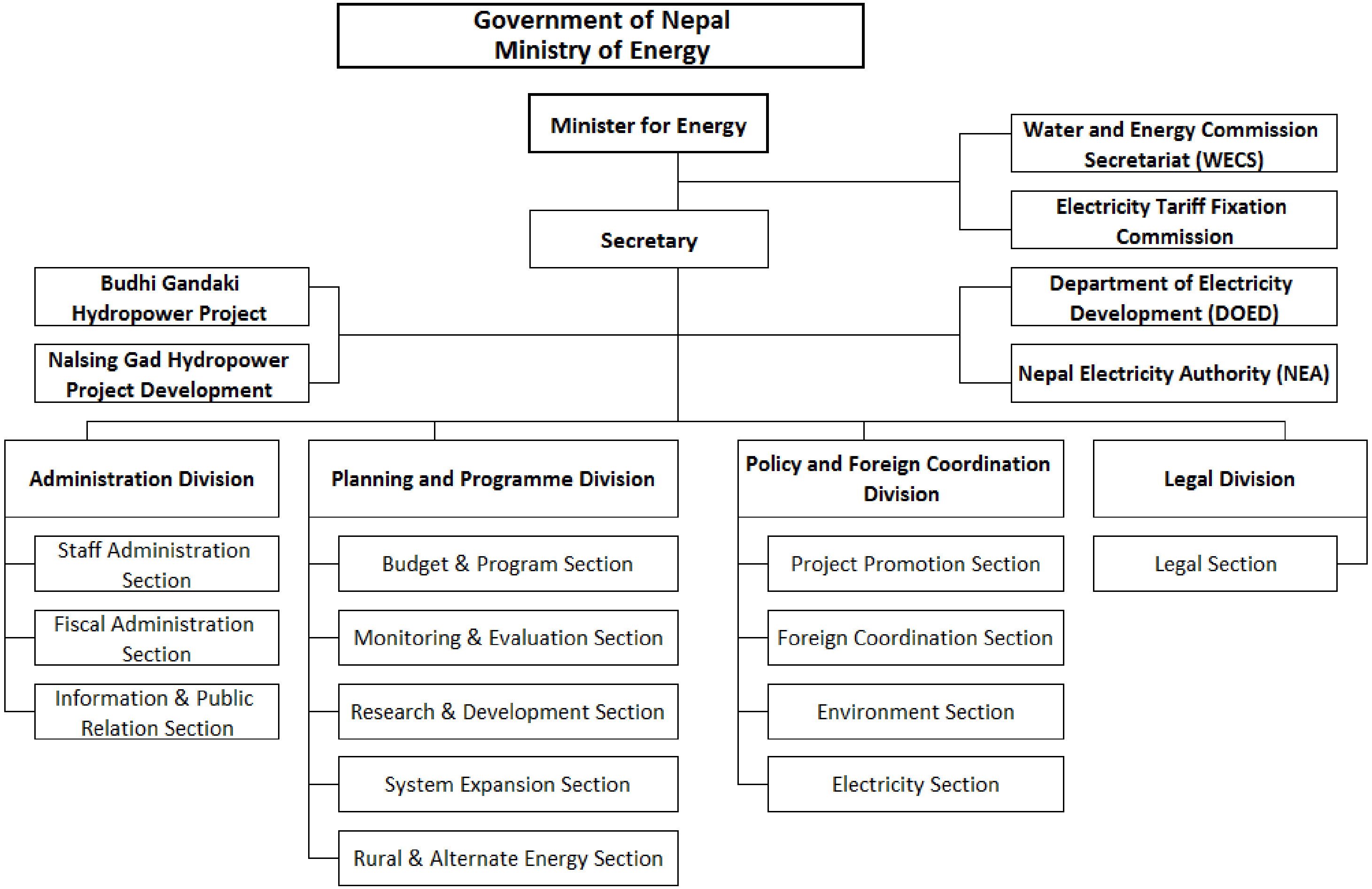

***Figure 3-2**: Organogram of Ministry of Energy (MoE)*

3.3.2.3. Water and Energy Commission Secretariat (WECS)

The Water and Energy Commission (WEC) was established by GoN in 1975 with the objective of developing the water and energy resources in an integrated and accelerated manner. Consequently, a permanent secretariat of WEC was established in 1981 and was given the name, Water and Energy Commission Secretariat (WECS). Currently, WECS is under Ministry of Energy.

Formal mandate

The primary responsibility of WECS is to assist Government of Nepal (GoN), different ministries relating to Water Resources and other related agencies in the formulation of policies and planning of projects in the water and energy resources sector.

Tasks and responsibilities

WECS has the following objectives:

- To provide assistance to the concerned ministries in formulating policies and objectives to be included in the perspective/periodic plan relating to the water resources and energy sector.
- To provide suggestions, recommendations and guidance with regard to multipurpose (mega and medium scale only) project development as well as to irrigation, hydropower, drinking water, industrial use of water, flood management and water navigation; and also regarding the promotion and development of such mega and medium scale projects, and protection of environment aspects relating to the above sectors.
- To formulate policies and strategies for the water resources and energy sector.
- To render opinion, advice and recommendation on bilateral and multilateral issues relating to water resources and energy.

The function, duties and rights of the WECS are as follows:

- To review and cause to review the multipurpose, mega and medium scale water resources projects before they are sanctioned by the GoN, and recommend their implementation as well.
- To formulate and cause to formulate on necessary policies and strategies conducting studies, research, survey and analysis with regard to various aspects of water resources and energy development in keeping with priorities and targets of the GoN.
- To analyze and cause to analyze the bilateral or multilateral projects relating to the development of water resources and energy, to formulate policies in this respect, and to review the detailed study and analysis of such projects.
- To enact and cause to enact the necessary laws pertaining to the development of water resources and energy.
- To establish and cause to establish the coordination among national and sectoral policies relating to water resources and energy sector.

Organizational structure

WECS is chaired by the Minister for Energy, comprising members from various government and non-government agencies (**Figure 3-3**). Members generally include the following and the Secretary of WECS serves as Member Secretary:

- Member, National Planning Commission (Water Resources)
- Secretaries of all Eleven Ministries of GoN
- Two persons nominated by the Government from among well-known water resources and energy specialist
- Dean, Institute of Engineering, Tribhuvan University
- President, Nepal Engineers' Association
- Representative, Federation of Nepalese Chambers of Commerce and Industry

The GoN may necessarily add or deduct and reshuffle the number of members of the Commission as and when deemed necessary. The tenure of the nominated members is two years. The Commission may also invite to its meetings experts or officials as and when deemed necessary.

Organogram of WECS

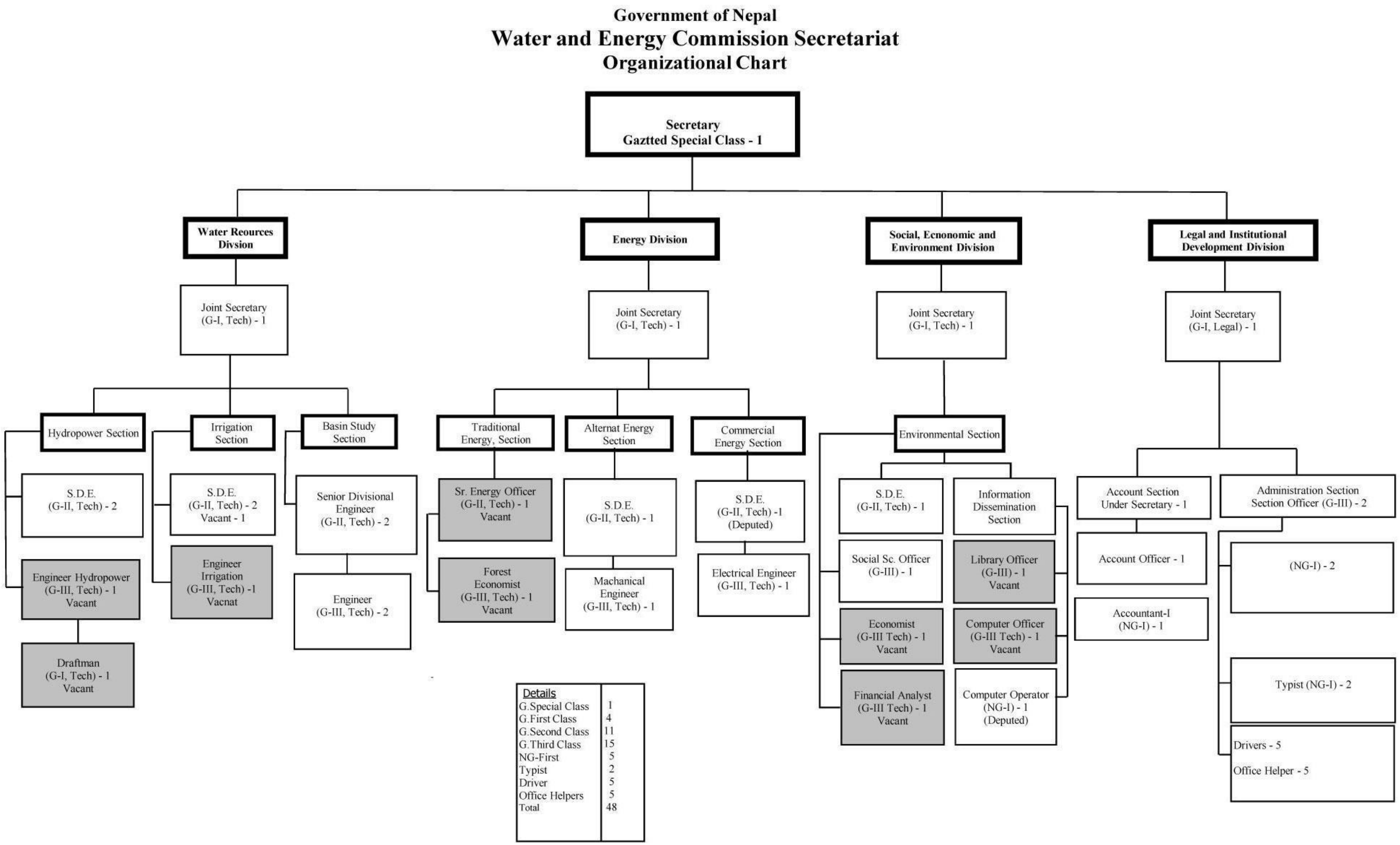

***Figure 3-3**: Organogram of Water and Energy Commission Secretariat (WECS)*

3.3.2.4. Department of Electricity Development (DOED)

Originally, the Department of Electricity Development (DOED) was established as Electricity Development Center (EDC) on July 16, 1993 (2050 Shrawan 1) under the then Ministry of Water Resources (MOWR). It was later renamed as Department of Electricity Development (DOED) on February 7, 2000 (2056 Magh 24). Currently, DOED is under the Ministry of Energy.

Formal mandate

The main mandate of DOED is to develop and promote electricity sector and to improve financial effectiveness of this sector at the national level by attracting private sector investment.

Tasks and responsibilities

The DOED is responsible for assisting the Ministry in implementation of overall government policies related to power/electricity sector. The major functions of the DOED are to ensure transparency of regulatory framework, accommodate, promote and facilitate private sector's participation in power sector by providing "One Window" service and license to power projects.

Organizational structure

The DOED is under the Ministry of Energy and led by Director General. DOED has 4 Divisions each led by Deputy Director General. Senior officials (DG/DDG) are supported by technical and non-technical staffs of different ranks (**Figure 3-4**). The organogram of DOED is presented below (need update to reflect 4 divisions instead of 3 indicated below).

Organogram of DOED

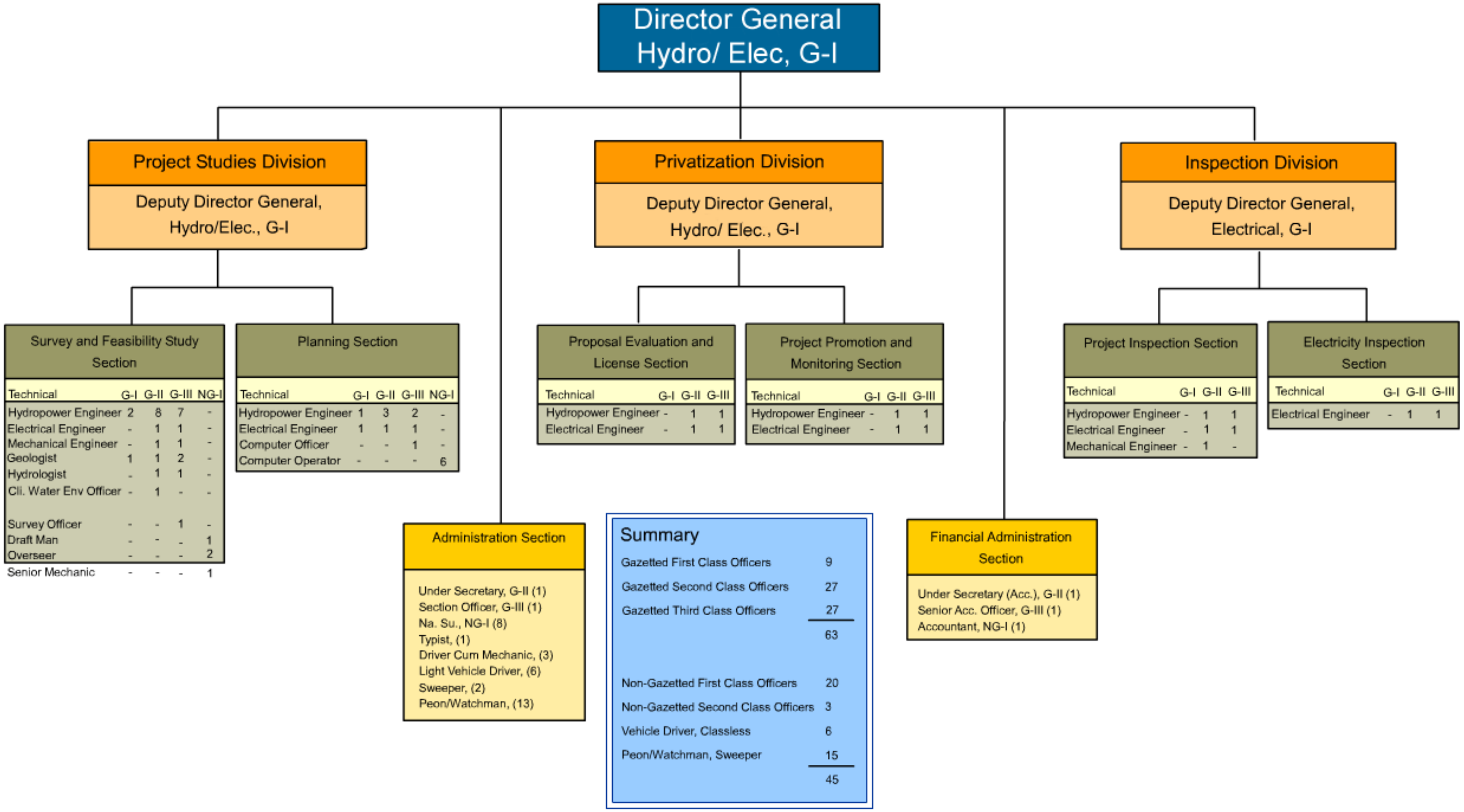

***Figure 3-4**: Organogram of Department of Electricity Development (DoED)*

3.3.2.5. Nepal Electricity Authority (NEA)

Nepal Electricity Authority (NEA) was created on August 16, 1985 (Bhadra 1, 2042) under the Nepal Electricity Authority Act. 1984, through the merger of the Department of Electricity of Ministry of Water Resources, Nepal Electricity Corporation and related Development Boards. The merger of the individual organisations was done to achieve efficiency and reliable service and to avoid overlap and duplication of works . Currently, NEA is under the Ministry of Energy.

Formal mandate

The main mandate of NEA is to generate, transmit and distribute adequate, reliable and affordable power by planning, constructing, operating and maintaining all generation, transmission and distribution facilities in Nepal's power system. Tasks and responsibilities

The NEA's major responsibilities are:

- To recommend to the Government of Nepal, long and short-term plans and policies in the power sector.
- To recommend, determine and realize tariff structure for electricity consumption with prior approval of Government of Nepal.
- To arrange for training and study so as to produce skilled manpower in generation, transmission, distribution and other sectors.

Organizational structure

As depicted in **Figure 3-5**, The management of NEA is entrusted to a Board of Directors, which is constituted with Minister for Ministry of Energy as Chairman and consisting of following members;

1. Secretary, Ministry of Energy GoN: Member
2. Secretary, Ministry of Finance GoN: Member
3. One prominent person from commerce, industry, or financial sector: Member
4. One person from consumers group: Member
5. Two prominent persons with experience in power sector from outside government: Member
6. Managing Director, NEA: Member Secretary

The Managing Director acts as member secretary as well as chief executive officer. The organogram of NEA corporate office is presented below.

Organogram of NEA

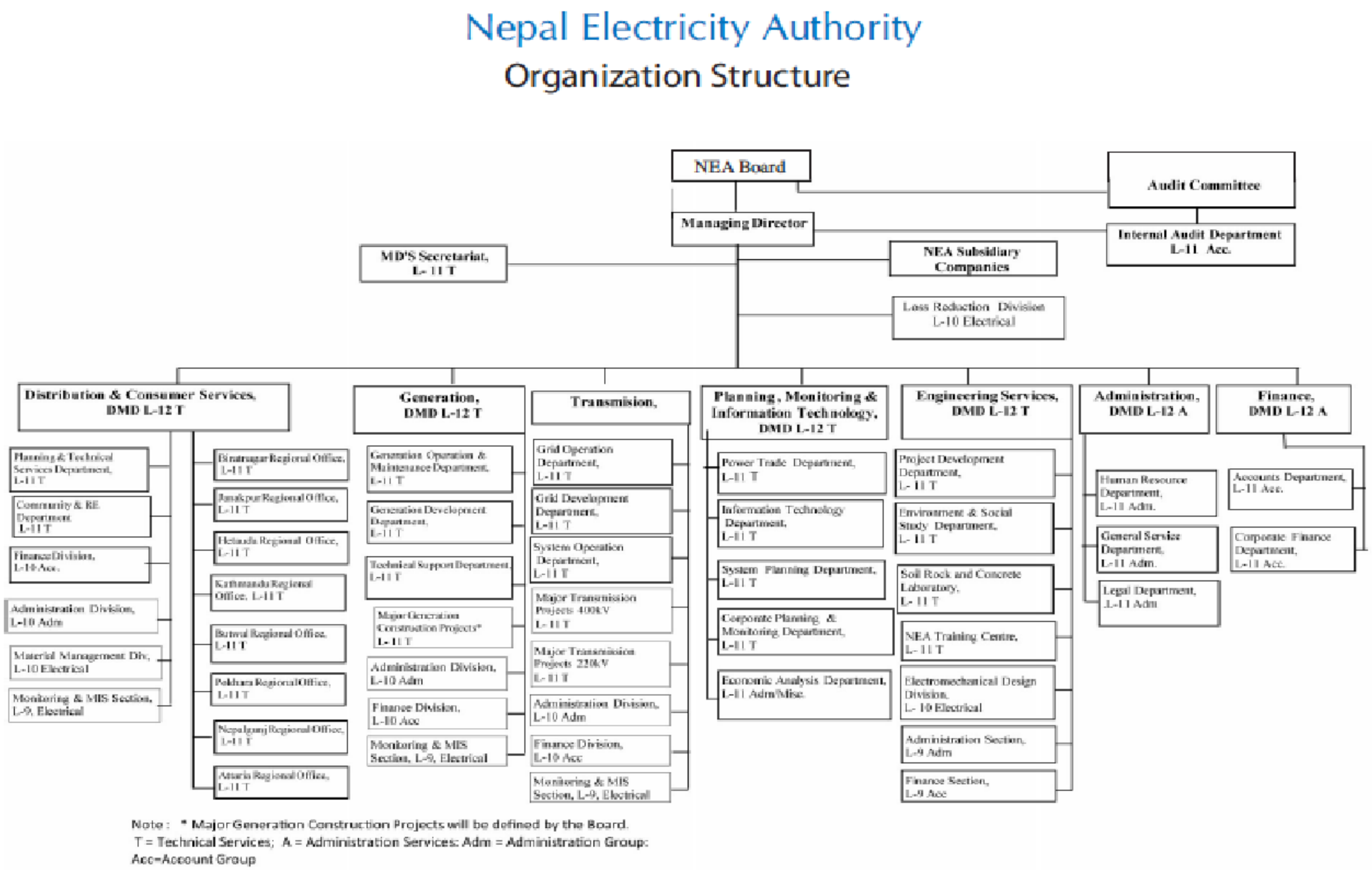

Figure 3-5*: Organogram of Nepal Electricity Authority (NEA)*

3.3.2.6. Ministry of Irrigation (MoI)

The Ministry of Irrigation was formally established in 2066 (BS) [2009 AD]. It was previously part of the Ministry of Water Resources.

Formal mandate

The Ministry of Irrigation is responsible for utilization and management of water resources to irrigate the agricultural land of Nepal, thereby providing the opportunity to overcome the barriers to economic development in the country.

The main objective of the Ministry of Irrigation is to prepare plans and policies and their implementation regarding development of irrigation for the efforts to achieve agricultural development targets.

Tasks and responsibilities

As per the Work Division (Second Amendment) Rules, 2066 of Government of Nepal, this ministry has been entrusted with the following tasks:

- Development of policies, plans and implementation for conservation, regulation and utilization of irrigation.
- Conduct survey, research and feasibility study of irrigation and its utilization.
- Construction, operation and maintenance and promotion of multipurpose irrigation project.
- Development of Human Resources and their capacity building.
- Activities related to Flood and River Training.
- Study, research, feasibility study, construction, operation, maintenance and development of irrigation.
- Promotion of private parties in irrigation development.
- Study, research and implementation of water resources.
- Groundwater Resources.
- Construction, conservation, integrated use of irrigation facility (including programs related to farm irrigation and small irrigation) of Irrigation Projects.
- Matters related to national and international level seminars, workshops and contacts.
- Matters related to bilateral and multilateral dialogues, agreements and understandings regarding irrigation.
- Coordination of institutions related to irrigation.
- Matters related to tax on use of water.
- Water Induced Disaster Management and Prevention.
- Study, research and implementation of Water Induced Disaster.
- Development of policies, plans and implementation for conservation, regulation and utilization of Water Induced Disaster Prevention.
- International representative on subject of Water Induced Disaster.

Organizational structure

Ministry of Irrigation is led by the Minister for Irrigation (**Figure 3-6**). Secretary of the Ministry is the main official supported by technical and non-technical staff of different ranks. The Ministry of Irrigation has three divisions: (i) Planning and Program Division; (ii) Policy and Foreign Coordination Division; and (iii) Administration Division. The Ministry includes 2 departments: (i) Department of Irrigation (DOI); and (ii) Department of Water-Induced Disaster Management (DWIDM). This Ministry also includes one key organization named Ground Water Resources Development Board (GWRDB).

Organogram of MoI

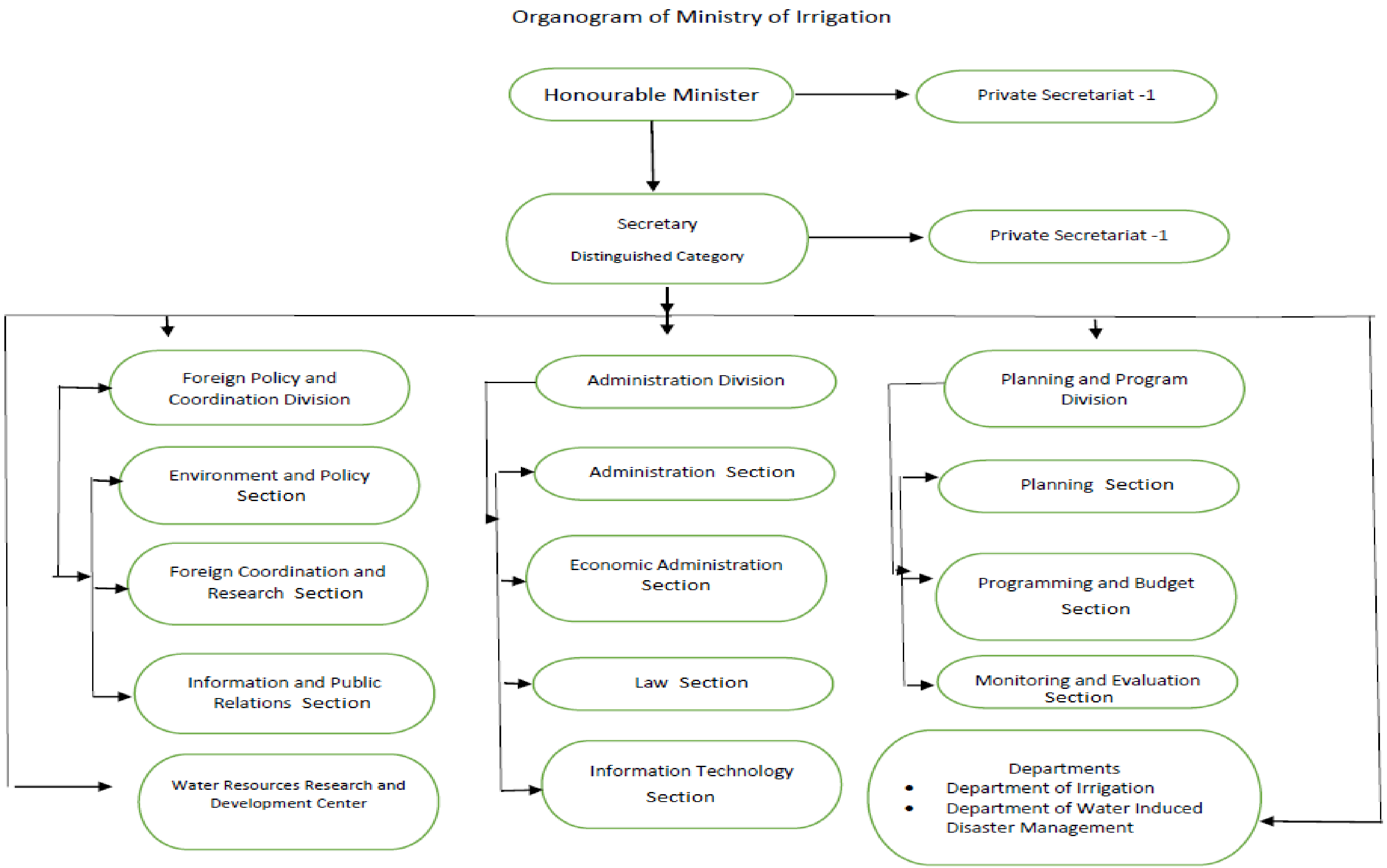

***Figure 3-6**: Organogram of Ministry of Irrigation (MoI)*

3.3.2.7. Department of Irrigation (DOI)

Originally, the Department of Canal was formally established in 1952 under the Ministry of Construction and Communication. The department then passed different stages working under different ministries and finally ended up as Department of Irrigation in 1987. Since the establishment of Ministry of Irrigation (MoI) in 2009, DOI has been working under it.

Formal mandate

The main mandate of DOI is to plan, develop, maintain, operate, manage and monitor different modes of environmentally sustainable and socially acceptable irrigation and drainage systems – from small to larger scale surface systems and from individual to community groundwater schemes.

Tasks and responsibilities

The key tasks of DOI include:

- To provide year round irrigation facilities and increase the irrigable area of the country to higher limits.
- To develop new irrigation projects and O&M of developed schemes
- To carry out river training activities to protect the floodways, floodplains and agricultural lands in the form of river bank protection such that the loss of properties caused by flooding is reduced.

Organizational structure

DOI (currently, Department of Water Resources and Irrigation) is one of the departments under the Ministry of Irrigation of Government of Nepal (GoN). The Director General of DOI is supervised by Secretary of MOI (**Figure 3-7**). There are four divisions under the umbrella of DG in DOI, each lead by Deputy Director General. Apart from these divisions, administrative branch, financial branch and legal branch are also directly administered by DG. There are five Regional Irrigation Directorates in each region under the supervision of DG. Twenty-six irrigation development division offices and twenty irrigation development sub-division offices in all regions work under the supervision of respective irrigation directorates. Besides, there are eight irrigation management divisions and 3 mechanical divisions in the structural organization of DOI.

Organogram of DoI

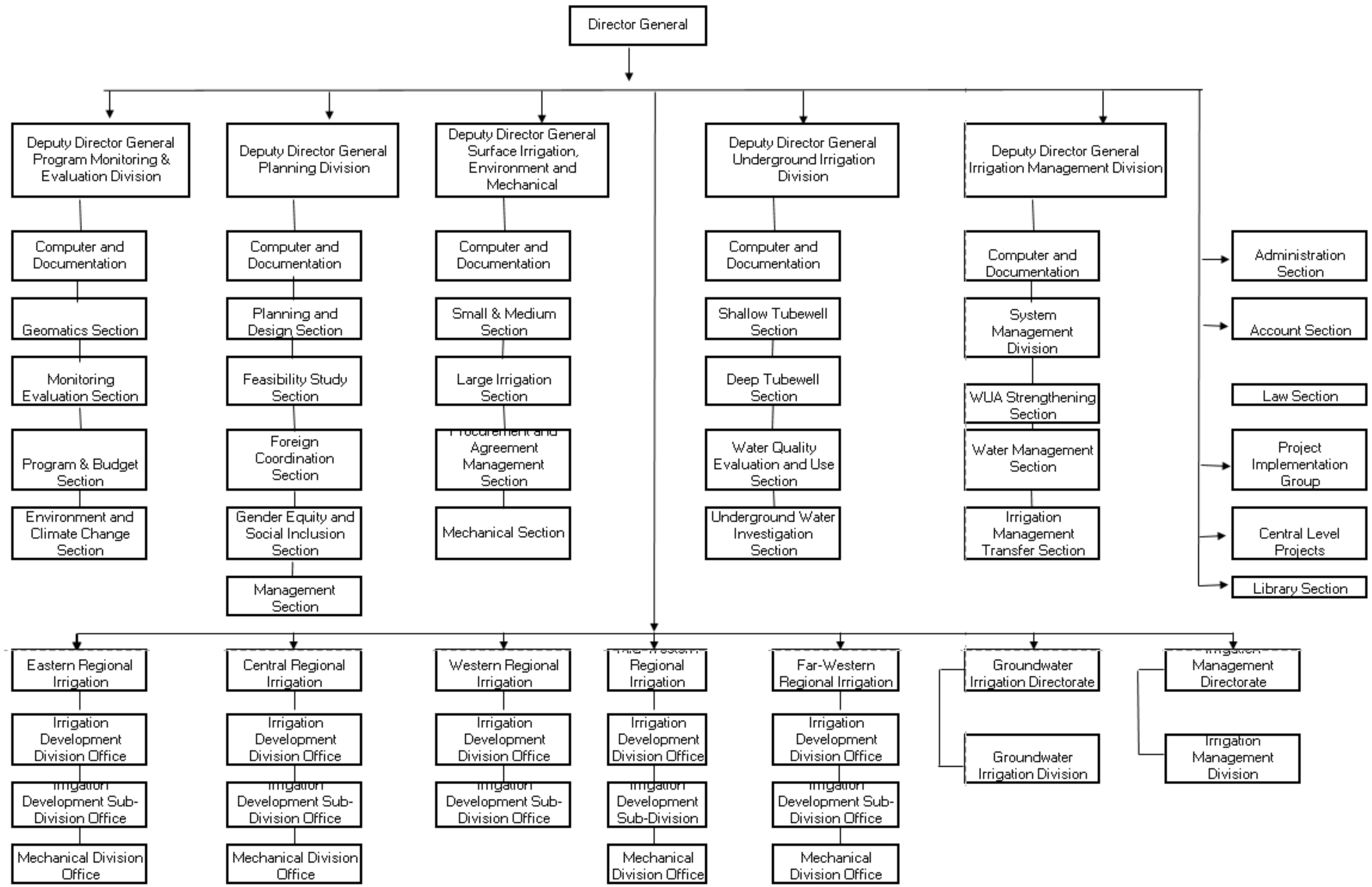

***Figure 3-7**: Organogram of Department of Irrigation (DoI)*

3.3.2.8. Department of Water Induced Disaster Management (DWIDM)

In order to mitigate these disasters in Nepal, the then Water Induced Disaster Prevention Technical Centre (DPTC) was established under the Ministry of Water Resources under an agreement between the Government of Nepal and the Government of Japan on 7 October 1991. The DPTC was continued for seven and half years under the participation of the concerned agencies of the Government and the co-operation of Japan International Cooperation Agency (JICA). To institutionalize the objectives and achievements of the DPTC, the Department of Water Induced Disaster Management (DWIDM) was established on 7 February 2000 under the Ministry of Water Resources. The then River Training Division of the Department of Irrigation was merged in the organizational structure of the DWIDM to strengthen its institutional capability. Since the establishment of Ministry of Irrigation (MOI) in 2009, DOI has been working under it.

Formal mandate

The main goal of DWIDM is to contribute in achieving the national goal of poverty alleviation through minimizing human casualties and damages of infrastructures due to water-induced disasters by the appropriate management and conservation of rivers and river basins of Nepal.

Overall objective of DWIDM is to implement the programmes of river and river basins conservation and to develop related appropriate technology, research, information systems, human resource and institutional development activities and to raise awareness of communities to mitigate water-induced disasters.

Tasks and responsibilities

In order to achieve the goal and objective above DWIDM is responsible:

- To formulate and implement water-induced disaster management policy and plans.
- To prepare hazard maps and risk zoning.
- To establish disaster information system and strengthen disaster reduction network
- To conduct community awareness programmes and trainings on water-induced disaster management.
- To activate Indo-Nepal Inundation committee(s).
- To prepare and implement Flood Plain Action Plan.
- To implement disaster mitigation measures.
- To strengthen institutional and human resources capacity.
- To identity environment-friendly water-induced disaster mitigation measures and construction methodology.
- To institutionalize and strengthen water-induced disaster rehabilitation system.
- To develop disaster information system and disseminate the disaster information.
- To perform the capability building of the Government and community for water-induced disaster mitigation works.

Organizational structure

DWIDM is one of the departments under the Ministry of Irrigation of Government of Nepal (GoN). The Director General of DWIDM is supervised by Secretary of MOI. There are four divisions under the umbrella of DG in DWIDM, each lead by Deputy Director General. Apart from these divisions, administrative branch, financial branch and legal branch are also directly administered by DG. There are 24 divisional offices under DWIDM.

3.3.2.9. Groundwater Resources Development Board (GWRDB)

With the aim to enhance groundwater study and investigation activities and to delineate potential area for groundwater irrigation development, Government of Nepal (GON) has established Groundwater Resources Development Board (GWRDB) under the Former Ministry of Water Resources (MOWR) in 1976. Since the establishment of Ministry of Irrigation (MOI) in 2009, GWRDB has been working under it.

Formal mandate

The mandates of GWRDB include:

- To carry out Groundwater investigation, exploration and studies together with groundwater utilization for irrigation, drinking water and other uses.
- To manage operation of tubewells and distribution of water for irrigation.
- To carry out the works for project implementation in accordance with the agreement between GoN and any foreign country or any International Donor Agency or Asian Bank.
- To carry out policy decision works for Project formulation, operation and implementation and monitoring of the works
- To fix and manage to collect the irrigation fee in groundwater irrigated areas.

Tasks and responsibilities

The main tasks of the GWRDB are:

- Identification of groundwater potential area in the Terai (shallow and deep aquifer) through geophysical survey and investigation tubewells.
- Exploitation of shallow and deep aquifer in the Terai for irrigation and drinking purpose.
- Develop technical manpower related to groundwater field.
- Regular monitoring of existing investigation tubewells for water level fluctuation, groundwater reserves and water quality.
- Study and investigation of mountain and Karst aquifer.

Organizational structure

GWRDB is under the Ministry of Irrigation of Government of Nepal (GoN). The board is chaired by the Secretary of Ministry of Irrigation, and the members include from various government departments (**Figure 3-8**). The executive head is Executive Director and works in close coordination with the Department of Irrigation. Organogram of GWRDB is presented below.

Organogram of GWRDB

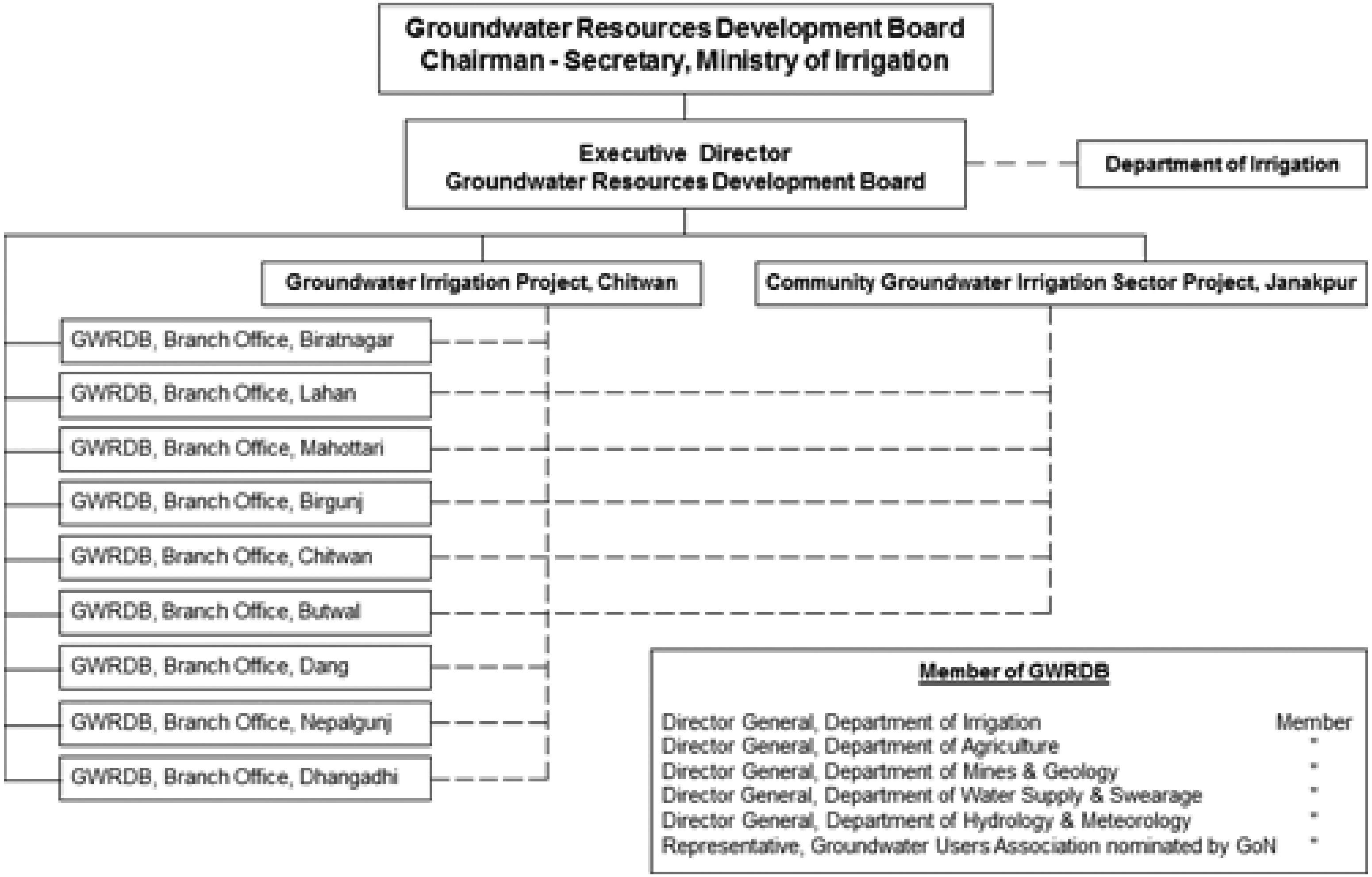

***Figure 3-8**: Organogram of Groundwater Resources Development Board (GWRDB)*

3.3.2.10. Ministry of Agricultural Development (MOAD)

Ministry of Agricultural Development (MOAD) is a governmental body of Nepal responsible for the growth and development of agriculture sector in the country.

Formal Mandate

The main mandate of Ministry of Agricultural Development (MOAD) is to improve the standard of living of the people through sustainable agriculture growth by transforming the subsistence farming system to a competitive and commercialized system.

Tasks and responsibilities

The Ministry of Agricultural Development (MOAD) is responsible for:

- To reduce poverty through increased agricultural production and productivity
- To make Nepalese agricultural products competitive in the regional and world markets by developing the foundation of commercial and competitive agricultural system
- To conserve natural resources, environment and ecological diversity and utilize them for sustainable agricultural development

Organizational Structure

The Minister of Agricultural Development holds the overall charge of the MOAD while the secretary acts as the administrative head and the chief advisor to the Minister on policy, planning and administration. The Ministry is the central apex body of Government of Nepal to look after agriculture and allied fields. The Ministry consists of five divisions, two centers, one research and development fund, two departments, five projects and autonomous body of one research council, Nepal Agriculture Research Council (NARC), one corporation, one development board, two companies and a few development committees (**Figure 3-9**).

Organogram of MOAD

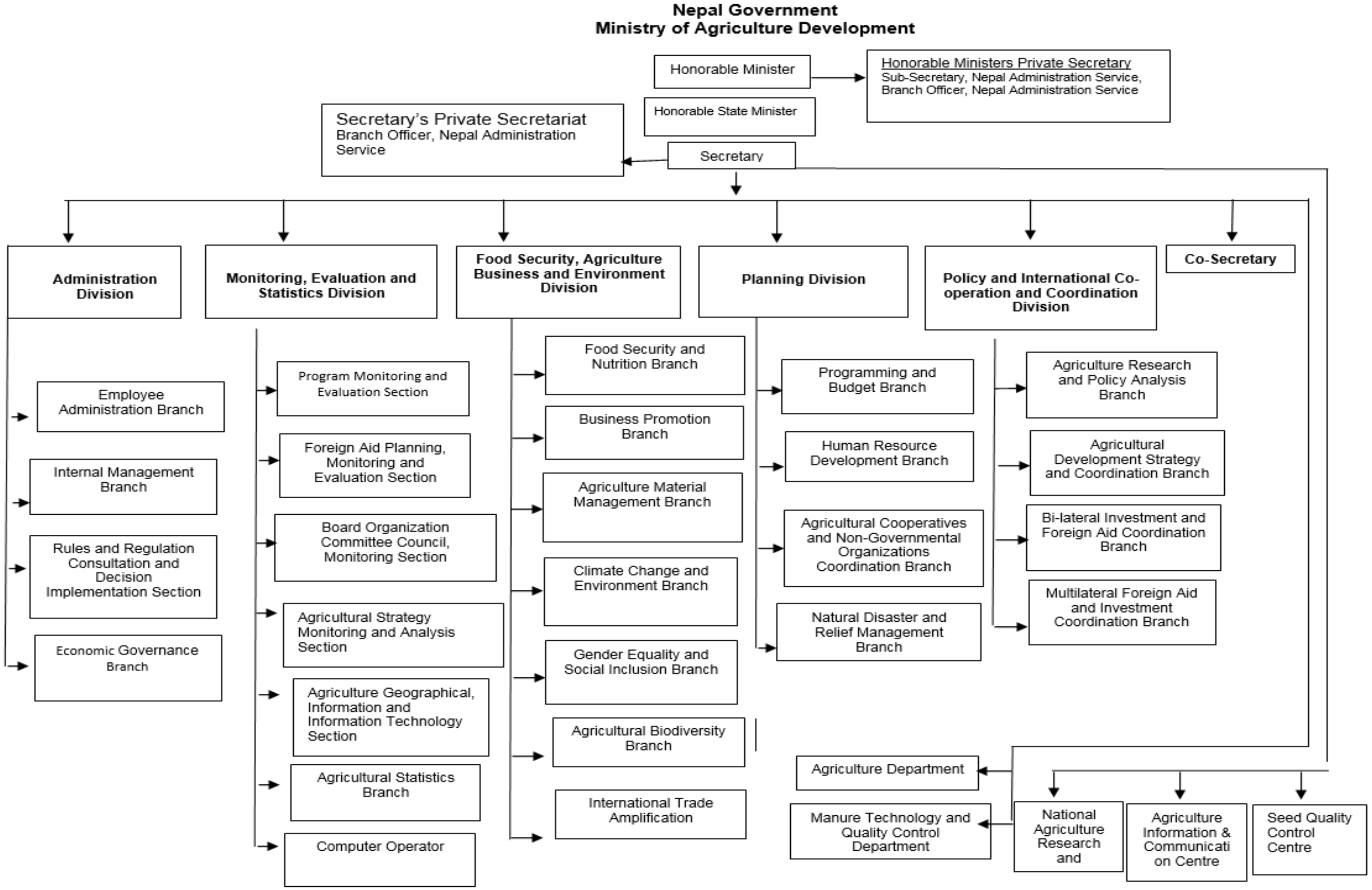

***Figure 3-9**: Organogram of Ministry of Agricultural Development (MoAD)*

3.3.2.11. Ministry of Land Reform and Management (MoLRM)

The Ministry of Land and Reform was formally recognized in 1987 as it split up from a larger Ministry consisting of food and agriculture.

Formal Mandate

This Ministry is directly responsible to implement the Land Act 2021 B. S. (1965). The Ministry aims to provide good governed and quality services with modern and simplified national mapping, cadastral, land administration and land management system.

Tasks and Responsibilities

Under the work division regulation (B.S. 2072) the Ministry's responsibilities include:

- Implementation, monitoring and evaluation of policies, plans and programmes.
- Land administration and revenue collection.
- National and International issues related to land.
- Establish and maintain Geodetic control networks, production of topographic maps, aerial survey and Geo-information.
- Management of Guthi Corporation and trust land.
- Implementing Land reform programmes.
- Human resource development through professional trainings in land survey and mapping and land management.

Organizational Structure

The Minister of Land Reform and Management holds the overall charge of the MOAD while the Secretary acts as the administrative head and the chief advisor to the Minister on policy, planning and administration. It includes 3 divisions: Administration; Planning, Monitoring and Evaluation; and Land Management. Administration Division is divided into six sections: Personnel Administration Section, Internal Management Section, Financial Administration Section, Legal and Decision Execution Section, Grievance Management Section, and Administrative Reform Unit. The Planning, Monitoring and Evaluation Division is divided into three sections: Planning and Program Section, Supervision, Monitoring & Evaluation Section and Land Information Coordination Section. The Land Management Division is divided into two sections: Land Administration Section and Settlement Management Section. In addition, eight development programs and projects are running in concurrence in other departments: Land Information and Archive Program; National Land Use Program, Land Reform, Freed Kamaiya and Freed Haliya Rehabilitation Program, Topographical Survey Program, Cadastral Survey Program, Geodetic Survey Program, Land Revenue Record Security and Strengthening Program (**Figure 3-10**).

Organogram of Ministry of Land Reform Management

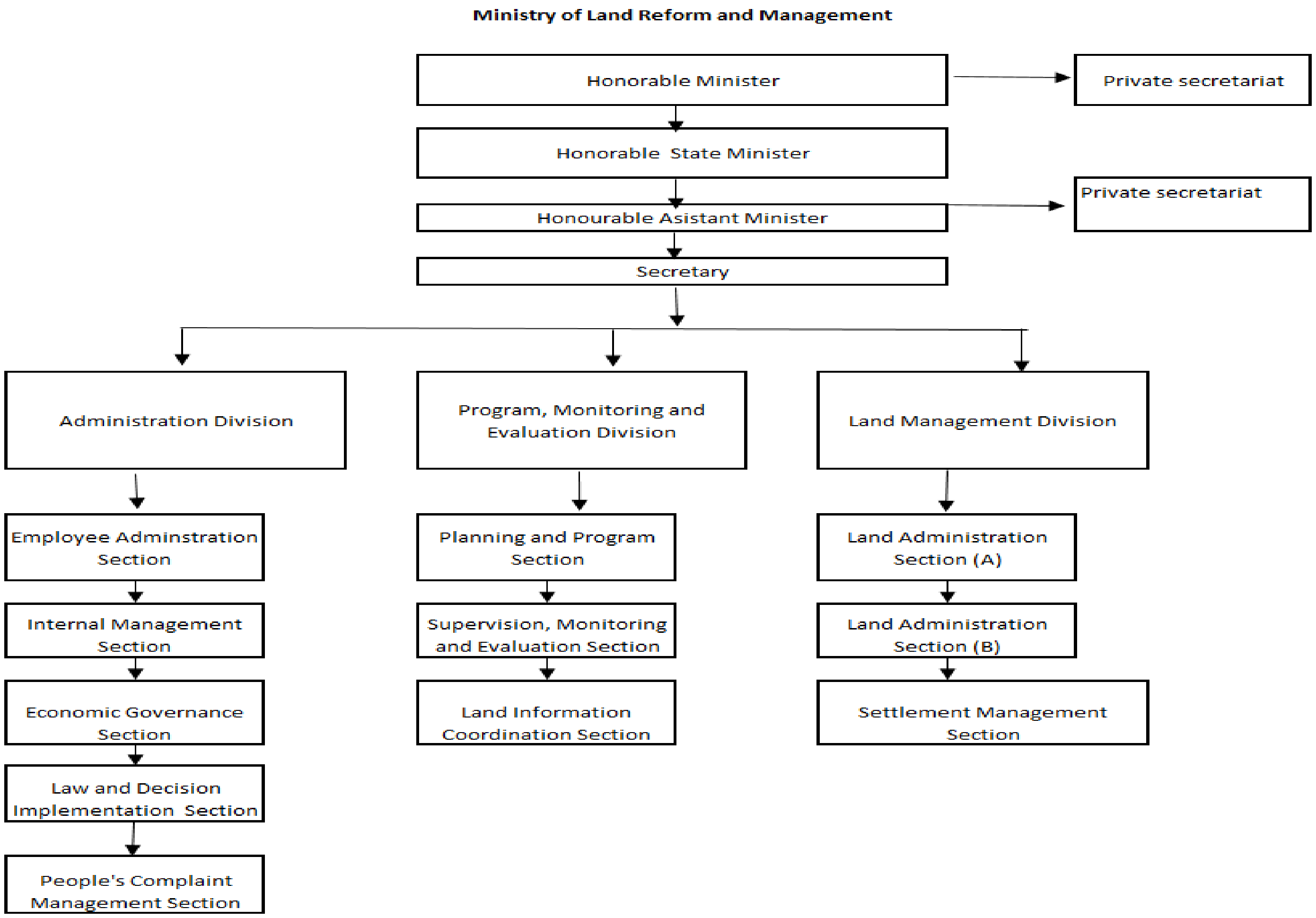

***Figure 3-10**: Organogram of Ministry of Land Reform Management*

3.3.2.12. Ministry of Forests and Soil Conservation

Ministry of Forests and Soil Conservation is a governmental body of Nepal that is responsible for the conservation of forests and soil in the country

Formal Mandate

The main mandates include:

- Management and conservation of forest resources and forest use by the general public and the forest-based industries and for business needs.
- Development of physical activities to apprise environmental consciousness of tourists.
- Development of medicinal herbs and expansion of domestication to create local employment and income generating opportunities.
- Management of soil fertility through catchment areas management and control of soil erosion.
- Maintain biodiversity of both flora and fauna in accordance with National Biodiversity Policy.

Tasks and Responsibilities

The key responsibilities of the Ministry as per the GoN Regulations 2069 are:

- Implementation, monitoring and evaluation of Forest and land-protection policy, plan and program
- Survey, mapping and boundary delineation of both state as well as private forest areas
- Protection, use, promotion and management of forest areas; and others

Organizational Structure

The Minister of Forest and Soil Conservation holds the overall charge of the Ministry while the secretary acts as the administrative head and the chief advisor to the Minister on policy, planning and administration. The Ministry is divided into five departments: Department of Forests; Department of Forest Research and Survey; Department of Soil Conservation and Watershed Management; Department of Plant Resources; Department of National Parks and Wildlife Conservation (**Figure 3-11**).

Organogram of MoFSC

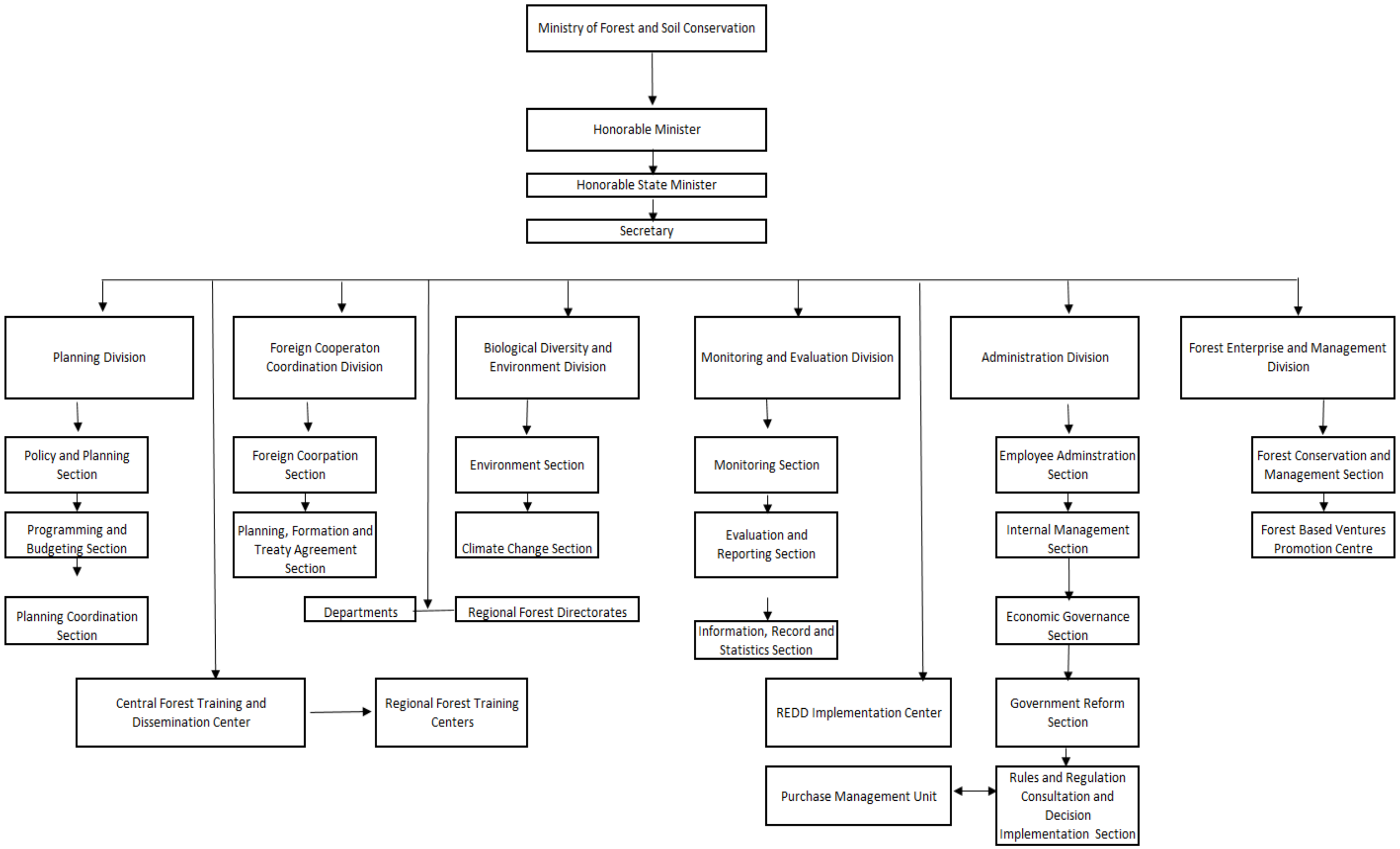

***Figure 3-11**: Organogram of Ministry of Forests and Soil Conservation (MoFSC)*

3.3.2.13. Ministry of Population and Environment

The Ministry of Population and Environment was formed in 2052 BS (1995/96). In the past it was briefly merged with Ministry of Science and Technology and was recently separated in 2072 BS (2015) and currently functions as a separate entity. The Minister of Population and Environment holds the overall charge of the Ministry while the secretary acts as the administrative head and the chief advisor to the Minister on policy, planning and administration. The Ministry is divided into three departments: Department of Hydrology and Meteorology; Department of Environment; and Environment Protection Council. Within the Ministry are also three divisions: Planning, Monitoring and Administration Division; Climate Change Management Division; Population and Environment Management Division.

Formal Mandate

The Ministry independently performs functions relevant to the environment sector, focusing on environmental conservation, pollution prevention and control, and conservation of national heritage as well as the effective implementation of commitments expressed in regional and international levels. The mandate includes implementing the Environment Protection Act 2053 and Environment Protection Regulation 2054, Environmental Guidelines, Standards and Directives issued by the Government of Nepal.

Tasks and Responsibilities

The main responsibilities of the Ministry of Population and Environment encompass matters related to environment and population and include:

- Formulate, implement, and monitor and evaluate plans, policies, and programs related to population and environment.
- Undertake and organize studies, research, surveys, trainings, national and international conferences and seminars.
- Maintain contact and coordinate with national and international institutions.
- Evaluate and review programs implemented by governmental and non-governmental entities.
- Development and use of labour force related to environment and population
- Explore and research progress made in the field of environment.
- Communicate and coordinate with universities related to environment.
- Agreement and understanding with bi-lateral and multilateral themes related to environment.
- Research, study and forecast hydrological and meteorological activities.
- Study, research, promote, regulate the use and growth of biological technology
- Climate Change and Resilience
- Publish and publicize matters relate to environment and population
- Pollution control, biodiversity conservation and balance
- Alternate Energy Development
- United Nation Population Fund and international agencies related to population

- Formulate, implement, monitor and evaluate plans, policies and programs related to population management and population and migration.

Organizational Structure

The Ministry of Population and Environment is headed by the Minister, while the Secretary acts as the administrative head and the chief advisor to the Minister on policy, planning and administration. The Department of Hydrology and Meteorology and the Department of Environment are currently under MoPE. MoPE is divided into three divisions: Planning, Monitoring and Administration; Climate Change Adaptation Division; and Population and Environment Management Division (**Figure 3-12**).

Organogram of MoPE

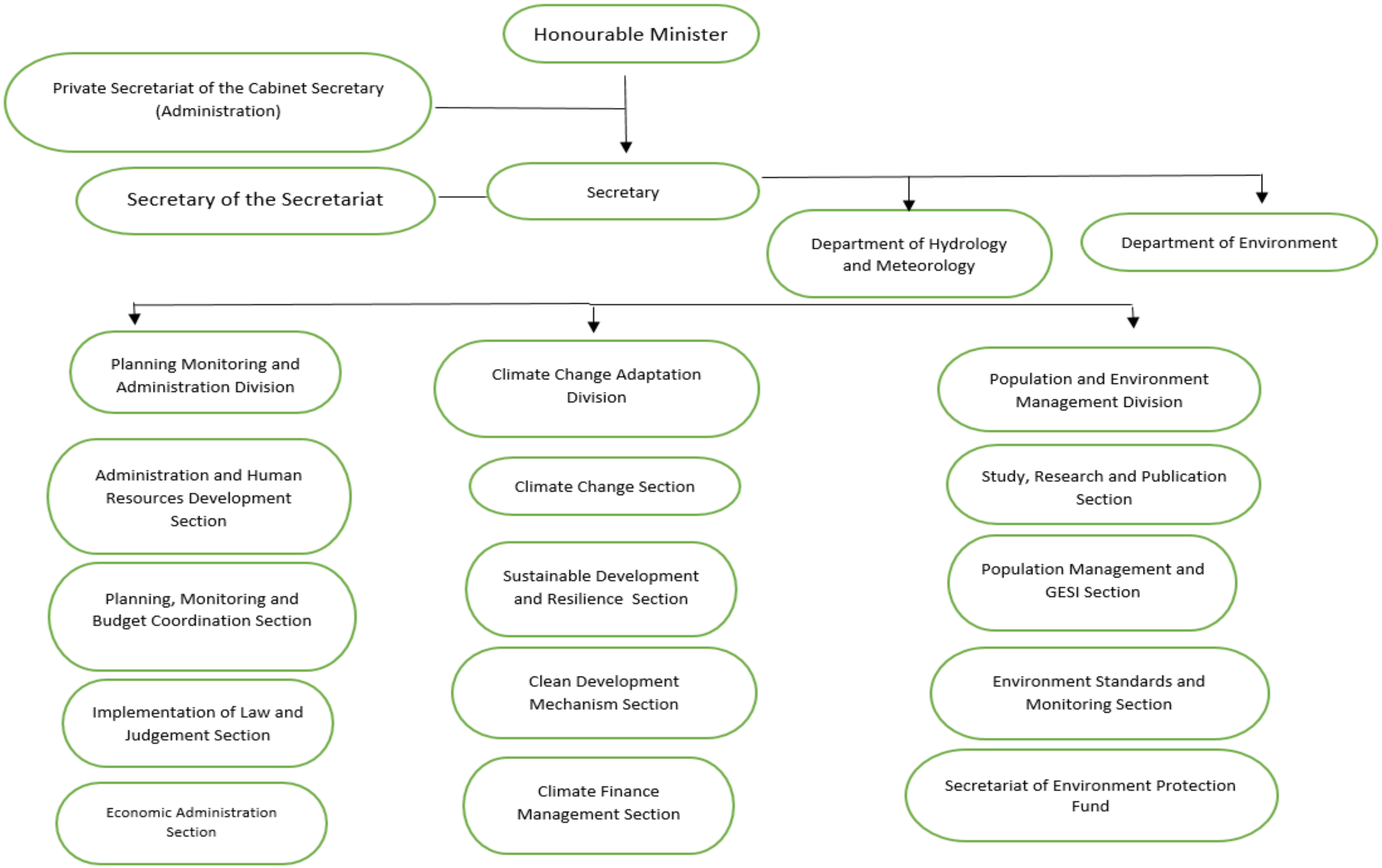

***Figure 3-12**: Organogram of Ministry of Population and Environment (MoPE)*

3.3.3. Politics, federalism and political parties

Democracy in Nepal can be traced back to the 1950s when Nepali activists, inspired by the successful independence movement in India, rallied against the autocratic Rana regime and aligned themselves with the exiled King Tribhuvan Shah. This led to the establishment of multi-party democracy. However, the Nepali Congress, who was at the forefront of this movement, was unable to maintain political stability despite winning a majority of votes in the 1959 elections. This resulted in a royal coup by Tribhuvan's son King Mahendra, and led to the arrest of political leaders in December 1960. A democratic system known as the *Panchayat* system was established based on the new constitution drafted by King Mahendra (Whelpton, 2005).

The *Panchayat* (committee) system followed a tiered system of democracy where direct elections were held at local village level. This sought to provide local representation at higher level of government since local representatives were picked to sit in on district and national level *panchayats*. However, the system was unable to critique the government since the king held supreme power in the absence of political parties and public opposition was highly restricted (Hangen, 2010). The three principles that guided the *Panchayat* era were: Hinduism, the monarchy and the Nepali language (Malagodi, 2013)

Once again the political parties sought to change the political structure of the then *Panchayat* system with a multiparty system. The *Jana Andolan* (1990) was helmed by the National Congress (NC) and the United Left Front, an alliance of moderate communist parties, with support from the more radical communist groups—United National People's Movement (UNPM) (Hachhethu,2006). This led to the formation of a new constitution that was adopted from the British model of parliamentary democracy aimed at providing a representative government and an independent judiciary.

The new Constitution brought together the right wing Rashtriya Prajatanra Party (RPP) and other left wing groups such as Communist Party of Nepal (Unified Marxist-Leninist) or CPN (UML). The first parliamentary election in 1991 followed a popular vote mandate where the NC emerged victorious and placed the CPN (UML) in the opposition role. These two political parties continue to be the major political players till date as evidenced in the ongoing local level elections[4].

The second constitution recognized the multi-party democratic system as well as the country's multi-ethnic and multi-lingual character. However, there is evidence to support the argument that this recognition in fact deepened the differences amongst the people. Although there was no restriction in terms of expressing concerns and critiques regarding the government, the representation of marginalized groups in the administration actually decreased under the post-*panchayat* system (Shneiderman et al., 2015). These circumstances thus allowed the underrepresented groups such as the indigenous nationalities and the Madheshis residing in the southern plains to organize themselves and spark the issue of ethnic politics in Nepal.

The growing dissatisfaction against the government's reforms came from the far-left Communist Party of Nepal-Maoist (CPM-M). The government's refusal to address their 40-point demand

[4] See Appendix for more information on the major political parties

instigated the attack on a police post in the mid-western district of Rolpa. The Maoists embarked on a decade long armed rebellion in 1996, which is known as the 'People's War'. Soldiers were recruited from schools and homes, some coerced by threat while others who had been historically marginalized were supportive of the movement. The demands for agrarian reform, land distribution and economic empowerment appealed the socio-cultural groups residing in rural areas who were undergoing a shift in critical consciousness arising from international aid groups who instilled the idea of 'empowerment' as well as ethnic activists who were vocalizing their resentment and resistance.

During the conflict the then King Gyanendra attempted to force an autocratic rule and seized full power, dissolving the parliament and declaring a state of emergency in 2005. In contrast to the previous royal coup, this attempt proved a disaster led to an unlikely alliance between the Maoist leaders and the mainstream political parties. The alliance forged a deal calling for the removal of the King, agreement of the Maoists to participate in the democratic government and the drafting of a new constitution. The King was stripped of his powers and Nepal was declared a sovereign and a secular state by the parliament and formally ended the war in 2006.

As the new government worked with an interim constitution there was a growing dissatisfaction among the Madheshis and indigenous activists such as Nepal Federation of indigenous Nationalities (NEFIN) on the exclusion of any reference to federalism, their central demand in the restructuring process, to ensure electoral representation based on proportion. After two elections (2008, 2013) the new constitution was formally promulgated on 20 September 2015, expedited due to the devastating earthquakes earlier that year. The Constitution left many political groups polarized mostly on the issue of federal boundaries. The Madhesh-based parties demand for an increase in the number of local units, proportionate to the population. Since the Terai area occupies a smaller area but is densely populated, the demand was to create two provinces instead of one. Moreover, the influence of the two powerful neighbours was evident in the events immediately following the promulgation of the Constitution. The Indian government was blamed for imposing an economic blockade in an indirect move to support the Madheshi parties, a move deemed highly insensitive considering the country and its people were still reeling from the disaster caused by the earthquakes. At the same time the government explored its trade links with the northern neighbour, China, in an attempt to decrease its dependence on India.

Federalism has been the subject of ongoing political unrest in Nepal with the objective of drawing borders between regions based on the ethnic and linguistic make up. Proponents of an ethnicity-based federalism is the assurance of a local ethnic majority which will provide a sense of security and belongingness to promote their own culture and identity (Aalen and Hatlebakk, 2008). However, the idea of federalism in Nepal poses a problem due to the intermixing of people across geographic and ethnic boundaries. There would be an ethnic majority in each region but new minorities will also be created in the process who will be subject to isolation and marginalization, albeit unintentionally (Adeney, 2000). Furthermore, there should be a balance of power to ensure a dual sense of loyalty, to the ethnic federal units as well as the unified democratic state. For this, a strong national government is necessary to ensure the demands of one federal unit do not pose any harm or take away from another.

The federal system would include three levels of government who will administer at Central, Provincial and Local level. The elected representatives will have power to make laws, raise revenue and fix policy (Nepali Times, 2017). There is also quota for women and Dalit candidates. Previously, these positions were filled by political representatives who have been mired in accusations of corruption and misappropriation of funds (Asia Foundation, 2012) hampering planned developmental activities. However, there is still significant contention regarding the state boundaries and conflicting ideas on how federalism should be achieved given the diverse topography, ethnicity and political stance. The agreement to create 7 provinces and 744 local units has been agreed upon by the major political parties but the number and boundaries at provincial and local level are still up for debate. Amongst the contention and dissonance, the government has moved forward with the local level elections that are taking place after an 18-year hiatus. The local elections are being conducted in three phases, with two phases complete as of July 2017 and the third phase scheduled for September 2017. Some Madhesh-based parties set aside their differences to form a unified Rashtirya Janata Party Nepal, and is set to elect local bodies in the third phase. Their boycott in the second phase backfired to an extent since many candidates participated as independent candidates or joined the UML given the eagerness of the people to participate in a historic election and push the country towards the path of development. It remains to be seen how the issue of the Madheshi parties will resolve given that the UML, the current frontrunner, has rejected their demand for constitutional amendment.

3.3.3.1. Political Parties[5]

Nepali Congress (NC)

Nepali Congress is one of the oldest functioning parties that has been at the forefront of the struggle for democracy in Nepal. It was founded in the 1940s when neighbouring India was inching closer in its fight for freedom. The NC led the anti-Rana movement in 1950-51 and also emerged victorious in the 1959 parliamentary elections. During the course of the democratic movement, the NC has participated in violent as well as non-violent opposition in the 1960-70s and in the *Panchayat* era. Taking the lead in the Jana Andolan in 1990, the NC has remained in the government, gaining majority in 1991 and 1999 and have maintained their stronghold for substantial periods since their initial victory.

The NC originated with the mission to overthrow the autocratic Rana regime and later adopted its ideology of democratic socialism committed to a multiparty parliamentary democracy and constitutional monarchy. Its policies have reflected a pro-privatisation and liberalisation stance post the 1990 but it has struggled to maintain a clear vision and adapt to the changing political climate nationally. The party has relied heavily on its dynamic leaders rather than focusing on ideology and delegating tasks based on rank to maintain unity. The inter-fighting amongst the senior ranks has led to the collapse of governments under NC leadership and the lack of commitment to the part as a unified body has paralyzed the party's ability to evolve and govern efficiently. The NC leader Sher Bahadur Deuba again led the country in 2017 as the Prime Minister, taking over from the CPN Maoist leader Pushpa Kamal Dahal (Prachanda) as part of the agreement of the coalition government to transfer power once the local elections take place. He oversaw the successful completion of the second phase of the local elections although the

[5] Extracted from Hachhethu, 2006

party itself was not as successful as predicted. He had an uphill task of ensuring the third phase, of the controversial Province 2, takes place with the participation of Madheshi leaders.

Communist Party of Nepal (Unified Marxist-Leninist)

The CPN (UML) group was founded in 1971 seeking inspiration from the Cultural Revolution in China, the Naxalite uprising in India and the peasant-landlord bifurcation in Nepal. Known as the 'Jhapali Group', this party occupied the far-Left position amongst other splinter groups of the CPN. However, the growth of the party can be traced to its ideological evolvement from class annihilation to the abandonment of Maoism followed by participation in the 1990 democracy movement with NC. In the 1991 elections CPN UML was the main opposition party, later changing its stance to a more peaceful competition in a multiparty democratic system. The CPN (UML) has fared well with its constantly modifying position in comparison to other parties. The organisational system has also worked well to expand its support base through party ideology rather than individual leadership. However, its less radical stance has alienated some of the individuals who found more in common with the Maoist approach. The current leader Khadga Prasad Oli has led the party to victory in the current elections, emerging as the biggest party at local level. KP Oli was the leader during the blockade and gained nationalist support for his stance against India for providing unofficial support to the agitating Madheshi leaders. Although CPN UML is touted as an anti-Madheshi party, it is interesting to note that it gave a tough competition in the low lying Terai region in the second phase of elections. Using its organisational strength, it displayed inclusiveness by fielding candidates based on ethnic majority in the constituencies.

CPN (Maoist Centre)

The CPN Maoist was formed after its split from CPN (Unity Centre), an alliance of Left splinter groups after 1990, to 'expose the sham of parliamentary democracy'. Under the leadership of Pushpa Kamal Dahal (Prachanda), the party led the armed rebellion against the monarchy and democracy. The militia under Prachanda's leadership grew from 200 to 100,000 with the goal to establish a republican system and follow the democratic government similar to China. They proposed for a complete restructuring of the state, including popular sovereignty, secularism, federalism, inclusive democracy and retention of the multiparty competitive system. After the end of the war in 2006, the party forged an alliance with other major political parties and contested in the national elections in 2008, with the highest number of seats and in 2013 becoming the third largest party. Its leader led the coalition government from 2016-2017 before resigning after the successful completion of the first phase of the local level elections. After UNL and NC, CPN has emerged as the third successful party in the current local elections.

Rashtirya Prajatantra Party (RPP)

The Rashtriya Prajatantra Party was formed with the merger of two different parties with similar ideologies. The leaders were former Prime Ministers during the *Panchayat* era and has a reputation for being pro-monarchy and the partyless *Panchayat* regime but has managed to assimilate itself with the changing political context to support constitutional monarchy and multiparty democracy. As a right wing party, the RPP led governments as nominated by the King during the period of war and King's direct rule. The leaders found common ground on having served during the *Panchayat* rule rather than similar ideologies. In the current elections only one candidate has been elected from the RPP party.

Rastriya Janata Party Nepal (RJPN)

The Rastriya Janata Party Nepal was formed ahead of the local level elections in 2017 to unite six Madheshi splinter groups to boycott the local level elections.

Nepal Communist Party (NCP)

The Nepal Communist Party (NCP) is currently the ruling political party in Nepal. It was founded on 17 May 2018, from the unification of two leftist parties i.e. Communist Party of Nepal (Unified Marxist–Leninist) and Communist Party of Nepal (Maoist Centre).

3.3.4. River basin planning processes and shaping of power struggle

The way different government agencies have adopted basin planning approaches as their means to sustain and gain bureaucratic power amidst the idea for federalism highlights how the idea of basin planning is shaped and reshaped not only by existing power structure and relationship, but also by continuous power struggles, that is taking place at both policy and institutional level. At policy level, this is manifested in the overlapping policies and legal frameworks, supporting and justifying different national government ministries' roles and responsibility in river basin planning. Institutionally, this results in the shaping and reshaping of national government ministries' envisioned bureaucratic territory, through the overall process of contestation. At present such contestation occurs rather indirectly, as the envisioned bureaucratic territory is mainly incorporated in policy and legal frameworks. Nonetheless, the overlapping institutional boundary as reflected in each government ministry's basin site selection for their so-called basin offices implies that the positioning of river basin as a new bureaucratic territory would result in direct bureaucratic competition between the different government ministries.

From a policy perspective, this highlights the importance of WECS consultation process of the draft Water Resources Policy as a potential platform where WECS and different sectoral ministries as well as the NPC could share and discuss their overall views on how river basin planning should be done through cross-sectoral collaboration, involving not only national level government agencies, but also incorporating development needs and aspirations of the to-be formed local government bodies. While WECS designed the consultation process merely as a means to gather other government agencies' and local bodies' inputs on the draft Water Resources Policy, linking this process with the outcome of local election is pertinent, if the draft policy is to incorporate local government bodies' views and perceptions on water resources management across scales. We argue that incorporating these views and perceptions could serve as the first step not only to fine tune national, provincial, local development perspectives, but also as institutional mechanism to prevent potential conflict concerning actual water use. In the aftermath of the local election, local government bodies would gain decision-making authority on water resources management, among others. Hence, when they view the policy as lacking actual significance in water resources management at local level, they would contest it. Also, bearing in mind that the new governance structure once the federal structure is activated could be entirely different, a series of consultation processes involving the newly elected local governments in selected sites would be required.

3.3.5. Linking politicians and bureaucrats in water governance diagnostic

Our research findings show how political competitions centred on power interplay between the major political parties drive the overall performance of administrative government, thus ensuring that national development planning processes (or the lack thereof) follow the defined political agendas, neither incorporating the country's long-term development vision nor coinciding with the development needs and aspirations of the local communities and the wider society.

It illustrates how political competition contributes to the preservation and reproduction of sectoral egoisms in general and with regard to water resources management in particular. It shows how political competition works in tandem with sectoral development planning approaches, through the transformation of government bureaucratic performance as part of political leverage, not necessarily linked with local community's views and perceptions and/or the grass roots realities. The analysis reveals the underlying rationale behind the current lack of planning and disjointed development activities, and how they are preserved and reproduced because they represent major political parties' and sectoral government ministries' interests and means to presume power and influence. Moreover, the analysis shows that while political competition drives the country's development planning processes, the latter was achieved not simply through political parties' domination vis-à-vis the government administrative bodies. Rather, it was achieved through synergizing and fine tuning political interest with bureaucratic interest (e.g. linking political leverage with access to development fund) as resembled in different strategies used by politicians and bureaucrats in shaping their relations. Hence, the country's scattered, inconsistent national development plan as well as its overlapping and disjointed development activities should not be viewed as an indication of severe lack of governance. On the contrary, it resembles how governance structure, processes, and outcomes are produced and reproduced through power relations and power interplay.

3.3.6. Grass roots forces and alliances shaping hydropower decision-making

Referring to the shaping of everyday politics as well as the formation of spatial alliances in hydropower decision-making at the local level, the analysis illustrates the shaping and reshaping of spatial logic driving hydropower decision-making processes, centering on the company's strategy to include and exclude local community's development needs and concerns, and how these coincide with its objective to proceed with the planned hydropower project. It argues that understanding this spatial logic is key to unpacking power relations (re)shaping hydropower governance landscapes, processes and outcomes.

The Nepal case study clearly shows how the company did not only form strategic alliances with the upstream Upper Karnali Concerns Committee (UKCC), it also undermined local community's potential ability to come with a unified voice demanding their collective needs and concerns. Lacking any spatial power to gain access to hydropower decision-making processes, downstream UKCCs' lack any bargaining power to push the company to agree on the negotiated terms or even start with the negotiation processes, as the latter is side-lined by upstream UKCCs' support to the planned dam project. While the central government has formulated and implemented various policies and legal frameworks to regulate and manage hydropower development in the country, our case study highlights key policy and institutional gaps in hydropower decision making. As various government agencies are competing for decision-making space, and bearing in mind the country's dependency on foreign direct investments and private sector actor for the sector development, there is a tendency to give the company some leeway to create their own decision-making space, resulting in the latter taking the center stage in hydropower project implementation at the grass-roots level.

Our research findings show that the current discourse on anti-dam movement cannot be framed without including local community's diverse views on hydropower development, their dynamic standpoints, how this evolves over time, and its implications for social justice (Sen, 2009; Visser, 2001; Young, 1990), while asserting that *'notions of justice are more likely to be plural than converge on a single meaning'* (Sikor et al., 2018: 14). Moving beyond distributional and procedural justice (Schlosberg, 2007), it highlights the need to *'recognize that justice has different meanings for different people in different places'* (Tschakert, 2009: 731), while unpacking the processes that (re)produce misrecognitions and exclusions, through which injustices are created and sustained. For the Upper Karnali case in particular, this means connecting upstream UKCCs' negotiated demand for land compensation payment with downstream UKCCs' concerns on how the planned hydropower project would negatively impact their agricultural and fisheries resources. Upstream UKCC and villagers view justice as getting the agreed land compensation value. Downstream UKCC and villagers view justice as getting their concerns heard and addressed by the company. Putting these different perceptions of justice within the context of hydropower decision-making, the paper highlights how views of justice can be contradictory, as this manifested in upstream and downstream UKCC and villagers' negotiation strategies with the company, and how the latter defines their respective position to support and oppose the planned hydropower project[6]. Or, as stated by Walker (2009: 40): *"as different groups will resort to different conceptions of justice to bolster their position, so will different groups work with different understandings of the spatiality of the issues at hand"*.

3.4. Conclusions

Placing ongoing discussion on river basin planning into the wider context of state transformation processes, our research findings bring to light the need to link current political reform efforts with the formation of local government bodies accountable to the local population as their direct constituents. Here, the main issue at stake lies not only in whether national, provincial, district or local governments would be the one leading the country's development plan and activities, or how

[6] *On challenges for cross-scale collective action and stakeholder representation in river basin management see Swallow et al. (2006) and Wester et al. (2003).*

their tasks and responsibilities would be defined following federalism, but also as to whether the different administrative governments could represent local population's development needs and aspirations, and be held accountable for that. While politics and power relationship will continue to shape and reshape the overall process of power struggles with regard to river basin planning, it is pertinent that the actual outcome of the envisioned basin planning will be significantly derived from informed and accountable decision-making processes.

Following federalism, decision-making authority and responsibility will be transferred from central government to elected local governing bodies. In the context of water governance, the political move towards federalism and the establishment of local governing bodies invalidate the current depoliticizing approach to water resources management. As federalism connects the idea of river basin planning and integrated water resources management with the overall notion of political representation and social justice (Clement et al., 2017), it urges the need to understand power structure, power relations and the politics shaping these power interplay as a central element, an integral part in water governance analysis.

Placing this within the context of state transformation and the current move towards federalism, it highlights the need to understand the overall shaping of spatial politics and broaden the overall notion of accountability of elected local governing bodies, beyond their respective administrative and political units (e.g., village, municipality), as it is pertinent that the planned development captures development needs and concerns of the poorest and most marginalized groups of the society. From a policy perspective, this highlights the role that can be played by local governing bodies in shaping the country's development in general and with regard to hydropower development in particular. Following federalism, local governing bodies could ensure that local community's negotiation with hydropower company is not based only on the relations between certain UKCC with the company, but most importantly driven by the need to distribute benefits and impacts of hydropower development more equally. This highlights the need to develop policy framework and mechanisms to govern and direct hydropower development practices at local level, to ensure that hydropower project captures local community's diverse development needs and aspirations.

Full information and analysis on the role of spatial alliances shaping hydropower decision-making processes at grass roots level is available in **Annex 3-3**. Full information and analysis on the positioning of river basin planning as a function of power and contested arena of power struggle is available in **Annex 3-1**. Full information and analysis on how the political-bureaucratic nexus works is available in **Annex 3-2**.

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3.6. Annexes

Annex 3-1: Suhardiman D., Bastakoti R., Karki E., Bharati L. (2018). The politics of river basin planning and state transformation processes in Nepal. Geoforum, 96: 70-76. (https://www.sciencedirect.com/science/article/pii/S0016718518302239)

Annex 3-2: Suhardiman D., Karki E., Bastakoti R. (2018). Putting power and politics central in Nepal's water governance. World Development, Under Review.

Annex 3-3: Suhardiman D., Karki E. (2019). Spatial Politics and Local Alliances Shaping Nepal Hydropower. World Development, 122: 525-536. (https://www.sciencedirect.com/science/article/abs/pii/S0305750X19301743)

4. Gender and Social Inclusion

Gitta Shrestha, Floriane Clement, Diana Suhardiman, Emma Karki

4.1. Context

Access to water is a key to human survival and well-being. Water access defines good health, food security, livelihoods and the fulfilment of spiritual and cultural needs. Nonetheless, not everyone has equal access to water and suffers distress and poverty as a result. Various factors have been documented to facilitate and curtail equal access to water resources, which include both biophysical and social factors. Among these gender differences in water access and management is prominent. The gender difference in access to water enlarges with other intersectional identities of social beings such as caste, class, age, disability, location and so on (Das and Hatzfeldt 2017). Essentially, the poor and marginalized, with limited access to assets, networks and livelihood options, face greater vulnerability in times of change and uncertainty (Ibid).

The advocacy for equal inclusion of both men and women in planning and management of gradually depleting and scarce water resources is immense (Naiga, Penker and Hogl 2017). Moreover, water supply scarcity has been widely attributed to poor non-inclusive water governance (Partnership 2002). The argument is since women deal with water more than men given their gender role both in domestic and productive water use, women should equally be encouraged to be water managers (Cleaver 1998). This idea is important from two perspectives. First, the issue is not limited to unequal access to water for domestic and productive use but also the increasing water risks and conflicts in terms of water scarcity and water-induced disasters. Water scarcity and disasters impact human well-being negatively and compound poverty and inequalities in communities. Second, due to changing family structures, changing lifestyle, fragmented land holdings and increasing food insecurity, men are increasingly out-migrating from the villages in search of better livelihood options. The declining interest of men, especially youths, in agriculture as a livelihood option is documented widely. In such a scenario, women are responsible for the household, including agricultural and other livelihood activities (Jaquet et al. 2016). However, due to unequal gender power relations, women, especially from vulnerable households, do not have influence on water decision-making (Upadhyay 2003). Research indicates that even the provision of women quota has been very elusive with regard to meaningful representation of women in water user associations (Pradhan 2015, Prokop 2004, Wambu and Kindiki 2015).

Despite decades of efforts towards gender mainstreaming and social inclusion in the water sector, a wide gap between policy commitments and outcomes remain. While the importance of women has been increasingly emphasized in policy and practice in the water sector (e.g., The Nepal Irrigation Management Transfer Project (IMTP), 2002), a number of empirical literature documents 'business-as-usual' approaches and lower/passive participation of women in water user associations. The methods and strategies adopted to overcome gender-based obstacles in projects related to water resource management remain vague (Sülün, 2018) paying no/less attention to social spaces and social processes that create pathways, social capital and facilitate [capabilities] access to resources. Gender mainstreaming in water policies has focused on promoting the participation of women in water user associations (WUA) in both water supply and irrigation through quotas for women's membership in these organizations. Women's participation in WUAs is encouraged and identified to be a key in enabling gender equality, a more equal participation in water governance, and a more equal share of water infrastructure and services.

Most stakeholders, including national government agencies, recognize the limited outcomes of policy initiatives in support of gender equality and women's empowerment. Government agencies point to gender norms prevailing in rural Nepal as the main factor accounting for the gap between policy intentions and practices. But many scholars emphasize the need to understand how organizations and institutions that design and implement water policies and programs are themselves gendered. Bringing about transformative change for greater gender equality at the local level requires addressing gender inequalities and masculine professional culture within public organizations that drive policymaking and implementation. Moreover, well intentioned efforts tend to overlook complex social dynamics in rural areas, which influence the effectiveness of women's participation. If initiatives are to succeed in promoting gender equality, they are expected to be considered in the light of the wider social and political contexts – of what makes a community or a society.

In this chapter, we aim to answer the following research questions:

- How gendered discourses, institutions and masculine professional culture contribute to policy gaps?
- Is social capital gendered? How social capital differs for men and women? How it impacts the capabilities of men and women to benefit from water resources?

4.2. Approach and Methods

We chose the *Social Relation Approach* (Kabeer, 1994) as a starting point to develop our research framework. This framework (**Figure 4-1**) is particularly relevant for this study as it allows analysis of gender inequalities across scales from the household to the state, by distinguishing immediate, underlying, and structural causes of inequalities across different institutional sites. It is also specifically well-suited to the analysis of planning processes as it allows a detailed analysis of gender within organizations, thereby allowing identification of entry points for designing gender transformative approaches within gender and development programmes. Following sub-sections first briefly introduces the original framework of Kabeer (1994), and then expands the discussion to the approach we adopted for this study based on the idea of justice developed by Sen (2009).

4.2.1. Social relations approach

The *Social Relations Approach* examines how institutions create, aggravate and reproduce social and gender inequalities. Gender relations are located as part of a broader set of social relations defined by caste, class, ethnicity, and age, among others. Social relations shape the roles, access to resources, rights, and responsibilities as well as people's claims on these. Institutions are defined as the rules of the games, and distinguished from organizations, who are the players of the game (North, 1990).

The framework distinguishes four key institutional sites: the state, market, community, and family/kinship. The market includes all private organizations that aim at maximizing profit, from farm enterprises to multinationals. The community includes several types of grassroots organizations while the family/kinship includes the household and extended family.

The framework also introduces five specific generic constitutive components of the organizations: i) rules (that is institutions), ii) activities, iii) resources, iv) people, and v) power. Rules are about how things get done and define who benefits and who is entitled to participate. Activities are about what is done and can be productive, distributive or regulative. Resources are about what is used and produced and include human resources (labor, education, skills), material (assets, financial), immaterial (information) or social resources (kinship, networks). People indicates who is in, who is out and who does what basically looking at the issues of inclusion and exclusion. Lastly, power is about who decides and whose interests are served.

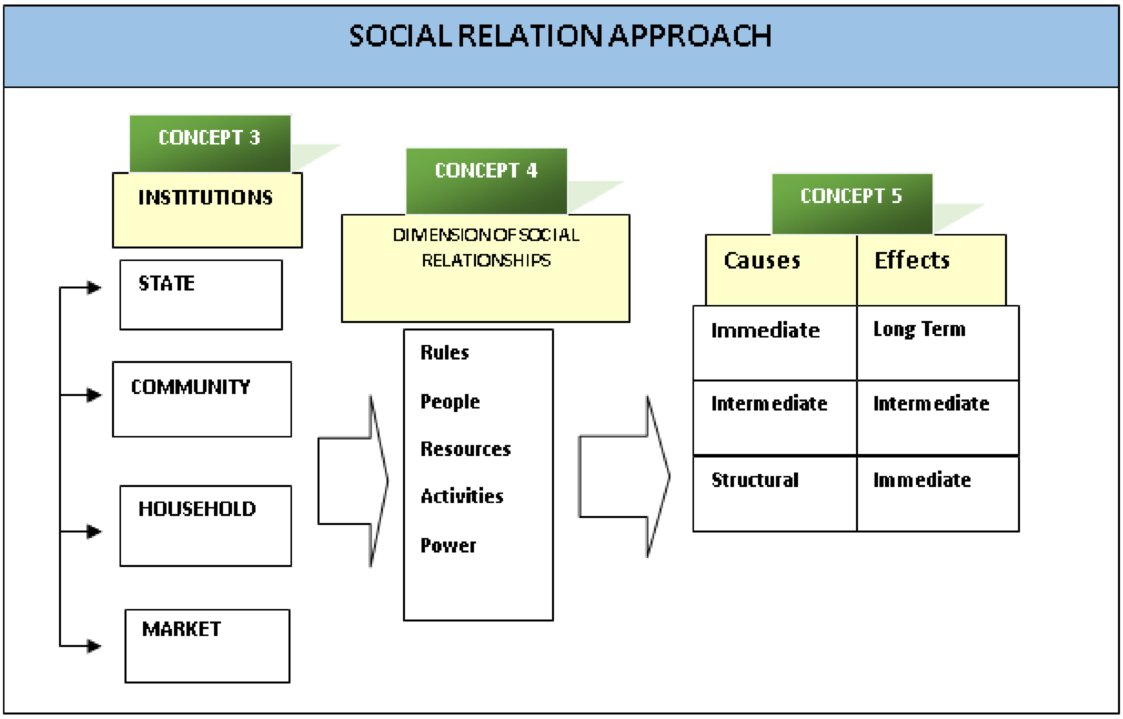

***Figure 4-1**: Social relation approach (Source: adapted from Kabeer, 1994)*

4.2.2. Customization of the social relations approach

For the purpose of this study, we added few variables that we felt were relevant in the context of our research. We added **non-government** (including federations of users, INGOs, NGOs and funding agencies) as **a key institutional site**. The role of non-government is particularly important in the context of the water sector in Nepal given the importance of international development assistance (IDA) in Nepal in general, and in the water sector in particular. Although Kabeer (1994), included non-governmental organizations (NGOs) in ‘community,’ we prefer to have them in a separate category as NGOs as the water sector might be more accountable to international development partners than to communities. Their activities are also more geared towards providing services to communities rather than advocating and representing their voices and interests. This spreads along a spectrum of downward accountability towards local water users, which we would expect to range from users' federations to NGOs, INGOs and finally development partners, along a higher to lower downward accountability continuum.

We also added one variable on **organizational culture**, drawing from Novib's framework (1996 in Mukhopadhyay, 2006). The organizational culture is an important determinant of gender inequalities within organizations, notably in the water sector in Nepal, which is characterized by strong masculinities (Udas and Zwarteveen 2010; Liebrand, 2014). We also introduced the concept of '**practices**' in relation to 'activities': '*A 'practice' (Praktik) is a routinized type of behaviour which consists of several elements, interconnected to one other: forms of bodily activities, forms of mental activities, 'things' and their use, a background knowledge in the form of understanding, know-how, states of emotion and motivational knowledge'* (Reckwitz, 2002, p. 249). Drawing from earlier work on institutional analysis (Clement, 2010), we also added four variables: the **biophysical context** and the **infrastructures** on the one hand, and the **political economic context** and **discourses** on the other hand.

The **biophysical context** shapes the distribution across time and space, availability and quality of water resources. The biophysical context therefore also strongly contributes to gender and social inequalities in the water sector and should be accounted for in our analysis. Similarly, infrastructures considerably influence how water is distributed temporally and spatially and to whom and who benefits from water; therefore, forming one of the products of the policy-making process related to water resource planning and development. We consider here any type of infrastructure, ranging from small-scale micro-hydro, ponds, individual tube wells and small-scale water supply and irrigation systems to large-scale hydropower dams and irrigation systems.

We expect that both the **political economic** context and **discourses** influence organizations and the policy process. The political economic context is an important factor affecting all components of the organizations, for instance resource allocation, definition of goals and objectives, and priorities set for the activities. It also shapes relative importance of the five different institutional sites (state, market, civil society and development organizations, community, and family/kinship) in shaping water resource access, planning and development.

We define **discourse** as "A specific ensemble of ideas, concepts, and categorizations that is produced, reproduced, and transformed in a particular set of practices and through which meaning is given to physical and social realities" (Hajer 1995, p. 60). Hajer (1995) argues that the way discourses frame environmental problems largely shapes institutional change. For instance, discourses on integrated water resource management (IWRM) tend to frame water issues as apolitical and technical, and call for institutional reforms that pay little attention to social and gender inequalities (Clement et al., under review).

4.2.3. Adopting a justice perspective

***Conceptualizing justice**: The water sector in Nepal holds strong justice issues associated with how water resource development is planned, who is included in the decision-making process, and who benefits - in particular in respect with hydropower development (Domènech et al., 2013; Gyawali, 2013; Onta and Tamang, 2013). There is therefore a potential tension between the means to achieve national economic growth and justice. Justice is also closely linked to issues related to gender inequalities. In this study, we have used the concept of justice as a normative approach for gender analysis. Justice usually includes three inter-related components: i) the fair distribution of benefits, burdens and risks associated with water resource development, ii) the recognition of diverse needs and values; and iii) their just representation in policy-making arenas. We argue that adopting justice as a normative approach allows not only evaluating the outcomes of decisions and policy processes but also facilitates the design of concrete policy recommendations towards gender-transformative approaches.

Justice and capabilities: Sen (1999) defines justice in terms of choice and freedom of the people involved - that is their capabilities to achieve the functioning (that is the 'beings' and 'doings') that they value. For Sen ''*the question of gender inequality ... can be understood much better by comparing those things that intrinsically matter (such as functioning and capabilities), rather than just the means [to achieve them] like . . . resources. The issue of gender inequality is ultimately one of disparate freedoms*'' (Sen 1992, p. 125 in Robeyns, 2003). The capability approach contrasts with philosophical approaches that concentrate on people's happiness or on the means to achieve well-being such as access to resources. Sen argues that policies and development programmes should focus on what people are able to do and be, on the quality of their life, and on removing obstacles in their lives so that they have more freedom to live the kind of life that, upon reflection, they have reason to value. The capabilities approach brings out the relationship between the public and private spheres of society and the implications of private inequalities, especially gender inequalities, in the establishment of social justice (Sen, 2008). The capability approach has notably been adopted by Nussbaum (2003) to analyse gender justice. Nussbaum (2003) however offers a different stance on the capability approach by providing a list of ten central human capabilities that are related to the body, mind and environment. Her approach contrasts to Sen's argument that the definition of capabilities should be context-specific and based on open discussion and deliberation.

Justice as a deliberative process: Sen's notion of justice is based on a comparative approach of justice. The latter does not seek to impose a top-down conception of ideal justice but rather integrates different values and perceptions of justice. Contrarily to Rawl's view of justice based on universal principles of distributive justice, Sen (2009) defends that such principles need to reflect on 'what' is being allocated and whose values and agendas are represented in the distribution of benefits or risks. Sen therefore theorizes justice as a deliberative process whereby different stakeholders are given opportunity to voice what they value. Sen defends a process wherein people can voice competing interests and values, deliberate on conflicting claims and reach acceptable decisions through reasoned arguments. Sen's justice approach also refutes that a single set of principles and institutions can resolve injustices in society. Sen draws on the Sanskrit verse of ethics and jurisprudence and presents a distinction between *niti* and *nyaya. Niti* refers to proper conducts and procedure while *nyaya* means judgement – a reliable means to get correct knowledge and to remove wrong notions. Sen regards institutions as a significant medium that facilitates the pursuit of justice by providing opportunities for public discussion, i.e. by supporting freedom of speech, right to information and providing space for informed and interactive discussions. Institutions are valued not for their existence but for the extent to which they recognize and include diverse needs and voices (Sen, 2009).

Justice and capabilities in water resource development: Water is a key component of human well-being. Whereas access to water for hygiene and sanitation is a key pre-requisite for bodily health and dignity, it is also a critical input for farming and rural livelihoods. Water has also a deep cultural, spiritual and symbolic value in South Asia, as in many other parts of the world and also supports healthy ecosystems and environments. The mainstream approach to water resources development and management, e.g. drawing from IWRM, has been criticized for delinking water issues from socio-political processes and issues related to social and gender equity around use, distribution and management of water resources (Mehta, 2006). Generally, water policies worldwide have been largely guided by markets and efficiency models, whereas they have rarely considered the needs and the interests of the marginalized (Syme et al., 2008). One of the reasons for this lies in the way water resource development has been framed. The latter is represented as a technical endeavour, where the objective is to control and distribute biophysical resources that are supported by engineering solutions (Allan, 2005; Mehta, 2006). Impacts have been largely evaluated in terms of economic efficiency, whereas there has been less attention on how water resource development affects social and environmental justice and well-being (Lancey, 2008). Conventionally, water's contribution to well-being is measured in terms of quantity, quality, regular supply and proximity to water sources. Mehta (2006) proposes to adopt broader values – freedom to choose, decision-making, social relations, autonomy and control, culture and identity and security. These broader values evaluate social exclusion, social displacement, and inequities in water supply and use, which have tangible/intangible implications for livelihood options, health, socio-cultural identity, daily routine and social relations. The capability approach helps to qualitatively evaluate the well-being of the disadvantaged and marginalized communities based on their capabilities and freedom, rather than evaluating the aggregate benefits from the water resources. Therefore, the capability approach can help to evaluate the varied impacts of socio-political process on diverse groups of people and recognize diverse needs and competing values of the water user groups.

4.2.4. Gender analysis framework

As outlined in the Chapter-1, the overall goal of the Digo Jal Bikas (DJB) project is to promote sustainable water resource development in Western Nepal through balancing economic growth, social justice, and healthy/resilient ecosystems. Six core work packages (WPs) and two supporting WPs are designed to achieve the project's goals and objectives. The framework developed for analysing gender in this study (**Figure 4-2**) explores how water justice is integrated across the different research components, notably in terms of distributional equity - access, use and management for sustainable water resource development in terms of institutional recognition and inclusion in decision-making processes. This helps to identify the immediate and structural causes of inequalities in terms of these three core components of justice (distribution, procedural, recognition) and in terms of capabilities among different social groups, along lines of age, gender, caste, ethnicity, disability, class, and geography, and help to highlight the gender and social inequalities that might result from water resource development projects deemed to foster national economic growth. The framework includes the following eight components: i) institutional sites; ii) organizations; iii) biophysical context; iv) infrastructures; v) political economic context; vi) discourses; vii) processes/interaction of variables; and viii) outcomes in terms of capabilities and justice. We followed Sen's approach of leaving open to discussion the capabilities and aspects of distributive justice that different social groups value.

In particular, we explored issues related to how water resources, provision and benefits are distributed among and within communities; to which extent individuals with different identities and from different social groups have the capability to influence decisions on water resource development and management, analysing the proximate, underlying and structural causes shaping these capabilities. In other words, the gender research addressed questions such as who is allowed and able to participate in decisions on water resource development and management? Who is being excluded? What is shaping the capacity of different users to access, control, use and benefit from water resources? How are water justice issues addressed within organizations?

4.2.5. Gender mainstreaming across all WPs and events

Potential data/information required for gendered analysis under each WPs were discussed in advance. Draft reports related to various WPs were then reviewed and given inputs to make the chapter inclusive from a GESI perspective. In case of various events such as KCAP (Knowledge, Capacity, Attitude, Practice) survey, radio program, masculinity workshop, dissemination workshops, etc., list invitees were reviewed and attempts were made to make the invitee list as inclusive as possible. Attention was given to make the list of speakers and panellists (where relevant) as inclusive as possible.

4.3. Results and Discussion

4.3.1. Gender in policies and institutions

Our research confirms and adds to the emerging scholarships on masculinities and gendered organisations and its impact on gender equality goals in Nepal (Zwarteveen, M. Z. 2008; Liebrand, J., & Udas, P. B. 2017). Our findings provide evidence on how dominant discourses, formal rules and professional culture, intersect to support and reproduce hegemonic masculine attitudes and practices of water professionals. Such attitudes and practices in turn favour a technocratic implementation of policy measures.

The predominant narratives, institutional arrangements and professional culture in the water sector have negatively influenced policy efforts towards gender equality. Gender issues are limited to the “WUA space,” with well-delineated experts, the sociologists, institutional set-up, the GESI unit, and activities. There are no spaces or incentives to reflect on and learn about GESI-related challenges. This has contributed to the technocratic implementation of democratic and participatory decision-making in water management – limited to following fixed procedures that do not address the root causes of injustice. Gender is perceived as a frivolous ethical gloss imposed by donors rather than as a technical subject. The narrow focus on WUAs and the lack of involvement of engineers in improving gender equality result in the loss of many opportunities for more gender-sensitive interventions.

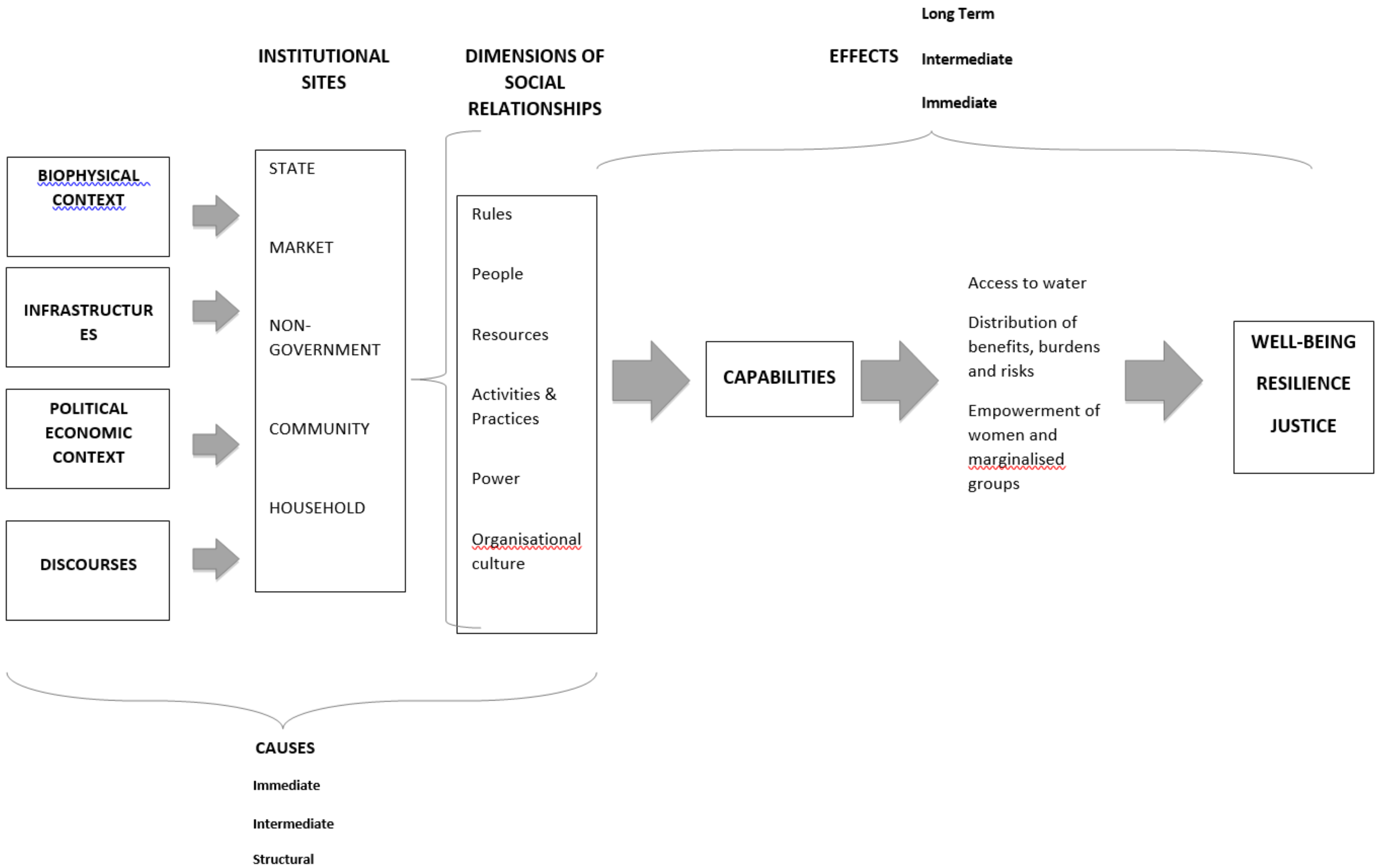

***Figure 4-2**: Analytical framework for gender analysis in Digo Jal Bikas (DJB) project*

The analysis revealed that organisational policy discourses, institutional structures and professional culture towards GESI matter in order to achieve gender and social justice goals at the community level. Discourses on water should extend beyond considering water as a natural and technical object. To see water as social closely related to hierarchy of identities, including gender, is imperative to achieve inclusive and sustainable development and management of water resources. As long as water management institutions do not acknowledge the social nature of water and the hegemonic masculinity of the professional culture in water governance, policy commitments towards greater gender equality will have little effect on the ground.

4.3.2. Gender in practice in water sector

The proposed solutions center on rural people's capabilities and social capital, which depend in turn, on their access to information, knowledge and opportunities. While men obtain these through a variety of formal and informal interactions, women are limited to mostly informal activities, which they create and lead, with a primary focus on women's issues (e.g., health and nutrition). Men, in contrast, dominate discussions and management of key resources, like water, thus putting women at a disadvantage.

People's capabilities and social capital are also shaped by unequal class, caste and patrilineal or male-centric networks. Women's links with formal and informal networks depend on their relations with men in the family. Therefore, women from poor and marginalized households, with fewer kinship and social ties, have fewer opportunities for empowerment. Male migration further complicates the situation, making women dependent on men relatives for work that is socially defined as masculine (such as transporting and operating water pumps). Women's access to information remains restricted as well, since outmigration leaves male "gatekeepers" largely in control of major decisions in the village.

How much social capital a person can mobilize depends on household relations. For example, women from migrant households who live with their in-laws are less likely to exercise agency or control, owing to their subordination to senior females. We found that when women form social capital mainly through patrilineal links, this weakens their ability to participate effectively in local water resource governance and limits their access to water, negatively impacting their well-being and reinforcing gender and social inequality within the community. Often, women are further disadvantaged by rigid social hierarchies, in which water access is defined by a wide array of factors, such as land ownership, land size, location and quality, labour availability; and water infrastructure.

4.3.3. Gender mainstreaming

During the entire phase of DJB, efforts were made to mainstream GESI issues in the research design, data collection, analysis of research, communication of results and action. Considering historical domination of men in water decision making and planning in Nepal, DJB made adequate efforts to represent women in all the activities conducted throughout the project. Women were invited as panel speakers, presenters, participants and beneficiaries. Participation of women in key events are provided here;

- Hydro-economic modelling and scenarios evaluation – stakeholders' consultation: Two workshops were held with national-level stakeholders in Kathmandu on June 7 and 8, 2018. The first of these workshops involved stakeholders from the central government departments and ministries, including energy, agriculture, soil conservation, and other relevant sectors. The second of these workshops involved primarily non-governmental national-level stakeholders, many of whom represented environmental or conservation sectors. The third workshop was held with local and regional stakeholders in Dhangadhi on June 11, 2018. The meetings in Kathmandu were conducted in English; the meeting in Dhangadhi in Nepali. Thirty-seven (37) participants joined the meeting, 12 of which were female.

- Town hall meeting in gender and irrigation: The DJB project co-organized a town hall meeting on gender and irrigation on 21st April, 2018 in Kailali together with PAANI and NEFEJ. Gitta Shrestha from IWMI participated and presented on the subject matter. The workshop raised awareness on issues related to gender and irrigation. The discussions revolved around how access to irrigation water is unequal for men and women farmers, why women are less involved in irrigation user committees despite national reservation of 33% in the user committees, and the way forward ensuring equal access to irrigation water for both men and women farmers. This town hall meeting provided an opportunity for the local government representatives, members from non-governmental organizations, civil society members, media representatives and men and women farmers to engage in discussion about the complex gender issues underpinning the access to irrigation water. Out of a total of 53 participants, 39 were female.

- Masculinities workshop: As part of the Digo Jal Bikas project, the IWMI Nepal office organized a one-day workshop "Unpacking Masculinity" on 11th May, 2018 in Kathmandu. The goal of the workshop was to initiate critical reflection among water stakeholders on gender issues within organizations. Water engineers, gender experts, and water sector development actors from government and non-government sectors in Nepal were invited to join the event. It was the first dialogue on masculinity in Nepal which through a series of interactive sessions paved the way for further discussion on how a masculine organizational culture impacts attitudes and practices within the water sector and how this in turn impacts the goal of gender equity and social justice. Twenty-four (24) participants joined the event, 11 of which were female.

- DJB dissemination workshop: The national level dissemination workshop of the DJB project was organized on 13th March, 2019 at Hotel Yak & Yeti in Kathmandu with the theme of "***Towards an Inclusive Vision for Sustainable Water Futures in Western Nepal***." More than 106 participants (42 of which were women) representing three tiers of governments (national, provincial, and local), development partners, (I) NGOs working in the water/environment sector, environmental journalists, experts, researchers, academia, and other relevant stakeholders actively participated in the event.

4.4. Conclusions

We argue that it is important that water organisations pay attention to their own spaces, practices and attitudes, in order to address and achieve equity and justice issues in water resource management at the ground level. To this end, we recommend to simultaneously address: 1) policy discourses, 2) organisational components and institutions, and 3) professional culture. From a discursive perspective, this means extending current framings of water as a resource to water as 'a symbol of identity, power and citizenship' (Mosse, 2008, p. 948) to move away from the engineering approach that dominates the water sector. It also requires including a greater diversity of voices on water needs, experiences and subjectivities to move beyond simplistic representations of 'the Nepali woman'. From an institutional point of view, this implies ensuring gender, ethnic, and class diversity at all levels of policymaking and implementation, allocating adequate financial and human resources for more socially just water management, and creating specific incentives towards this goal, by changing performance evaluation and promotion rules. Lastly, with respect to the professional culture, it is important to institutionalise values that promote positive masculinities of empathy and respect within organisations. Opening spaces for male and female staff to discuss opinions and experiences on gender can be a first step towards enhancing their skills, sensitivity and capacity to understanding and addressing gender and social hierarchies in their daily practices.

At the project/community level, to make water management more just and effective, this research calls for investment in the social capital and capabilities of women and marginalized people generally, with particular emphasis on women's linkages and networks, so they can contribute more effectively to water governance. The study offers the following recommendations: 1) Create more opportunities for women to play technical and non-technical roles in organizations and projects; rural women will feel more comfortable to create social relations with female staff members, thereby extending their social network beyond their community; 2) Introduce incentives for organizations and projects to monitor the effects of household and community social relations on water access (along gender, class, caste, and age lines), to take action aimed at diminishing the influence of these factors, and to address household gender relations through group methods (e.g., creating safe spaces to discuss local gender and social norms); 3) Design policies and activities that enhance collective action in rural communities, based on increased trust and social well-being.

4.5. References

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4.6. Annexes

Annex 4-1: Shrestha G., Clement. F. (2019). Unravelling gendered practices in Nepal water Bureaucracies. Water Policy, 21(5): 1017-1033. (https://iwaponline.com/wp/article/doi/10.2166/wp.2019.238/69912/Unravelling-gendered-practices-in-the-public-water)

Annex-4.2: Shrestha G., Pakhtigian E., and Jeuland, M. (2019). Women who do not migrate: Social relations and participation in Western Nepal. Journal of Rural Studies. (In Preparation).

Annex-4.3: Shrestha, G. and Clement, F. (2019). Social capital and collective water resource governance in Far-West Nepal: A gendered perspective. Journal of South Asian Development. (In preparation).

5. Water Sources and Access

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5.1. Introduction

Access to water is key to human survival and well-being. Water access defines good health, food security, livelihoods and the fulfilment of spiritual and cultural needs. Access to water, however, is often not adequate to realise a life's full potential. One of the first steps to improve livelihoods is to increase available benefits from water. Nonetheless, not everyone has equal access to water and many experience distress and poverty. Various factors have been documented that either facilitate or constrain equal access to water resources, which include both bio-physical, socio-economic, and institutional/policy factors.

Water resource availability is one of the important factors that can facilitate or constrain water access. Water availability in Nepal is highly dependent on monsoonal weather patterns, which vary temporally and spatially. Heavy monsoon precipitation falls in the months of June through September, followed by dry spells for the rest of the year. During these dry spells, the Tarai areas rely heavily on river waters where available, and to a much larger extent, on pumped groundwater for domestic and agricultural purposes. Despite an abundance of groundwater in the Tarai region, tube well development is still minimal, causing constrained access. The mountainous region stakes its survival on springs as the main source of water, given the extreme topography that make river water withdrawal extremely difficult. Similarly, a large section of arable land in the hills is under-utilized due to various reasons such as inadequate capacity of many tenant and marginal farmers to access water resources available in the nearby area.

Water availability and access are further constrained by climate change and variability. Nepal in general is vulnerable to climatic change and variability. The Far West region of Nepal is further disadvantaged given its the much lower rainfall, making it particularly sensitive and vulnerable. Building resilience within farming communities in the regions of the Far West thus calls for managing water efforts at a range of scales from field to basin level. In this context, approaches to watershed management with aims to support the natural system and slow down the flow of water out of the landscape are required. This calls for understanding the hydrology, the physical conditions, natural and human induced characteristics and socio-cultural aspects in order to build comprehensive watershed management. At the field level, on-farm water management to efficiently use available water resources during periods of low availability is required. This shall come on the back of concerted efforts to develop local water resources, temporally store water through both natural and constructed infrastructure and maintain a resilient environment and human capacity to sustain such a system.

As the government of Nepal has prioritized water as an important resource for development and economic growth (WECS/GoN, 2011), it is crucial to explore and develop a knowledgebase and tools to visualize availability of water sources and their development potentials, as well as evaluate water access to plan and manage existing and future water resources. Detailed mapping of local water sources is expected to form the basis of assessing changes in the system over past years and to plan sustaining and/or remediating actions for the future. This approach is premised on the view that climate change is a real driver of change and a stressor for the agrarian system, but managing the farming environment as a holistic unit through approaches to enhance natural resilience of the hydrological system would curb the extremity of climate change impacts.

To provide evidence for developing strategies to optimally utilize available water resources and related ecosystem services for sustainable socio-economic development of local communities, this chapter aims to elaborate the following aspects: mapping local water sources at pilot study sites; evaluate facilitating as well as constraining factors for water access; and then design and implement a suitable set of techno-social interventions for enhancing the access to water. The analyses are carried out at three pilot sites, namely, Kuti (in Kailali district), Punebata (in Doti district), and Mellekh (in Doti district), selected based on a set of criteria. The pilot interventions are aimed at: (i) Improved understanding of opportunities for more efficient use of existing technology and new technologies, which can contribute to agricultural productivity improvement and thus food security; (ii) Improved understanding of the willingness of farmers to engage in pioneering models of collective land and water management to overcome structural constraints to water access.

5.2. Methodology

Figure 5-1 depicts the overall methodological approach adopted in this study. A combination of biophysical and social analysis, with primary and secondary data sources, were conducted. Sites were selected based on a set of selected indicators. The determinants of the access to water were identified based on literature review and relevancy to the study area. The determinants were quantified based on the data collected from primary and secondary sources. Daily rainfall and temperature were the secondary data used in this study. They were acquired from the Department of Hydrology and Meteorology (DHM), the Government of Nepal. In case of primary data, a combination of participatory approach (e.g., focus group discussion, FGD, and key informant interview, KII), field observation, guided transect walk, and household surveys were carried out. The FGD included a set of open-ended questions that aimed to capture perceptions of people on various aspects of the determinants that affect the access to water. In addition to this, water sources mapping was carried out in selected villages and site specific sets of physical and social intervention were done to improve water access at field level.

5.2.1. Site selection

Three sites/villages from the Karnali and Mohana river basins were selected to represent various diversities in the basin, such as ecological, socio-economic, and topographical, among others. The sites were identified based on analysis of 17 indicators related to biophysical (five indicators), socio-economic (six indicators), and logistical (six indicators) factors. The indicators also included aspects like landholding and composition of social groups, especially ethnic and disadvantaged groups. For the purpose of site selection, the indicator values were collected through a set of participatory techniques such as FGD and KII. In addition, field observation and a guided transect walk was also conducted. After careful analysis, the following three sites/villages were identified/selected as the study area: Kuti village in Kailali district, and Punebata and Mellekh villages in Doti district (**Figure 5-2**).

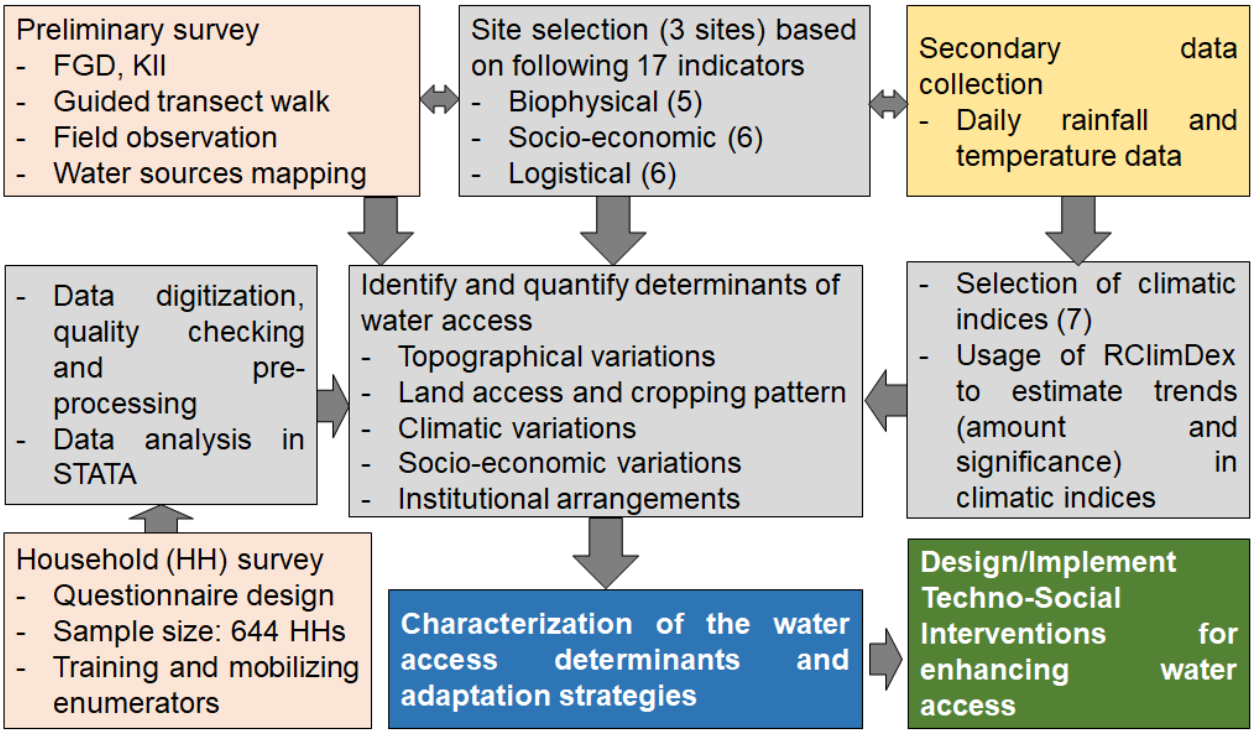

Figure 5-1*: Methodological framework adopted for water source mapping, water access evaluation, and designing/implementing techno-social interventions.*

Mellekh village is located in Khatiwada VDC in Doti District. Khatiwada VDC covers a large altitudinal range from the Seti River up to the periphery of Khaptad National Park. Mellekh market center is situated at Lon 80.946^{0}N Lat 29.348^{0}E at an elevation of 1910m amsl. Punebata village is also located in Khatiwada VDC in Doti district. The village is located at Lon 80.931^{0}N Lat 29.292^{0}E at an elevation of 840m amsl. Compared to Mellekh, this village is located at a much lower elevation and is highly fertile and accessible. Kuti is a remote village located in Kailali district bordering India with a central location point at Lon. 80.948^{0}N and Lat. 28.477^{0}E. at an elevation of 155m. The low elevation and close proximity to Kandra and Mohana rivers on the Northern and Southern side results in flooding during the monsoon.

The population distribution, land ownership, and land tenure characteristics in three intervention villages are presented in **Table 5-1, Table 5-2,** and **Table 5-3**. The total population of the three villages was 3888 with a slightly higher percentage of males in the population. The total population also varied across the villages. Overall, about 12.1% households were landless, the highest proportion of landless was in Kuti village. The average landholding was 0.47 ha, being more in Kuti village compared to the other two villages – average cultivable land was slightly less – 0.44 ha. Overall, about 15.2% of households rented-in land for cultivation whereas 14.8% households rented-out land to others. A Large proportion of tenant farmers was found in Punebata village whereas large size of rented in/out was in Kuti village.

Table 5.1: *Population distribution in intervention villages*

District	VDC	Village	No of HH	Population	Male %	Female %
Doti	Khatiwada	Mellekh	245	1440	51.3	48.8
Doti	Khatiwada	Punebata	179	1103	50.0	50.0
Kailali	Lalbojhi	Kutti	220	1345	50.6	49.4
OVERALL			**644**	**3888**	**50.7**	**49.3**

Source: Baseline survey of intervention villages, 2017

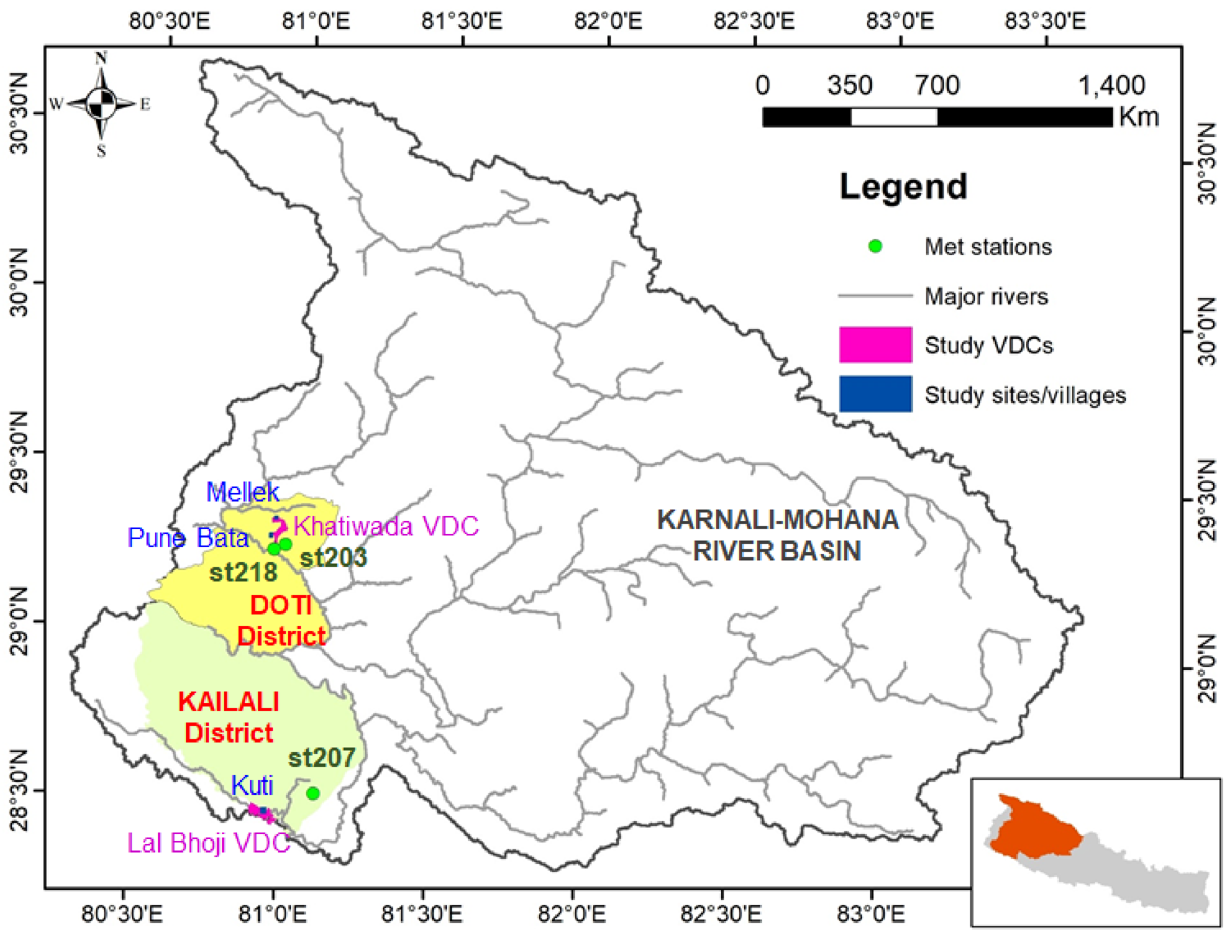

Figure 5-2: *Locations of study villages in Karnali and Mohana basins, Nepal..*

Table 5.2: *Land ownership situation in intervention villages*

Villages	HH with land %	HH without land %	Average land owned (ha)	Average cultivable land (ha)
Mellekh	86.9	13.1	0.40	0.38
Punebata	91.6	8.4	0.40	0.34
Kutti	85.9	14.1	0.60	0.60
Overall	**87.9**	**12.1**	**0.47**	**0.44**

Source: Baseline survey of intervention villages, 2017

***Table 5.3**: Land tenure characteristics in intervention villages*

Villages	HH who rent in land - %	HH who rent out land - %	Average land rented in - ha	Average land rented out- ha
Mellekh	7.8	4.1	0.24	0.42
Punebata	29.6	23.5	0.17	0.25
Kutti	11.8	19.5	0.53	0.80
Overall	**15.2**	**14.8**	**0.31**	**0.49**

Source: Baseline survey of intervention villages, 2017

5.2.2. Identification of water access determinants

A literature review as well as a field visit was conducted to identify the determinants that affect water access across the study sites. After critical review and in consideration of the study sites, the following determinants were identified as relevant for this study. The determinants as well as their logical links to water access are shown in **Table 5-4**.

***Table 5.4**: Determinants that makes differential access to water in the study areas*

Determinants	Indicator	Logical link to water access
Topographical variations	Elevation range (masl), derived from digital elevation model (DEM)	Water at lower elevations are rather readily available from ground or surface sources compared to high elevation hill slopes. Therefore, water access is likely to be better in lower elevation (e.g., Terai)
Land access and cropping pattern	Access to land; Cropping intensity and patterns	Water-intensive cropping patterns are likely to impact water availability to others. (people/area/future time)
Climatic variations	Various (7 nos.) indicators related to temperature and precipitation (please refer Table 3 for the list and description of indicators)	More precipitation is likely to enhance water availability, which, depending upon other conditions, may help enhance access to water. Higher temperature may result in more water loss due to evapotranspiration and therefore may adversely affect access as well as demand Shift/variation in temperature and precipitation have impact on vegetation patterns, which affects agricultural production in Nepal.
Socio-economic variations	Demographics, gender, age, migration/mobility; and cast groups	Higher caste groups and/or those with better economic conditions (either by remittance or other sources of income) are likely to have better access to water
Institutional arrangements	Participation, water allocation, decision-making and collective action	Existing practices for water allocation and decision-making mechanism constitute institutional arrangements for water management and thereby influence access to water

5.2.3. Field surveys

Community level data was collected through a series of field surveys using a combination of participatory techniques and field observations. At the beginning, the research team conducted a participatory resource mapping, wellbeing ranking and wealth ranking with men and women separately to identify water resources, settlements, distribution of *khet land*[7] and households. Through these unstructured but guided discussions, significant insights into the social and biophysical state of the community was mapped. The participants were also asked on availability, access and uses of various natural resources, as well as the management arrangements of the same. Upon completion of the Focus Group Discussions (FGDs) and Key Informant Interviews (KIIs), a list of key features for on-site observation was prepared. These walkthroughs also offered an opportunity for the technical team to collect information to support the development of feasible options for piloting. Data were collected through notes, GPS location and camera photo captures. A community map and water source map were developed using publicly available GIS data sources such as Google Earth and ESRI shape files. These maps incorporated both primary data and secondary data to provide a spatial presentation of the community's resources, as well as areas of concern and areas of opportunities.

Crop calendar exercise was conducted in each study village to get an overview of cropping patterns and engagement in farm labour. Two separate FGDs were also held in each village with men and women to get an overview of land ownership trends, migration, livestock and current water use and management. FGD participants represented heterogeneity of the village. The FGDs also attempted to get an understanding of the success and failures of past water management interventions in the study villages. Concurrently, a guided transect walk was conducted to identify available water sources in each village. In a later visit, an FGD was conducted in each village to specifically understand the current practices on land tenancy, water use and collective action to inform potential approaches and adaptation strategies.

A household survey was carried out with all 644 households (HHs) in each study village. Out of 644 HHs, 220 were from Kuti, 179 from Punebata and 245 from Mellekh villages. Household survey was conducted by experienced enumerators using a set of pre-tested questionnaires.

5.2.4. Data analysis

The survey data was digitized and stored in MS Excel and STATA for further quality checking and pre-processing. Data quality was assessed, usable data was screened and then used for further analysis. The status on key aspects of the study villages was then described based on descriptive statistics. The collected data was analysed using STATA, a statistical analysis software. Details of the data analysis are provided in Annex 5-1. Climate shocks and responses were also analysed, but to a wider area, and results are provided in Annex-5-2.

5.2.5. Design of techno-social interventions

The information collected from the field survey on agricultural practices, cropping system, access to land and water, water governance and market linkage was analysed and implemented on local level interventions by IWMI in similar projects where it was reviewed and analysed. The findings on climatic and non-climatic variables and effects on crop production due to available water resources and access to water can be implemented through introduction of new agro-technology, climate resilient seeds, better crop management practice, and use of fertilizer. Those intervention

[7] *Khet land* refers to irrigated flat land.

activities, including both technical (introduction of plastic ponds, water saving technologies, landscape management, improved seed and fertilizer) and social (collective approach, trainings, behaviour change, etc.), were designed and implemented as techno-social interventions in the three study sites/villages. These interventions belong to so called “no-regret” adaptation strategies.

In all the three sites that were based on the topographic variations comprising of mountain, hill and Plain regions, access to land and water, available sources, climatic variations and proposed cropping system following physical interventions, were designed and implemented:

- Installation of weather stations to collect rainfall, temperature, humidity, and evapotranspiration data.
- Rehabilitation and construction of ponds in the Hill and Mountain regions.
- Development of a solar-powered shallow tube well to extract groundwater in the Terai.
- Capacity building on water management, crop management, and agronomical practices.
- Introduction of micro irrigation techniques like check basin, furrow, drip, and sprinkler for on-farm irrigation water management.

Learning from past project experiences, a problem tree analysis, and discussion in each hamlet, collective models and physical infrastructure development was done with site specific modification in the intervention villages. However, due to differences in land characteristics and the land tenure situation, it is possible for the intervention model to be different across intervention villages. Intervention approaches are identified as physical (technical interventions) and social interventions, which were described in the following sections. This package was developed considering willingness to participate, technical feasibility, social feasibility and budget. The implementation of those interventions are discussed in more detail in subsequent sections. Based on this understanding, the collective farming approach serves as a potential solution for landless and poor farmers as a social intervention. This model brings together farmers voluntarily from similar background in a group of 10-20 households. Decisions in the group are made in a participatory manner, benefits are distributed equally and rules and penalties are in place for non-performers.

There are two types of models that can be followed depending on the needs of the farmers (as illustrated in **Table 5-5**). The first type is when farmers form a group and identify plots of land that are available for rent. The land is rented to the group from the landlord rather than to an individual, and members of the group share rent. Labour, inputs, marketing and accessing credit are approached by a group as a whole and benefits are shared equally. The second type involves a partial approach to the collective model. In areas where farmers own plots of land but require assistance in inputs, labour etc. this model can be followed. A farmers group is formed, including households who own land next to each other or rent one plot and divide it into smaller sub plots. Farmers can grow crops to their liking. However, inputs, labour, and technology are shared amongst group members. The basic idea is to share resources and costs to reduce the burden on individual households. Group members can take turns securing credit, going to the market to sell vegetables etc. In all three sites, capacity building will be a major focus. It includes training programs covering water management, crop management, groups and institutional strengthening and market linkages. Trainings may vary across the intervention villages. Physical interventions vary across intervention villages. The implemented physical interventions that could be suitable to specific a village are tabulated in **Table 5-6.**

Table 5.5*: Different approaches to collective farming*

Collective Farming Model	Land	Labour	Training	Water Technology	Market Linkage
Full Collective	Members pool money to rent a plot of land to cultivate as a group	Members of the collective work together on the same plot of land	Members receive training on water management and crop management	Members will take turns sharing the technology installed	Members can either take turns accessing the market to sell their produce and divide the profit or travel individually to sell
Partial Collective	Members cultivate on their respective land	Members may choose to either work on each other’s land or work as individual households	Members receive training on water management and crop management	Members will take turns sharing the technology installed	Members can either take turns accessing the market to sell their produce and divide the profit or travel individually to sell

***Table 5.6**: Final intervention plan for the three study villages/sites*

Site	Hamlets	Issue	Potential Solution	Intervention conducted	Willingness to participate	Challenges	Opportunities for Risk Management
MELLEKH	Rokainara	Low water availability during the dry season	Source Protection and pond rehabilitation with improved irrigation facilities	Pond rehabilitation, Collective Farming approach, on farm water management solution (micro irrigation, improved seeds)	There is a pond located in Rokainara that can be rehabilitated for agricultural use.	Farmers may abandon micro irrigation techniques due to non-availability of accessories like laterals and poor maintenance Farmers may not maintain and repair ponds which are for communal use which could lead to conflict.	Provide contacts and link with market to ensure accessories can be purchased, in case of operational damage and training to maintain system intact Ensure group sets aside money for repair and maintenance during group formation
	Alaitwada, Katuwalgaon			Pond rehabilitation, Collective Farming approach, on farm water management solution (micro irrigation, improved seeds)	There is one pond located in each hamlet that can be rehabilitated for agricultural use.	Farmers may abandon micro irrigation techniques due to non-availability of accessories like laterals and poor maintenance Farmers may not maintain and repair ponds which are for communal use which could lead to conflict.	Provide contacts and link with market to ensure accessories can be purchased, in case of operational damage and training to maintain system intact Ensure group sets aside money for repair and maintenance during group formation
PUNEBATA	Punetola tole	Less water availability during dry season	Source Protection or Effective utilization of available water using improved tools and techniques	Pond Construction, Collective Farming approach, on farm water management and research plot for different type irrigation (micro irrigation, improved seeds)	There are many natural ponds scattered around the village and farmers are highly interested in converting them into concrete ponds. Each pond is used by at least 6-8 households.	Farmers may abandon micro irrigation techniques due to non-availability of accessories like laterals and poor maintenance Farmers may not maintain and repair ponds which are for communal use which could lead to conflict.	Provide contacts and link with market to ensure accessories can be purchased, in case of operational damage and training to maintain system intact. Ensure farmers group set aside money for repair and maintenance during group formation
KUTI	Lakhrai Tole Lobasta Tole	Flooding Poor access to water in dry season	Embankment and artificial cutoff (long term) Increased water access in dry season (immediate solution)	Sunflower pump with tube well installation, collective farming, farmers' training, improved seed distribution and research plot with different type of irrigation	Farmers from both communities are willing to participate but finding a large parcel of land to rent is slightly difficult since many farmers have small land parcels scattered around the village.	Farmers may not follow collective farming approach after project duration. Farmers may abandon micro irrigation techniques due to non-availability of accessories like laterals and poor maintenance	Provide contacts and link with market to ensure accessories can be purchased, in case of operational damage and training to maintain system intact

5.3. Water Sources

The status of water sources was mapped in the selected site through primary and secondary data, presented in map form and discussed in detail in the following sub-sections.

5.3.1. Mellekh village, Doti

The studied catchment is located in Khatiwada VDC, Doti district. The area of interest for potential project interventions (**Figure 5-3**) lies in a rugged mountain terrain with elevations ranging from 1265 to 1980m amsl. Slopes ranging from 0.8 to 85% characterize the area. The area of interest covers an area approximately 3.2 km^2, lying between latitude 29.326^0 – 29.348^{0}N and longitude 80.930^0 – 80.953^{0}E. The village is comprised of four main localities and the bazaar area. The main settlements are in Saudnara, Rokkanara, Alaitwada and Katuwalgaon localities.

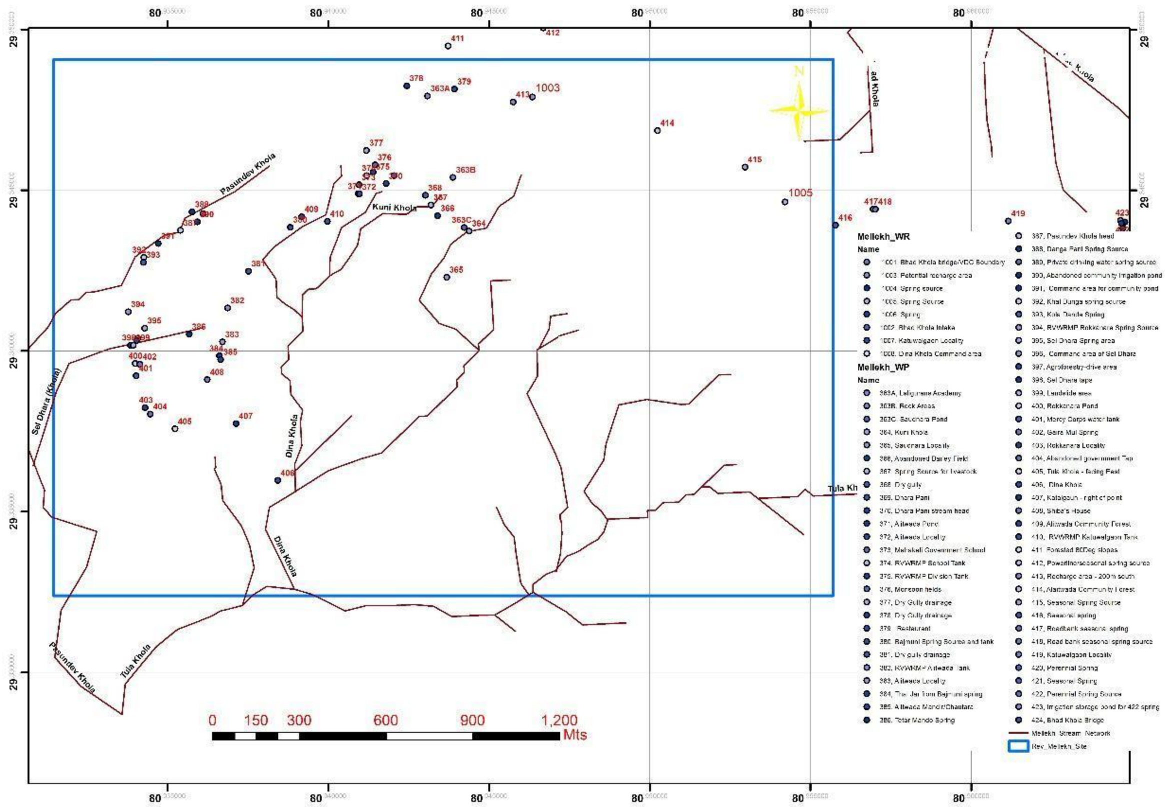

Figure 5-3: *Water sources and biophysical features in Mellekh village, Doti.*

The soils in the village are Ochrepts (21%) with a general top soil texture of clay-loam to medium sand (Hengl et al., 2016). The top soil is underlain by fragmented rocks that form the spring contact line at points of intersection with ground surface. There are various spring sources for domestic and livestock water requirements out of which Bhad Khola, Khola Dada, and Bajmuni have been identified for development by the Rural Village Water Resources mapping Project (RVWRMP) to supply the localities with domestic water taps. RVWRMP has facilitated training of community members in vegetable and tree plantations to add value to the domestic water supply system.

The changes in spring and river flows were observed all across the watershed with greatest impact on the concrete ponds constructed under different projects having failed. This indicates a very drastic change in recharge in the watershed with the spring sources targeted during the design of these ponds drying up and/or shifting positions. This calls for closer monitoring of weather and climatic patterns in implementing sustainable infrastructure, as well as more concerted efforts to build up the resiliency of these locations through comprehensive land and water management strategies.

5.3.2. Punebata village, Doti

Punebata village lies between Goudare Gad to the west, Sellapani Khola to the north and Pandhara Khola to the south (**Figure 5-4**). With a slope of 0.5 – 60% running on an east to west direction, the village lies on an elevation range of 640 – 1190m amsl within the area of interest. The village is comprised of Wards 4 and 5 of Khatiwada VDC, Doti District. The village is comprised of two localities: Pune Bata and Pune Tola. The village is located between Latitude 29.284^0 – 29.299^0N and Longitude 80.925^0 – 80.937^0E with the area of interest being approximately $1.1km^2$.

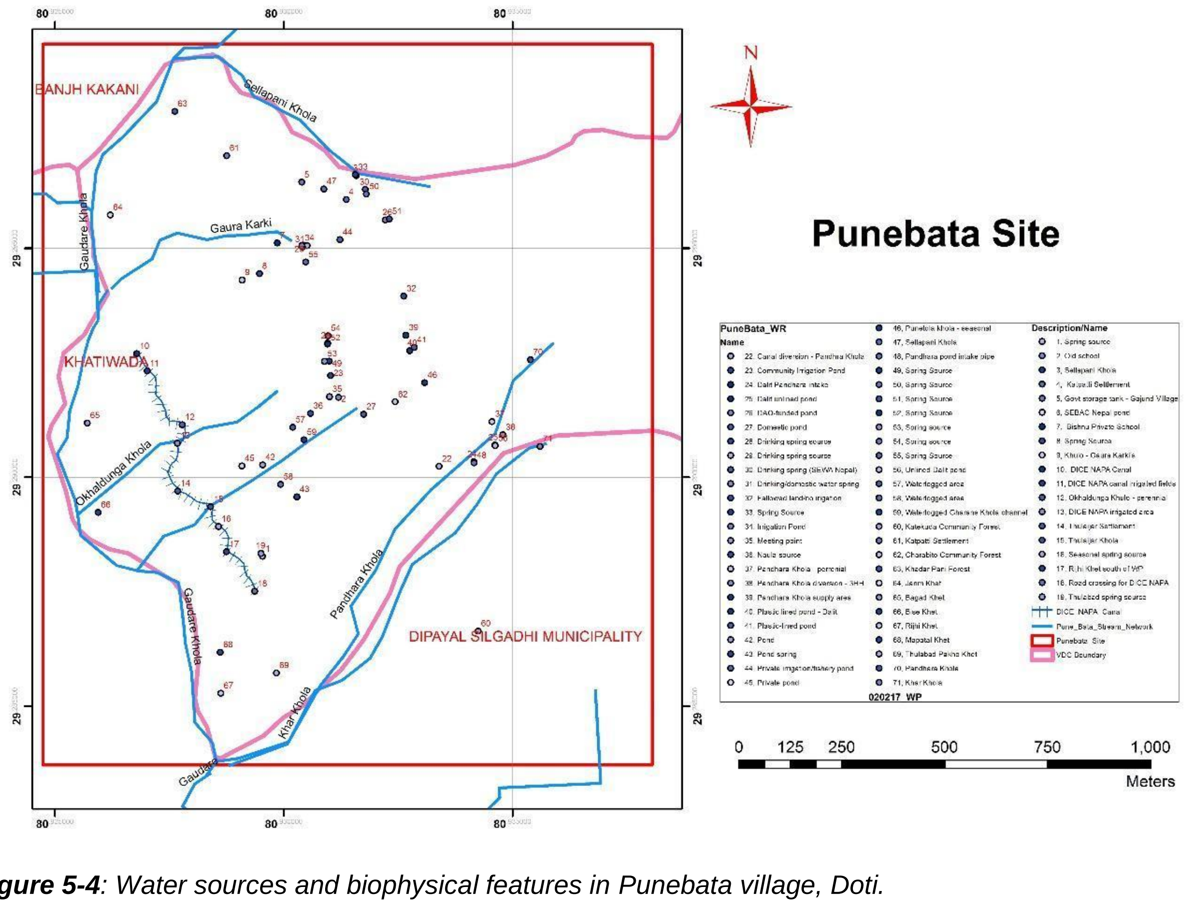

***Figure 5-4**: Water sources and biophysical features in Punebata village, Doti.*

The village has numerous spring water sources (Naulas) that are not all developed due to low flows and/or financial limitations. Most of the springs lie in the areas northeast of the study area (**Figure 5-4**). With numerous storage ponds (lined and unlined), the community has built an interconnected network between springs and ponds to transfer water to fields and households around the residential belt (longitude 80.93^{0}E). The community has significant water resources, most of which are tapped. Domestic water needs are generally met from a number of spring sources that are both protected and unprotected. Water for drinking, cooking and cleaning is generally collected from the primary sources as these are considered to be of better quality. Water for other domestic and animal use are obtained from storage tanks and other pipe networks. A number of distributed concrete and plastic lined ponds are spread around the community and interconnected with pipes facilitating a valuable decentralized water distribution system. Other water sources include the Goudare Gad, Sellapani Khola, Khar Khola and the Pandhara Khola. The area around the head of Gharans Khola, lying around the central belt of the village experiences seasonal waterlogging from the numerous spring sources.

5.3.3. Kuti village, Kailali

Kuti village is located in Lalbhoji VDC of Kailali District. The village is comprised of Chamoradha Tole, Kuti Tole, Lobasta Tole and Lakhrai Tole. The area of planned interventions are bound between latitudes 28.466^0 – 28.485^{0}N and longitudes 80.941^0 – 80.962^{0}E (**Figure 5-5**). The target area is approximately 4.4 km^2 from within which project implementation areas are selected. Kuti village lies on the flood plains of the Mohana and Kandra rivers with elevations between 145 – 55m amsl and slopes of 0–2%.

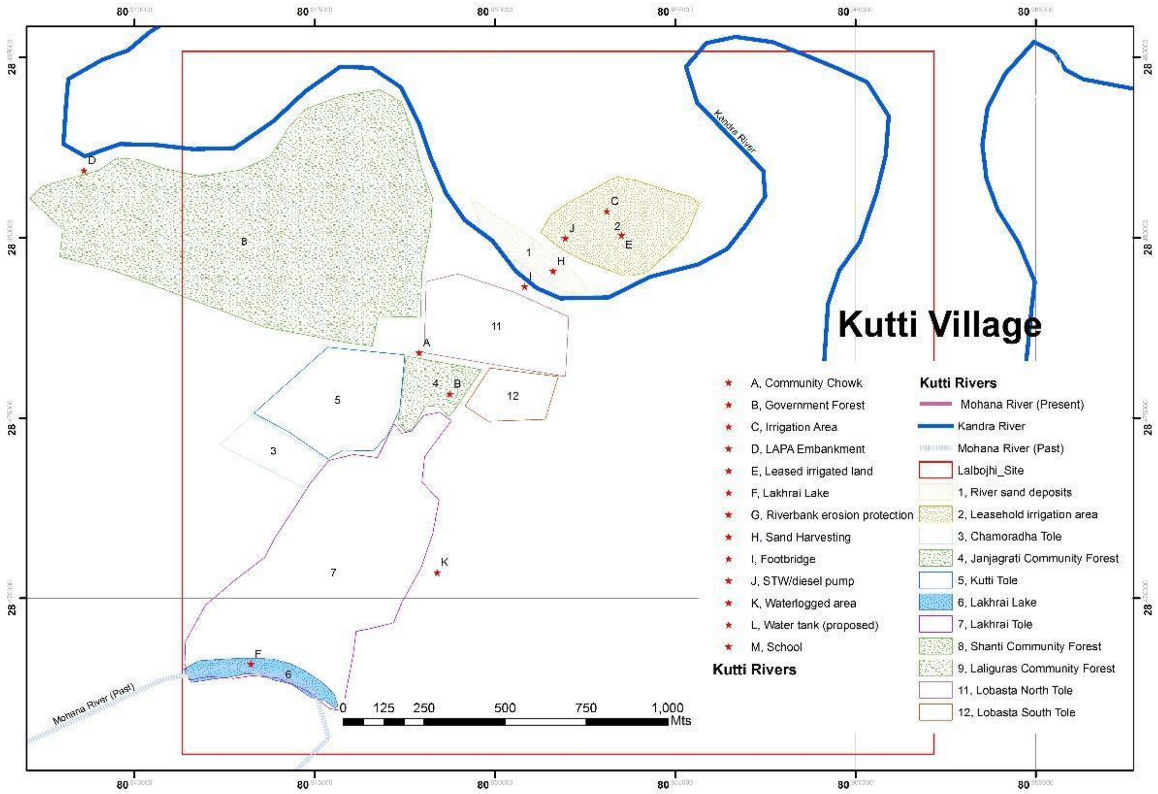

***Figure 5-5**: Study area of Kutti Village showing significant biophysical features.*

Due to the flat terrain of the village and its location between Mohana and Kandra Rivers, the area is prone to flooding during the monsoon as well as waterlogging for two to three months after the monsoon. This is a normal occurrence though has been more extreme in the recent past. This resulted in the government, through the VDC Local Adaptation Plan of Action (LAPA) emergency program, to fund the construction of an embankment along the Kandra River in 2013. This has reduced the extent of flooding but some low-lying Khet land still gets flooded.

There is sufficiently available groundwater and/or river water but limited access to facilities: tube wells for irrigation have been installed by a number of farmers but these are not sufficient, especially during peak irrigation periods. There is water logging of fields, especially in the monsoon season. Use of tube wells is further limited by the costs of pumping with some cases, where access to tube wells is charged as well.

5.4. Evaluation of Water Access

Mellekh lies in a rugged mountain terrain having few spring sources. These sources are not sufficient for both drinking and irrigation purposes in terms of quantity. Similarly, Punebata has mild slope terrain with several springs, which are used mainly for domestic and irrigation through ponds. Communal ponds are poorly maintained and unable to meet demand, especially in the dry season. In Kuti, major deterring factors of water access for agricultural purposes are limited number of pumps and tube wells and high cost associated with rental and physical infrastructure.

The average landholding size is 0.47 ha with 12.1% households being landless. Overall, about 15.2% of households rented-in land for cultivation whereas 14.8% households rented-out land to others. A large proportion of tenant farmers was found in Punebata village whereas a large size of rented in/out was in Kuti village. Overall, average rented-in land size was 0.31 ha whereas average rented-out land size was 0.49 ha.

Cropping patterns varied across the study villages given the diverse topography, climate and land availability. In Mellekh, farmers practice a two-crop system. During monsoon, paddy is planted in *khet* land while maize, barley and soybeans are grown in *pakho* land. During winter, wheat is grown in khet land while mustard is planted alongside it. Lentils are also grown during the winter season. In Punebata, paddy and wheat are grown during summer and winter seasons, respectively. Farmers have been growing vegetables for decades and almost every HH sells vegetables in the local markets of Dipayal and Pipalla. One common phenomenon is the shift to a water-intensive cropping pattern, which will demand more water. Although the land in Punebata is highly fertile there is low productivity due to water insufficiency. Similar to other parts of the Western Tarai, farmers in Kuti also plant two crops a year (i.e. paddy and wheat). Paddy is planted in the monsoon season whereas wheat is planted in the winter season alongside mustard and pulses. Given the high winter rainfall in Kailali district, wheat is irrigated by rainwater. However, irrigation is required during both wheat and paddy season because of frequent dry spells. Given the lack of labour in the village, farmers limit cultivation to the “high-fertility” areas, leaving areas with less fertile soil and insufficient water fallow. On the other hand, water-intensive cropping patterns, such as vegetables in dry seasons, in some parts of the village face constrained water access.

The analysis on temperature and precipitation indicate that the Hills and Mountains are getting hotter. In the case of the Terai, both maximum and minimum temperatures are increasing. These values indicate that the variability range of both maximum and minimum temperature is widening. Across all the three sites, temperature is increasing in summer, which ultimately affects the access to water for agricultural use. Farmers have perceived that the changes in precipitation (i.e. erratic rainfall) and changes in temperature have also shifted the cultivation time of crops, which has significantly reduced production.

From the analysis, it has been observed that all three-study villages experience either too much or too little water affecting their overall agricultural production. People in Mellekh reported high water insufficiency in both monsoon and winter seasons (**Figure 5-6**). Results showed diverse range of water insufficiency in Punebata due to an imbalance in accessing water from ponds. Overall, Kuti is water sufficient all year round. Farmers, especially in Mellekh, have reported high water insufficiency in both monsoon and winter seasons. Farmers in Punebata have access to three canals, yet farmers experience a range of diversity in terms of water sufficiency. This can perhaps be explained by the imbalance in accessing water by farmers who rely on ponds located on private land.

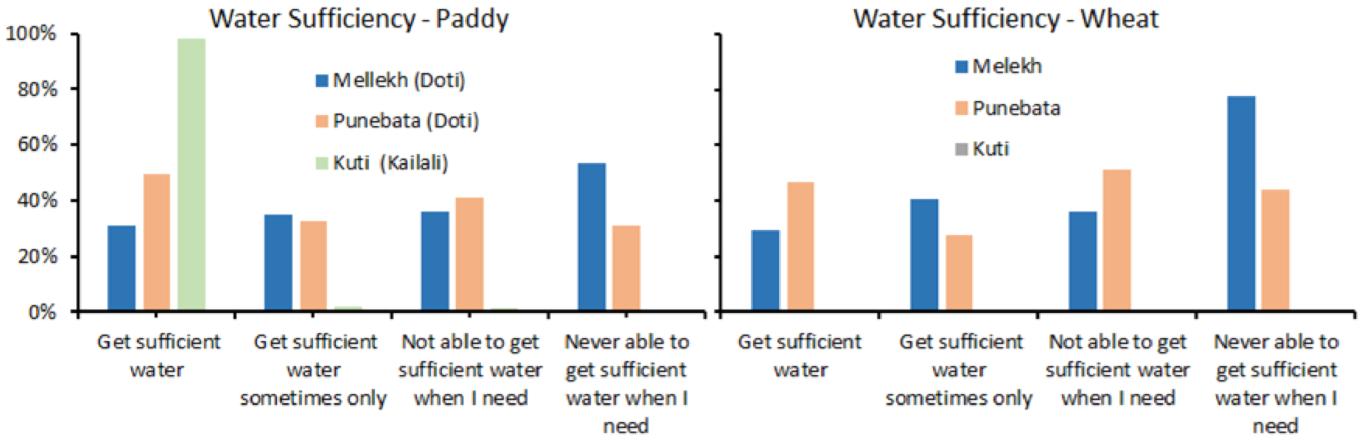

***Figure 5-6**: Water sufficiency in study villages*

Water access varied considerably in the pilot intervention villages. A baseline survey revealed that the sources of irrigation varied across pilot intervention villages (**Table 5-7**). In hill/mountain villages, mainly stream/spring contributed, but in the Terai village groundwater was the main source of irrigation. In Punebata village, surface pond was also the main source of irrigation.

Overall, most of the land (88.7%) had some access to irrigation sources but this was limited to monsoon/early winter only. In hill/mountain villages, water availability declines in stream/springs. In Terai villages, access to groundwater was constrained by energy cost/availability and fragmented land size. Result showed that tube well and pump ownership is very low in Terai villages indicating a dependency on rental market.

***Table 5.7**: Access to water resources in intervention villages*

Villages	River/stream	Springs	Groundwater	Pond	Others
Mellekh (Mountain)	84.5	3.6	0.0	0.0	11.9
Punebata (Hills)	63.7	2.9	0.0	26.9	6.5
Kuti (Terai)	3.4	0.6	93.2	0.0	2.8

Source: Baseline survey of intervention villages, 2017

In Mellekh, there are several spring sources surrounding the village. These sources are mostly used for domestic and livestock requirements. Agriculture is mostly rainfed and the village lacks pumps and irrigation canals. There are several irrigation ponds built by other development agencies, which are in dire conditions. Irrigation becomes extremely difficult during dry season preceding the monsoon in July.

In Punebata there are several small ponds connected to pipes that bring water to the khet land. There are several canals, some concrete and some makeshift, that irrigate the khet land and are shared communally. There is a large pond built by CARE Nepal, which stores water before being distributed in the village. Water is distributed on a rotation basis with the households with land nearest to the water source receiving water first. This process continues until all the land in the village is irrigated. There is a level of trust in this arrangement and while there are minor conflicts, the system seems to be followed by everyone in the village. However, not every household receives sufficient water at the required time, which can create issues.

In Kuti village, households access groundwater for drinking purposes via deep bore wells. The community did not report any issue in accessing water any time of the year. However, Arsenic contamination in the groundwater is an alarming issue. Many fields had irrigation tube wells powered by either diesel or electricity. According to our survey, water is available easily from shallow tube wells and the two rivers surrounding the village. A small oxbow lake—Lakhrai Lake, a remnant from the Mohana River, is a potential source of lift irrigation for the purposes of our project.

Details on various factors facilitating as well as constraining water access are provided in Annex 5-1.

5.5. Implementation of Techno-Social Interventions

The designed techno-social intervention activities and approaches were adopted at field level to ensure the defined objectives. For this, regular monitoring and implementation through group, key informant interview, focus group discussion, capacity building through training, development of physical intervention activities, and continuous data collection on physical, social, and economics was conducted. The major physical interventions implemented in the three intervention sites are discussed in more detail in subsequent sub-sections.

After the selection of the specific activities, the team also engaged with the community to ensure the physical interventions complement the socio-cultural aspect of the collective farming approach.

The team hired local field assistants to liaise with the community and the team. Assistants were hired to ensure that farmers' concerns are communicated at regular intervals, and meetings on updates and collect data are organized regularly. A guideline document was also prepared and provided to each LFA.

LFAs engaged closely with the community to form collectives. Farmers with adjacent plots were given priority to ensure equitable distribution of resources. At the same time, this allowed farmers to communicate regularly and form a network to provide feedback to each other. The LFA measured and mapped the plot of each group member. The intervention was customized based on the findings and reflected the community's willingness to participate. In Mellekh and Kuti two groups were formed, and in Punebata one group was. The details of the groups are listed in **Table 5-8**.

Table 5.8*: Group details from three pilot sites*

Village	Hamlet	Total Members	Male	Female
Mellekh	Rokainara	15	7	8
	Alaitwada/Katuwalgaon	12	6	6
Punebata	Punetola	10	7	3
Kuti	Lakhrai	16	3	13
	Lobasta	10	0	10

5.5.1. Mellekh village, Doti

Mellekh village is fairly large and spread out. The varied topography of Mellekh village provided a diverse range of issues in each hamlet. Given the large size of the village, the team focused on the lowest hamlets of Rokainara, Alaitwada and Katuwalgaon. Water for agriculture use is a pressing issue throughout the village but previous interventions have proved either unsuccessful due to technical failure or abandoned due to lack of repair and maintenance. The water coming from the drinking water tap looks like wastage as overflow, and there were many dysfunctional ponds. In this context, utilization of those unused overflow water and ponds could be potential interventions. In this context, intervention was done only in selected hamlets, including rehabilitation of existing ponds, intake protection, and introduction of micro irrigation techniques.

Rehabilitation of pond (Raniban and Thulaijar)

There is a stone water spout in the village where people visit all year round to fetch water. There is a potential to build a pond in that area to collect water for the community, which can be used both for domestic and agricultural use. In addition to this, there is a RVWRMP drinking water tap, where water had overflowed in most of the season demonstrating higher availability than use. There is possibility to tap overflow water which can be collected at the Raniban pond (**Figure 5-7**) and Thuliajar pond (**Figure 5-8**) through pipe after rehabilitation.

Improvement of existing canal and rehabilitation of Rokainara pond

There is a canal in Rokainara village that has potential for further improvement. There are spring sources above the canal, which need to be protected. Synergies need to be established with two other ongoing projects (FINNIDA and ADB supported projects) around the same village. It helps avoid any tension and duplications. Overall, improving canals supported by a recharge pond (**Figure 5-9**) can help irrigate a large number of plots around the village.

Spring source protection

There is a spring source, which needs to be protected and water can be transferred to the Rokainara pond through pipes. The Department of Soil Conservation and Watershed Management (DSCWM) had been already carrying out bioengineering work to increase the water yield and protect the land. In addition to this, IWMI did source protection work along with intake construction using local materials and cement.

Sprinkle and drip irrigation:

Introduce water efficient irrigation techniques in both villages mentioned above to improve the water productivity and water use efficiency.

Crop-related interventions:

Changing crop calendar to cash crops introduced more climate-resilient crops.

Figure 5-7*: Raniban Pond, Mellekh village a) before intervention b) after intervention.*

Figure 5-8*: Thulaijar pond, Mellekh village a) before intervention; b) after intervention.*

Figure 5-9*: Source Protection and rehabilitation of Rokainara pond, Mellekh village.*

5.5.2. Punebata village, Doti

In this village, there are several ponds of small-medium sizes as can be seen in Figures 5-10. The lack of a sense of ownership creates challenges in collective water management and sharing. The private ponds are well maintained but the community ponds are dilapidated. In the lower part of the village, there is one spring source, which needs significant protection in terms of both quantity and quality. IWMI discussed with locals and after their commitment to use te unused water for agricultural purposes, a new pond was constructed (**Figure 5-10**). In addition to this, there was one spring source with an unlined pond. There was significant seepage loss in that pond, hence IWMI provided a plastic sheet for lining to reduce seepage loss. IWMI also introduced water efficient irrigation techniques like drip and sprinkler that can be useful to grow vegetables.

The researchers motivated farmers to change crop calendar from traditional crops to cash crops introducing more climate-resilient crops.

***Figure 5-10**: Punetola pond, Punebata village a) before intervention; b) after intervention.*

5.5.3. Kuti village, Kailali

Flooding is a key issue faced by people here, though dry season water availability is also equally crucial. The Kandra River floods every monsoon and cuts off the village from Bhajani Municipality for several days (**Figure 5-11**). It is difficult to develop flood control structures in this case as the project's primary focus was on dry season agriculture. Based on discussions with the community and available land and water resources, potential interventions are listed below:

***Figure 5-11**: The Kandra river flows between Kuti village and Bhajani Municipality.*

Promote solar-powered pumps

There are no surface irrigation schemes available in the village since farmers only use ground water. Some of the farmers are using diesel powered irrigation systems primarily for wheat and paddy irrigation. Some of the farmers are using electric powered irrigation systems to irrigate vegetable crops in kitchen gardens. There is an energy constraint for lifting the groundwater. IWMI therefor introduced 80-watt solar powered irrigation systems to lift the shallow groundwater using a shallow tube well, which on average discharges 0.3-0.4 litres per second (**Figure 5-12**).

Sprinkle and drip irrigation

Water efficient irrigation techniques could be useful to grow vegetables that optimize the water use and improve water productivity.

Crop-related interventions

Changing crop calendar to cash crops, and more climate-resilient crops.

***Figure 5-12**: Micro irrigation technology and solar pump installation at Kuti village.*

5.6. Evaluation of Techno-social Interventions

After a certain amount of time has passed post intervention installation, intervention activities need to be evaluated using appropriate indicators. In this research, short duration for collection of data and limited resources limited the evaluation process. Effort was still made to evaluate the intervention activities as listed in **Table 5-9** below.

Table 5.9: *Evaluation indicator for the intervention activities*

Aspects	Methods used	Indicator
Appropriateness of interventions	KII, consultation	Farmer's satisfaction
Usefulness of weather data	Data interpretation	Farmer's perception
Access to water	Field Observation and FGD	Irrigation facilities at field and equitable distribution
Cropping system	Field Observation and FGD	Change in cropping pattern, cropping intensity
Crop productivity	Field Observation	Improved water use efficiency, increased yield
Profitability	Field Observation	Increased yield and selling with good price
Behavioural change	KII, Stakeholder Consultation	Change in behaviour

5.6.1. Appropriateness of interventions

The cropping pattern in all three villages varies as paddy-wheat-fallow, paddy-mustard-fallow. Most of the land is fertile with low productivity due to water insufficiency. In Mellekh, there are several springs mainly used for domestic and livestock requirement and rainfed agriculture. Several ponds are available but do not function well, and require maintenance for proper use. In Punebata, there are several small earthen and concrete ponds used communally for agricultural purposes by transferring water through earthen canals. Most of the earthen canals are not functioning well and seepage losses are quite high. While designing the intervention types, need based and nature-based solutions are important. These include:

- Collective farming to reduce the difficulties of cultivating in a small unit of land;
- Rainwater trapping structures with cascading of ponds to collect water to enhance reusability of water as appropriate for the landscape;
- Protection of spring sources with bio-engineering approaches to improve water yield;
- Conservation of agro-biodiversity (drought resilient crop with low chemical input and water efficient)

In addition, community based adaptation approaches were adopted during intervention design through participatory approaches to contribute to poverty alleviation. Repair and maintenance of existing ponds in cascade systems, reuse of overflow from tap and source protection with environment friendly structures using bio-engineering were selected as physical infrastructure in both Mellekh and Punebata. In addition to this, water transfer through flexible and HDPE pipes from pond to field in order to minimize water loss with micro-irrigation techniques such as drip and sprinkler were selected at the farm level. Similarly, micro irrigation techniques with shallow tube wells were selected as intervention types at Kuti village. Solar energy is used to pump water from the tube well. Solar pumps were used (small size 80 kw) because they are efficient and cheaper than other technologies. This has been verified in past project activities through a comparative assessment of economics for per unit of water use for different energy source types. The farmers in the Terai area are using groundwater, which can be extracted easily if energy sources are available. Farmer's perceive that there is abundant groundwater and are therefore not concerned with preserving it. This research therefore informed them about water saving tools and technology, which helped to reduce unnecessary water use and can help to protect groundwater resources for future use.

Farmers were provided irrigation related equipment such as drip kits, solar pump sets and construction materials required for the pond repair work. Members of the groups received inputs such as seeds, fertilizers as well as agricultural knowledge and training. Research plots established in Punebata and Kuti will be developed to compare water productivity with different types of irrigation techniques.

Overall farmers in Mellekh were highly satisfied with the rehabilitation of three ponds in their village. The community and the LFA worked well together and there were no conflicts reported in the use of water through the interventions. Many farmers in the three villages reported that this was the first intervention to provide piped water for irrigation use all the way to their agricultural fields. Many have returned to land that was left fallow in previous years due to insufficient water during the dry season. From the KII and FGD with the farmers, interventions in the respective villages were found to be appropriate and farmers were satisfied with the performance.

5.6.2. Data collection and usages

In all three villages, a temperature logger, evaporation pan, and rain gauge were installed to collect weather data (temperature, humidity, evapotranspiration, and rainfall). The main purpose was to inform farmers about the local weather, and train them for application of the data for cropping system design.

In Mellekh the rain gauge was installed in an open farm terrace behind the field assistant's house. The tub for measuring evaporation was broken and was replaced. The temperature/humidity sensor had run out of battery and the LFA had been unable to set up the sensor to run on solar power. However, the connectors on the solar charge controller were broken (**Figure 5-13**). The LFA was instructed on setting up a pole in his yard to affix the sensor device. The LFA was also given a checklist to monitor the data measured and stored by the sensor. These technical difficulties affected data collection.

In Punebata the rain gauge was also placed in an open area in the field of a farmer's house (**Figure 5-14**). The evapotranspiration bucket was placed on top of an outdoor toilet to ensure children or livestock do not disturb the water levels. The temperature and humidity sensor was placed outside on the terrace of the house, and due to some issue it had stopped working. Upon further investigation, the team found that the device had been damaged and could not be repaired. The device was brought back to Kathmandu.

Figure 5-13: *IWMI researchers working on repairing the convertor for the solar panel during a monitoring visit.*

Figure 5-14: *Evapotranspiration bucket in Punebata village.*

In Kuti, the rain gauge and evapotranspiration bucket were placed in an open space (**Figure 5-15**). The temperature sensor was not set up correctly and did not record any data. The device was placed under a corrugated sheet roof and the farmer was asked to set it up away from the roof to ensure accurate data.

While the duration of the project was not enough to collect data over a significant period of time to analyze any trends, the community was still able to learn how to record and discuss the data collected and plan accordingly.

Figure 5-15*: Local Field Assistant (LFA) recording evaporation and rainfall data in Kuti village.*

5.6.3. Access to water

All three ponds in Mellekh seemed to be in fairly good condition with majority of the pipeline work completed. The LFA had worked closely with the community to layout the pipelines and connections to ensure that the system was flexible to accommodate sharing of water across members and non-members of the DJB collectives. The LFA and locals acknowledged that water was a shared resource so they had to be conscious not to create conflicts by laying pipelines to only benefit members of the DJB collectives. The pipeline has multiple connectors and possibility for diversions along the entire section to allow members and non-members to temporarily disconnect the pipes and access the water during their turn. Such consideration has made the pipeline more equitable, preventing non-members from breaking the pipes when they need to access the water.

Multiple farmers agreed that current practices have led to better management of water, within the collectives and in the larger community. More water is available for farmers that live down the hill in Katuwalgaon and Rokainara after the two irrigation ponds upstream of settlements were formally connected as part of DJB interventions. The pond rehabilitation has fixed the issue of leakages and helped increase overall water available for irrigation. There is increase in irrigation water available due to efficient distribution and delivery of water using pipes rather than open unlined manual canals that result in many delivery losses. Irrigation water use can now be extended because more water is available and pipes can be combined to carry the water to barren lands. The DJB pipeline goes from irrigation pond to the heart of the town, from where farmers can connect their personal pipes to take the water to their fields. Pipe systems and aforementioned increase in water availability has reduced the time required to irrigate fields. A farmer from the Alaitwada collective said that previously five ropanis took 2 days for irrigation as they had to carry the water down, and the water flow from the canal was slow. Now they can irrigate the same amount between 7am - 7 pm in one day.

In Punebata, farmers are using water for both irrigation as well as domestic purposes from the newly constructed ponds. Before project intervention, there was a spring source, which was not protected. Farmers are not storing water in ponds, water was either lost through infiltration or lost through the earthen canal. However, after the intervention, the spring has been protected and villagers can use the water for domestic purposes. The overflow water stored in newly constructed ponds can be used for irrigation in the respective fields through the pipe. After intervention, farmers have better access to irrigation water that can be suitable mainly for vegetable farming.

In Lobasta community farmers said that generally the solar pumps have given them capacity to irrigate their fields and opportunity to save money that would otherwise have been used for hiring of diesel pumps and purchasing of diesel. The solar pump is working well for the current season because farmers can irrigate in the daytime when the sun is out. In Baisakh-Jeth (April-May), it will be difficult to irrigate during the daytime as the heat is strong and watering the fields will make the seedlings wilt. It would be good if farmers can get batteries with 3-4 hours of charging to allow use of the pump after sunset in hotter months. The money saved from using solar during the day and selling vegetables was also put back into paying for diesel since water requirement for paddy was not being met by solar pump only. In essence, the community was able to diversify their options depending on the crop requirement. Besides agriculture, the intervention also had an unexpected benefit to the community. One of the households was able to use the solar pump for water supply during the marriage ceremony of her three sons. One of the oldest group members, Chuliya, used the solar pump all day to supply water for the wedding feast organized at her home. She saved significant money by avoiding an electric pump, which would have added a financial burden. As a widow, she has no other income source and joined our collective to grow vegetables for commercial purposes.

The community in Lakhrai was also able to benefit from the solar pumps. They mentioned the decrease in costs associated with renting diesel pumps. However, it should also be noted that several farmers farthest away from the bore holes had decided to instead revert back to diesel pumps, indicating that perhaps the rotation is not working for the ones located furthest away. This did not result in conflict, but could in cases where diesel pumps are not available or the farmers do not have the means to pay for them.

5.6.4. Cropping system

In all the three intervention sites, farmers are mainly growing rainy season crops due to poor access to water in the dry season. The cropping pattern in all three villages varies as paddy-wheat-fallow, paddy-mustard-fallow. Most of the land is fertile with low productivity due to water insufficiency. In Mellekh, there are several springs mostly used for domestic and livestock requirement, while the agriculture is mostly rainfed. After intervention, farmers are growing vegetables (Spinach, potato, cauliflower, cabbage, chilly, onion, garlic, bitter gourds etc.) in all the three villages. Overall, the cropping system and cropping pattern in the dry season changed significantly. We can observe the increased cropping pattern with an extra harvest after the project intervention, but due to limitations of the research, quantification could not be done.

5.6.5. Crop productivity

An apparent impact of providing increased water access to farmers across all three sites was also to increase overall crop productivity. In Mellekh and Punebata, the farmers reported low water availability, which was largely responsible for low levels of crop productivity. Through the rehabilitation of ponds and expanding the network of beneficiaries, the interventions proved beneficial to the farmers in the first year. In Kuti, farmers were more or less able to access water through ground water pumping but many relied on renting pumps, which added to their costs. Solar pumps were introduced to diminish the costs associated with pump rentals and fuel/electricity costs. The addition of three pumps to the community in Kuti was successful in the first year to make water an affordable resource.

Farmers in Mellekh expressed satisfaction in the construction and usage of water from the pond and the pipeline. Prior to the intervention many farmers practiced single crop farming due to insufficient water. Many lands were left fallow during the winter season where typically wheat is grown. During follow up discussions, farmers indicated their plans to sow wheat given the availability of piped water available for irrigation use only. At the same time, the trainings and high value seed distribution enhanced the farmers' capacity to grow vegetables. Very few farmers were growing vegetables prior to the intervention and many relied on local seed varieties. They were not aware of the technicality of growing vegetables and making compost. After the training and improved access to irrigation, provided by the project, farmers are more hopeful that their harvest will be better. One farmer mentioned, “The land is not fertile, the water is not enough. Farming here is not worth it to even feed our family. But we are hoping the harvest will be easier and better this time with irrigation.”

In Punebata village, farmers also expressed satisfaction with the construction of the pond and the transition from a private to a communal pond. This allowed for a larger network of beneficiaries and served as an example for mutual benefit. Almost all households already grow and sell vegetables but irrigation during the dry winter months was still a concern. Households with access to a pond had an advantage over others who relied on rain water. Some farmers were also asked to test micro irrigation technology like drip irrigation and sprinklers to demonstrate the benefits to other farmers. Trainings and seed distribution were also helpful in providing additional technical knowledge to farmers who may have missed out on trainings provided by other organizations.

In Kuti, farmers mentioned that the hybrid seeds provided by the project have been very good, with one seed yielding five plants. Some of the female farmers said the training was also helpful because in the past they would just spread the seeds randomly. Now they know how to measure and space out each seed and they can see that this also makes it easier to track plant growth. Farmers said they had one other organization give a similar training before as well.

Similar to farmers from Lobasta village, the Lakhrai group said that the project provided access to better seeds and made it easier for them to farm vegetables at home. Most female farmers tried using the solar pumps themselves during plantation in Baisakh (April-May). Production from local seeds was negligible and farmers' lacked skills in vegetable farming. With hybrid seeds, they have been able to sell excess seeds, though some farmers have also had problems with insect infestation.

Overall, in all three villages, farmers reported increased productivity mainly in dry season crops due to access to water, access to improved seeds, improved fertilizer, and training on agronomical practices and water management.

5.6.6. Profitability

In all the three villages, money has been saved from the purchase of seeds (and diesel in Kuti only). Collective action has also provided a space for farmers to share problems, solve issues and face challenges together. We had developed the sheets to calculate the cost incurred from land preparation to harvesting including labour, seed, machinery, inter-cultural operation etc., but due to the limited time, findings could not be reflected here. Based on interactions with the farmers during monitoring of intervention work, they did report increased selling price, improved bargaining power, cost saving in input due to collective action and increased crop productivity resulting in significant change in profitability compared to previous years.

5.6.7. Behavioural change

The Far Western region is a hotbed for developmental activities yet the sustainability and functionality of the activities post project period is a growing cause of concern. The team encountered many abandoned ponds and taps in need of dire repair in both villages in Doti. The high intensity of such activities has also changed the mindset of the local community that reflects on the maintenance and upkeep of heavy construction interventions. Under the DJB project the focus was on rehabilitating existing infrastructure and learning more about the issues encountered during common resource pool sharing approaches. At the same time, we encouraged farmers to join the group only if they were willing to follow the collective farming approach. During the intervention period the team engaged in a critical discussion surrounding gender in agriculture to bring underlying issues to the forefront. At the end of each session, there were success stories and some lessons learned.

In Mellekh, the community was largely positive towards the construction process and resource sharing. A water allocation chart was proposed to ensure equitable distribution of water, especially during the dry months. Group members allocated numbers to households to get their approval based on their own understanding and community perception. There was a strong sense of communal benefit amongst group members and it was decided that they would continue allocating water as they had been doing and only use the crop rotation schedule in case of conflict (**Figure 5-16**). The members also proposed to get approval on the water allocation chart from farmers outside the collectives, because the plots are not contiguous and some farmers outside the collectives have plots between those belonging to collective members, and will therefore also be using the water. This is a testament to the strong community integrity they feel. Still, they thought the crop rotation exercise and having a clear back up plan was a good idea to adopt.

Figure 5-16*: Development of water allocation chart in Mellekh village.*

In Punebata there was a conflict situation wherein members of the same family were engaged in a public argument regarding water sharing. Prior to project intervention, there had been a small earthen pond on the land of one now-member of the collective. However, as he had not invested any money or time into improving it, the pond was generally viewed as communal. Still, others were hesitant to use it. The "owner" was willing to make clear that the pond is communal by having all members of the newly formed collective contribute to its construction, thereby cementing joint ownership under customary views of property. However, a conflict still ensued between several family members with plots closest to the pond, and discouraged other group members from accessing water that is already a source of contention. Surprisingly, both parties agreed that a new tap would help solve their issues instead of mediation.

In an effort to diffuse the tension and better understand the issue of water sharing, a discussion on gender through a series of activities took place. Members and a few non-members of the collective participated in the gender training guided by the Participatory Gender Training Manual (Leder et al., 2016). An introductory exercise focused on discussing preferences for either a girl child or a boy child followed by a short lecture session on differences between sex and gender.

Other discussions and activities focused on gendered roles in the community and linking the overall workload with time spent on a daily basis. Using photos of various agricultural and household work, the farmers were asked to indicate whether each task illustrated in the photo is conducted by either man only, mostly men, men and women equally, mostly women or women only (**Figure 5-17**). At the end of the exercise the farmers discussed changes in the work responsibility compared to their childhood days and their visions for the next 15 years. Many activities listed under “women only” or “men only” shifted towards the “men and women equally” indicating that the farmers are hopeful for change for the next generation. Also, men and women both recognized that the numerous tasks that fall under women’s responsibility at the household level often remain unquestioned. Work typically done by men is usually conducted in a public space and is considered “hard work” or work that requires technical skills such as ploughing and driving a tractor. While the farmers agreed that slowly women can also acquire skills to operate machinery, but ploughing using livestock will always be a man’s job due to the cultural norms associated with women ploughing. The training ended with a short skit to provide an opportunity for men and women to switch roles and display a light-hearted snapshot of their daily lives.

Figure 5-17*: Gender training in progress with group members from Punebata village.*

An irrigation rotation scheduling exercise was also conducted to alleviate the water sharing conflict (**Figure 5-18**). The water allocation was decided based on plot size, proximity to the pond and whether the plot was used to grow vegetables or not. Similar to other ponds in the village, the collective decided that the rotation would change seasonally, with the 1st member to receive water becoming the last to receive water the next season. This was an attempt taken to reduce conflict and ensure those with plots further away will benefit from access to water from the pond even in the dry season. The community has not reported any other conflicts since.

***Figure 5-18**: Group members signing their positioning on water allocation chart in Punebata village.*

In Kuti there were no reported conflicts in deciding on and taking turns with using the pump for irrigation. The collective members also have very strong beliefs in coordinating to help each other. For example, farmers often combine their pipes to help carry water to farmers whose fields are farther away. Currently, scheduling is done on an ad hoc basis as needed. Whoever is ready to irrigate their fields will come and fetch the pump. Farmers will informally discuss and establish the next pump user a day or two ahead, or sometimes on the day itself. The decision is then communicated to relevant collective members over the course of the day. Farmers don't have any schedule fixed for the upcoming winter cropping. There is still time as most of them are currently busy preparing their fields for the next crop. The team suggested preparing a chart to help plan the timing of pump use to irrigate their fields but the community members were comfortable with their current modus operandi. In cases where there is a strong sense of community integrity, imposing an order can even create conflict and undermine the sense of solidarity, so it is important to be responsive to this.

Two sessions of gender training took place in Kuti village (**Figure 5-19**). Following the discussions, we conducted the gender training. In the discussion women insisted that not all men help out and while there are some men who have now started to share childcare responsibilities, the primary caregiver is still the mother. Fathers tend to spend time with their children during play time since the mother is responsible for feeding the baby. Farmers commented that the training helped them recognize these activities: men and women are equal, workload should not fall on only one, if everyone works together as per their capacities, everything can be completely quickly.

***Figure 5-19**: Gender Position bar activity in Kuti village.*

The success of this model relies completely on the group member's ability to work together for mutual benefit. The strength of the group lies in the group member's coordination in working together and using their network to increase productivity.

5.6.8. Overall sustainability

One of the issues regarding sustainability beyond the project is to ensure that farmers continue to engage in high value crop production. While seeds were provided for the first two seasons, it was routinely explained to the collectives that farmers would need to use the collective as an entity and bargain as a group in the future. The farmers will first need to figure out how many seeds and fertilizers each household needs and what crops each of them will be planting. The collective should raise money from each household accordingly to create a collective pool to purchase seeds from a wholesale seed and fertilizer dealer. A representative can be collected to purchase seeds from the market and distribute it among the team members. When collecting money, the members should also pitch in some money for the representative, to compensate him for the time spent getting the seeds for the whole group. Members can also take turns being representative for different seasons. Doing so will help farmers purchase their inputs at a cheaper rate and also save them all time. Farmers should also consider collective selling of their produce to the market as they begin producing more.

5.7. Conclusions

Improving water management in agriculture and the livelihood of the rural people requires mitigating and preventing land degradation. In most of the intervention area, land degradation is driven by the complex socio-political and economic context. Smallholder agricultural systems with nature-based watershed and water conservation techniques are important intervention activities to mitigate land degradation activities in the project area. Enhancing the multi-functionality of agricultural land as well as conserving ecosystems could be the pathway for poverty reduction and resource conservation in the western region of the project area.

Water productivity mainly relates to the net socioeconomic and environmental benefit using water in agriculture, including fisheries, livestock, crops, and mixed system. Increasing water productivity, especially the profitability and value produced per unit of water, is an important pathway for poverty reduction in project areas. Many farmers in the project area could raise water productivity and profitability by adopting proven agronomic and water management practices as intervened by the DJB project. In addition to this, integrated and multiple use of water for crops, fish, livestock, and domestic purpose could be important pathways to increase the value derived from per unit of water used.

Initial reflections indicated that hamlets with marginal and tenant farmers would benefit the most through the collective approach. However, the in-depth discussions provided a different outcome. In some instances, the social feasibility does not always link up with technical feasibility and projects must avoid engaging in areas where conflict already exists. While the project seeks to benefit groups that have been largely disadvantaged, the collective farming approach seeks some level of investment from the farmers. The main objective of the project was to target marginal and tenant farmers, but in reality, the groups were comprised of farmers who did not rent land for the purposes of this intervention. The costs involved in renting land proved to be a significant impediment. In such instances, the intervention can benefit communities who perhaps have already benefitted from similar projects in the past.

Communities in Doti district are fairly comparable in terms of land ownership, but the range of land holding varies greatly across hamlets in Kuti village. Communities in Kuti village who often rent land are also heavily reliant on seasonal migration. Men are largely absent and it is usually the women, children and elderly who are left behind. This adds significant burden, financially and labour wise, to engage in such interventions. At the same time the communities preferred other types of training, indicating a decrease in interest in agricultural activities. A long-term engagement would provide an opportunity to engage with such communities and foster a relationship based on trust towards change. Efforts can include sharing the cost of rent and ensuring market linkage for farmers to foresee a potential source of income and make efforts to invest in renting land for a longer duration.

Based on these observations as well as discussions with stakeholders and farmers, each group expressed satisfactory remarks on the techno social interventions. The team expects the farmers group to continue growing vegetables and sharing resources. However, the actual situation can only be determined once a follow up visit is made a few months after the end of the project. The success in terms of taking up ownership after the project lies on the group's efforts to work together for mutual benefit. There are many factors that determine the sustainability of the intervention wherein all involved stakeholders, from farmers to development partners to local government, have respective roles and responsibilities. Therefore, a close engagement and regular coordination and communication between the community, the organization, and the local government from the very beginning of site selection, to implementation, to project handover is essential.

First, there needs to be a sound understanding of the area and social dynamics of the potential intervention sites. Prior information on the location will ensure that interventions can be contextualized and customized for communal benefit. Stakeholders also stressed on developing interventions for multiple water use to diversify the network of beneficiaries. This was one of the biggest priorities of our project and several field visits and discussions took place to ensure an iterative dialogue between IWMI and the community on a regular basis. During the intervention phase an important factor is to maintain trust between both parties and to conduct public audits and keep stock of past and current projects. This is especially helpful for the community and the local government to keep track of the developmental activities in their area. In many instances, several organizations are working under the same sector but are scattered in such a manner that the actual benefit is difficult to measure. This will also allow communities to accept or reject interventions based on past success and failures, and perhaps help streamline future development activities.

At the end of the project, it is equally important to handover the technology and knowledge developed during the course of the project. The IWMI team conducted a handover session during the end of the project in the presence of all involved stakeholders. The weather instruments and data collected during the project period were also included in the handover process. At the same time there were concerns regarding buying seeds in the future and collecting funds for repair and maintenance of the technology. While the project provided seeds for two seasons, the farmers are expected to invest some of the profits made by selling vegetables/savings made by growing vegetables at home to buy more seeds. The collective forms a unit wherein farmers can pool together money and purchase seeds in bulk and bargain for a discounted rate. This was discussed with each group at the follow-up visits. The case is similar for creating a fund to repair the ponds/solar pumps in the future for uninterrupted use. Communities were repeatedly asked to collect funds on a monthly basis for repair work but many insisted on collecting funds when a problem arises, which could potentially lead to an interruption depending on the group dynamics. All the collectives were linked to their local technicians and Agrovet representatives to ease future communication.

5.8. References

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5.9. Annexes

Annex 5-1: Bastakoti R.C., Karki E., Thapa B.R., Pandey V.P. (2019). Dealing with variations in access to water: An assessment of challenges and coping strategies in Western Nepal. Climate and Development (Under Review).

Annex 5-2: Pandey V.P., Sharma A., Dhaubanjar S., Bharati L., Joshi I.R. (2019). Climate shocks and responses in Karnali-Mahakali Basins, Western Nepal. Climate, *7*, 92. (https://www.mdpi.com/2225-1154/7/7/92)

6. Environment

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6.1. Introduction

Rivers are highly diverse ecosystems, provide habitats for hundreds and thousands of animals, and are a key parameter for economic and social development. In recent decades, wide ranges of anthropogenic activities, both nutrients inputs and hydro-morphological changes, have influenced river systems altering natural functions and their services to nature and people. The rivers also serve a number of other uses including livelihood, social and cultural needs of riparian communities. When a river's water resources are used for multiple purposes, it is often not realistic to maintain its natural flow regime intact. As a result, continued degradation of river ecosystems and loss of aquatic biodiversity are widespread (Dudgeon et al., 2010; Shan and Shah, 2013). Therefore, a compromise has to be reached between satisfying human demands for economically important uses of water, maintaining the ecological health of a river, and satisfying livelihood, social and cultural needs of communities. Environmental flows (hereafter, E-flows) estimation tools help make this compromise in a scientifically sound manner.

There is an increasing recognition of the need to allocate water for environmental purposes, besides the more traditional allocation to cities, industries and agriculture. During the planning and design stages of water resources development projects, these E-flows should be considered explicitly alongside those of other users. These E-Flows requirements ought to be defined on the basis of observed direct linkages between changes in ecosystem character and the delivery of important ecological services to people (e.g., fish as food, high quality drinking water, riparian trees for house construction and recreation, etc.).

The term E-Flows typically describes a flow regime that maintains different components of a river's ecosystem in a prescribed state of "ecological health", while being subjected to water resources development. This flow regime spells out the quantity, quality and timing of water flows required to sustain ecosystem components as well as the various services they offer (Arthington, 2012). The different ecosystem components include riparian ecosystems, linked wetlands or floodplains and the various plant and animal species within the water system (King, 2016). The E-Flows are equally important for human well-being. A healthy river may support local livelihoods, and also hold significant aesthetic, cultural and religious values (Alston and Mason, 2008). Therefore, incorporating livelihood and socio-cultural factors into E-Flows provides a more holistic concept of "river health" management.

E-Flows assessment methods are generally applied at two levels of complexity (Tharme, 2003, Smakhtin and Eriyagama, 2008) as reconnaissance level and comprehensive level. Reconnaissance level methods are based primarily on ecologically relevant hydrological characteristics (indices) or analysis of hydrological time series. They are also referred to as desktop methods. Comprehensive level methods either require more detailed hydrodynamic habitat modelling (e.g., habitat simulation methods), or follow a detailed scenario-based approach addressing the flow requirements of the entire riverine ecosystem, ecosystem dependent livelihoods as well as spiritual/cultural requirements. (e.g., holistic methods). Desktop methods are usually used at the planning stage of water resources projects in order to make coarse estimates of E-Flow requirements (EFR), and are usually followed by the implementation of detailed estimation methods. From practical viewpoint, an estimate of E-flows considering hydrological, ecological, and socio-cultural aspects of river systems gives a more realistic assessment.

Hydrology and river flow is a major determinant of physical habitat in streams which affects the biotic composition (Bunn and Arthington, 2002). Flow regime and landform determines the shape and size of river channels, distribution of riffle and pool habitats and the stability of substrate. Macroinvertebrates are vulnerable to erratic flow patterns and sudden increases in flow cause catastrophic downstream drift to as much as much as 14% (Bunn and Arthington, 2002). Fish may be stranded on gravel bars or trapped in off-channel habitats during rapid flow decreases (Bradford, 1997). Flow plays a very important role in fish as it is linked with critical life events such as phenology of reproduction, spawning behavior, larval survival, growth patterns and recruitment (Bunn and Arthington, 2002). The sediment amount in river is also affected by flow regimes; high sediment levels in streams have retarding effect on macroinvertebrates and fish communities (Sullivan and Watzin, 2008) as sediment load hinders the growth of periphyton which reduces the availability of algae to grazers and decreases the densities of scrapers, shredders and predators (Ndaruga et al., 2004).

Similarly, disturbances in river system due to construction of water infrastructures affects the abundance and composition of downstream habitats, such as benthic macroinvertebrates and fishes, due to reduced flow and water level (Tachamo Shah et al. In Press). Small man-made weirs (1-2m height) have been found to have negative effects on sensitive macroinvertebrate taxa such as the Plecopterans which reduces macroinvertebrate richness at the downstream reaches, whereas they lead to high abundances of tolerant taxa, such as dipterans at the downstream sites (Mbaka and Mwaniki, 2015). The abundance and diversity of macroinvertebrates generally declines in response to increase or decrease in the flow and fishes have consistent negative responses to alteration in magnitude of flow (Poff and Zimmerman, 2010). River impoundment causes the blocking of fish passage which is mostly followed by the disappearance or decline of major migratory species in the river upstream of barriers (Bunn and Arthington, 2002; Osmundson et al., 2002). Furthermore, water quality of the river depends upon the water quantity and dilution rate (Chen et al., 2013). Ephemeroptera, Plecoptera and Trichoptera taxa (EPT taxa) were found to be lower in numbers with water quality degradation therefore they can be good indicators of water quality change (Shah and Shah 2013) whereas severely polluted sites were found to be characterized by severe reduction in species diversity and mainly dominated by tolerant taxa such as Chironomidae, Syrphidae and Oligocheata (Shah and Shah 2013). There is a need to incorporate natural patterns of flow variability in flow E-Flows guidelines (Arthington et al., 2006). Studies have found that instead of a single ecologically acceptable flow duration, it is recommended to use seasonally varying flow duration so that different flow needs at different times of the year are accounted for (Acreman, 2005).

Models such as In-stream Flow Incremental Methodology (IFIM) and Physical Habitat Stimulation Model (PHABSIM) have been developed by the U.S. Fish and Wildlife Service and for broader implementation of E-Flows in water management Ecological Limits of Hydrologic Alteration (ELOHA) framework has been developed (Renofalt et al., 2010). The objectives of this chapter are - i) to evaluate the river health under present condition; and ii) to develop E-flows tools for Western Nepal. The Western Nepal Environmental Flow Calculator (WENEFC), developed as part of the Digo Jal Bikas (DJB) project, is a desktop software tool facilitating such planning level assessments of EFR in the rivers of Western Nepal. In addition to estimates purely based on hydrology, it also offers a method to incorporate ecological, social and cultural requirements in order to estimate E-Flows

6.2. Materials and Methods

6.2.1. Sample design and implementation

The study was conducted in the headwaters of Karnali, Mohana and Mahakali Rivers in the Mid-Western and Far-Western regions of Nepal (**Figure 6-1**). Mahakali and Karnali are glacier and snow fed rivers and are major tributaries of the Ganges River System in South Asia. Only about 32.4% of Mahakali basin drains in Nepal territory. The Karnali river, with the length of 507 km, is the longest river in Nepal. Majority of the basin falls in Nepal with only 6.9% of the upstream areas falling in Tibeto-China.

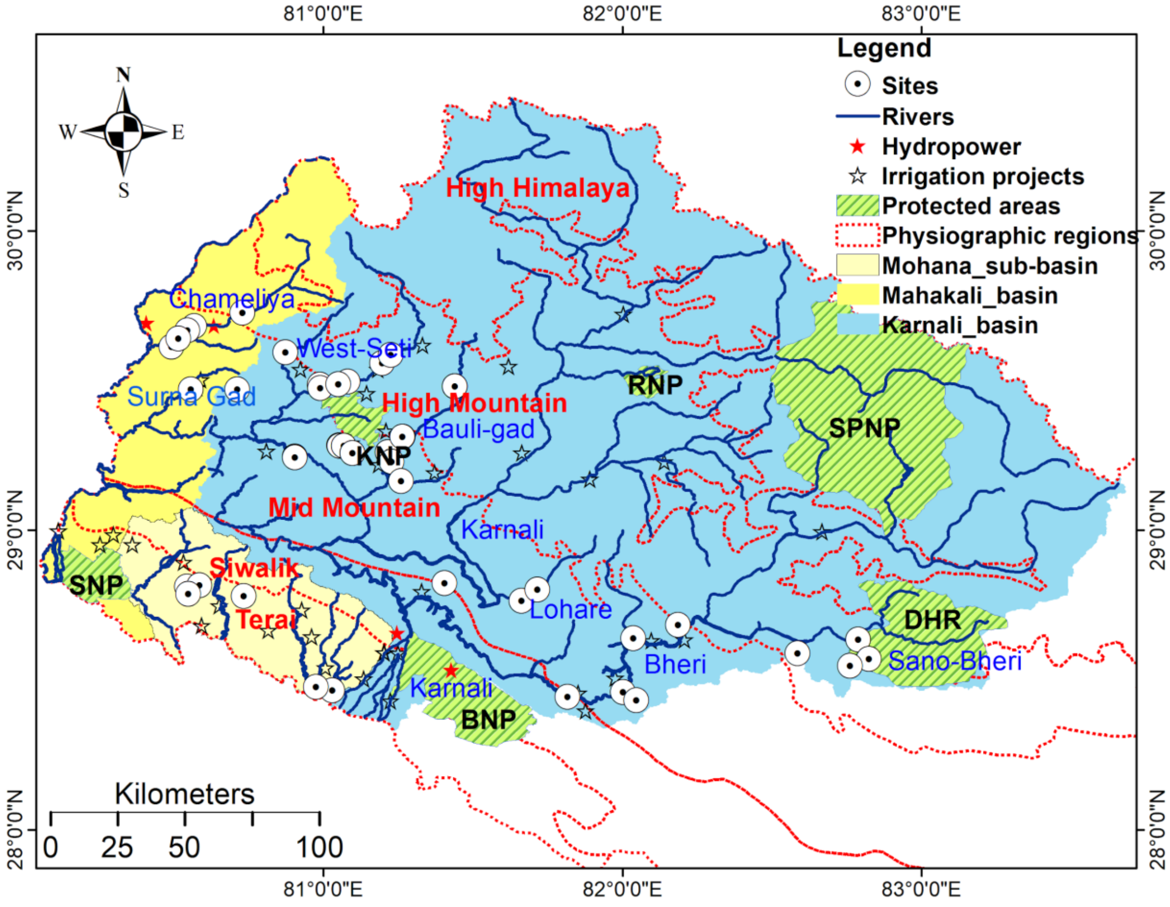

__Figure 6-1__: Distribution of sampling sites in rivers of Mahakali, Mohana and Karnali basins in Western Nepal. Circle indicates sampling site. Star (Black colour) represents irrigation projects and proposed hydropower projects. Protected areas are provided in short form where SNP = Suklaphata National Park, KNP= Khaptad National Park, RNP= Rara National Park, BNP= Bardiya National Park, SPNP= She-Phoksundo National Park and DHR= Dhorpatan Hunting Reserve.

Benthic macroinvertebrates samples were collected seasonally from headwaters of Mahakali, Mohana and Karnali basins in the year 2016 and 2017. The sampling sites are shown in **Figure 6-1**. Samplings were carried out in three seasons. The number of river stretches selected for post-monsoon, baseflow, and pre-monsoon seasons were 36, 50 and 41, respectively. (**Table 6-1**). Post-monsoon samples from Manohara downstream, Kandra and Patharriya in Mohana basin were taken in the year 2018. Rivers downstream of diversion schemes and upstream (or without water diversions) were considered as disturbed and natural sites, respectively. In disturbed sites, water used to be diverted for domestic, agricultural, operating water mills and micro/hydro-power generation.

***Table 6.1**: Sampling sites in Mahakali, Karnali and Mohana basins for three seasons of the year 2016 and 2017. In Category column, Letter ,"A" stands for abstracted site, N stands for Natural site and D stands for dam/small weir site. The number 1 and 0 in the three seasons columns indicate study undertaken and without study, respectively. Symbol * indicates samples collected during post-monsoon season of the year 2018.*

Basin	Catchment	Name of River	Category	Post-Monsoon (Nov-Dec, 16)	Baseflow (Feb-Mar, 17)	Pre-Monsoon (Apr-May, 17)
MAHAKALI	Mahakali	Surna Gad	A	1	1	1
		Ghatte Khola	N	1	1	1
	Chamelia	Ghatte Khola	A	1	1	1
		Agari Gad	A	1	1	1
		Chameliya River	N	1	1	1
		Jimadi Gad	N	0	1	1
MOHANA	Mohana	Godawari River	A	1	1	1
		Manahora Khola	N	1	1	1
		Manahorakhola/ Downstream	A	1*	1	1
		Kandre Hola	A	1*	1	1
		Chaumala Khola	N	1	1	1
		Pathariya River	N	1*	1	1
KARNALI	West Seti	Phulaudi Gad	N	1	1	1
		Phulaudi Gad	A	1	1	1
		Ghandi Gad	N	1	1	1
		Ghandi Gad	D	1	1	1
		Ghandi Gad	A	1	1	1
		Kala Gad	N	1	1	1
		Kala Gad	D	1	1	1
		Kala Gad	A	1	1	1
		Kala Gad	D	1	1	1
		Bahuli Gad	N	0	1	1
		Sunigad	N	0	1	1
		Thulo Khola	N	0	1	0
		Seti River	N	1	0	0
		Sani Gad	N	1	0	0
		Jueli Gad	N	0	1	1
		Jueli Gad	A	1	1	1
		Vyaguete Khola	A	1	1	1
	Budhi Ganga	Bauli Gad	N	0	1	1
		Bauli Gad	A	0	1	1

		Bauli Khola	A	1	1	1
		Aanai Khola	N	0	1	0
		Ekri Gad	A	1	1	1
		Ekri Gad	A	1	1	1
		Jijadhi Gad	N	1	1	1
		Jijadhi Gad Dam	D	1	1	1
		Jijadii Gad	A	1	1	1
		Kailash Khola	A	0	1	0
		Chipke Khola	A	1	1	0
	Karnali	Loharekhola	A	0	1	1
		Loharekhola	N	0	1	1
		Vakule Khola	N	0	1	0
	Bheri	Juge/Juai Khola	A	1	1	1
		Pasakanda Khola	A	1	1	1
		Palasangri Khola	A	1	1	1
		Kuvende Khola	A	1	0	0
		Kailash Khola	N	0	1	0
		Cheda Gad	N	1	1	1
		Narsingh Khola	N	0	1	0
		Sani Bheri	N	0	1	1
		Karke Khola	N	0	1	0
		Small Stream At Rukumkot	N	0	1	0
Total				36	50	41

6.2.2. Laboratory analysis

6.2.2.1. Sorting and determination of benthic macroinvertebrates

The benthic samples were thoroughly washed in clean water in the laboratory. The sample was then transferred to a white enamelled tray. Each invertebrate was picked up and preserved in 85% ethanol. The sorted specimens were identified under stereo-microscope (model no. SZ61 OLYMPUS) to different taxonomic resolution (**Table 6-2**).

Table 6.2: *Taxonomic resolution of benthic macroinvertebrates*

Class	Orders	Taxonomic resolution	Reference
Gastropoda	Bassomatophora	Genus/species	Nesemann et al. (2007)
Oligochaeta	Haplotaxida	Genus/species	
Clitellata	Rhynchobdellida	Genus/species	
Insecta	Ephemeroptera, Plecoptera, Trichoptera	Genus	Unpublished keys 2006 of ASSESS HKH project
	Diptera, Heteroptera, Megaloptera, Coleoptera	Family	
	Odonata	Genus/Family	Moorse et al. (2004); Nesemann et al. (2011)

6.2.2.2. Data analysis

Non-metric multidimensional scaling (NMDS, Bray-Curtis Similarity) was applied to assess the impact of water abstraction on composition and diversity of benthic macroinvertebrates. NMDS technique explores any similarities or dissimilarities in community data as it does not require any assumptions of multivariate normality and yields good results even when large numbers of data sets have zero values (Clarke, 1993). NMDS was conducted on benthic macroinvertebrates data for seasonal variations and water abstraction categories using Sørenson's distance measure in the R software. Prior to NMDS analysis, benthic macroinvertebrates' count data were transformed to log (x+1). Adonis test was carried out to test whether the benthic macroinvertebrate assemblages significantly differ among seasons, and between water abstraction categories.

6.2.3. River health assessment

Biological assessment or bio-assessment is the practice of inferring the health of streams, rivers and lakes based on aquatic organisms in the systems. Benthic macroinvertebrates based biological assessments are emerging as effective tools in evaluating the ecological status of aquatic ecosystems. This approach capitalizes macroinvertebrate community responses i.e., richness and abundance to disturbance. Bio-assessment rely on the fact that the biotic composition in undisturbed or pristine habitat conditions is measurably different from that of disturbed habitat conditions.

Biotic index (GRSbios/ASPT abbreviates Ganga River System Biotic Score per Average Score per Taxon) was used to assess the ecological health of rivers (Nesemann et al. 2007; Shah and Shah, 2012). The index has listed 420 taxa with taxa tolerance scores at different taxonomic level- species, genus and family. Taxa tolerance score varies from 1 to 10. The value "1" indicates highly tolerant to pollution/organic load while 10 indicates highly sensitive to pollution/disturbance in the study site. The index is calculated by sum of taxa tolerance scores divided by number of scored taxa. The index value ranges from 1 to 10. The values are classified into five scales that provide RQC I to V (**Table 6-3**). The biotic index value increases with increase in taxa richness in a site while abundance of taxa do not influence the index value.

***Table 6.3**: Transformation scale for river quality classes (Nesemann et al., 2007)*

Index value for Midland	Index value for Lowland	River Quality Class (RQC)	Status	Color band
6.51-10.00	6.00-10.00	I	High	Blue
5.51-6.50	5.00-5.99	II	Good	Green
4.51-5.50	4.00-4.99	III	Fair	Yellow
3.51-4.50	2.50-3.99	IV	Poor	Orange
1.00-3.50	1.00-2.49	V	Bad	Red

6.2.4. Development of E-Flows calculator

The Western Nepal Environmental Flow Calculator (WENEFC) was developed by incorporating simulated monthly flow values at 157 locations on the Karnali-Mohana and Mahakali rivers of Western Nepal. The simulated flows are outputs of Soil and Water Assessment Tool (SWAT) hydrological models of the two river basins (Please refer to **Chapter-2** for details). Two methods were developed to estimate E-Flows, namely, hydrological method and holistic method. The Hydrological Method is based only on hydrological considerations and the Holistic Method is based on hydrology, ecology and socio-cultural considerations (**Figure 6-2**). The Hydrological method follows the procedure developed by Smakhtin and Anputhas (2006) whereas the Holistic method is based on the results of ecological and social surveys conducted under the DJB project. Both Hydrological and Holistic Methods estimate EF requirements to maintain the rivers in different management categories ranging from "pristine" to "highly modified".

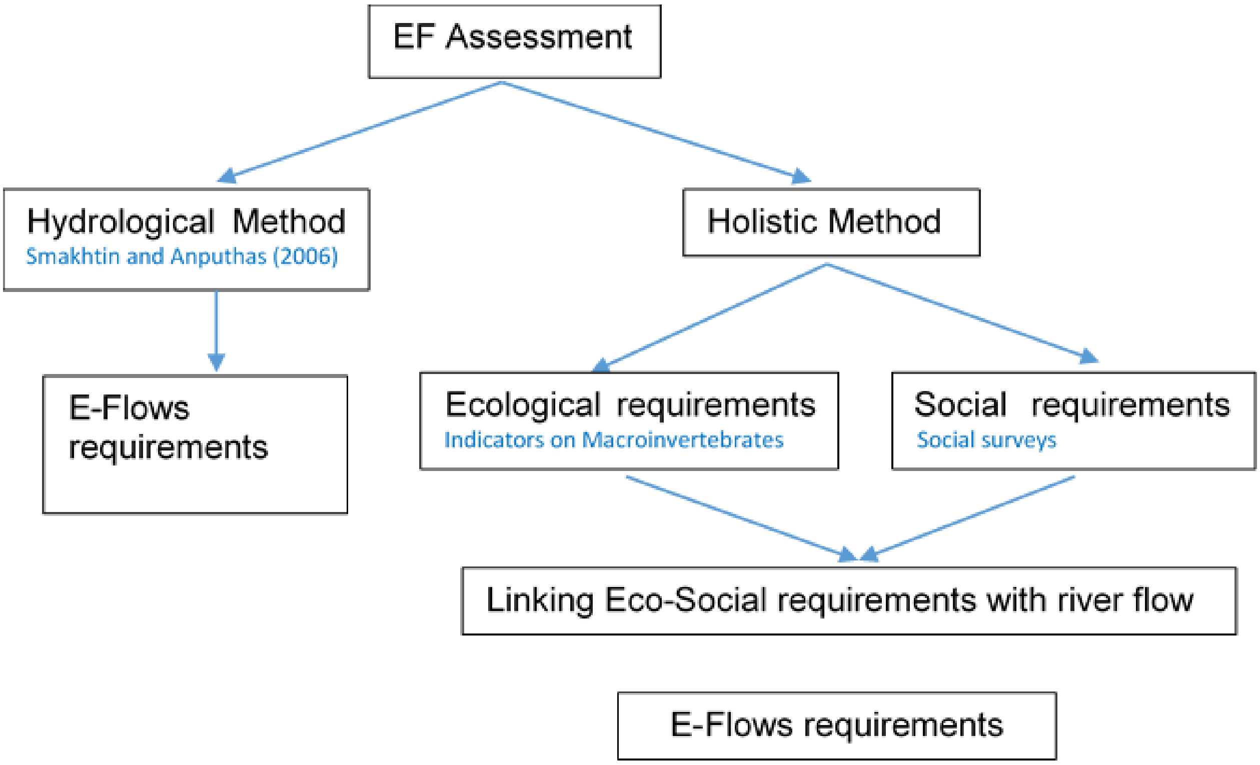

***Figure 6-2**: Schematic diagram showing the development of the Western Nepal Environmental Flow Calculator (WENEFC).*

6.2.4.1. Hydrological Method

The Hydrological Method starts with constructing the "Natural Flow Duration Curve" at locations of interest and subsequently modifying it to generate "Environmental Flow Duration Curves" corresponding to six different Environmental Management Classes (EMCs), following the procedure developed by Smakhtin and Anputhas (2006). A Flow Duration Curve is a cumulative probability distribution function of flows at a particular location, i.e., it graphs the probability of equalling or exceeding a given flow value at a location of interest (**Figure 6-3**). The procedure starts with constructing the Natural Flow Duration Curve with monthly flow values. Once constructed, it is shifted to the left along the probability axis to produce six Environmental Flow Duration Curves. Each curve characterizes the quantity and timing of flows that need to be maintained in the river in order for the river to be placed in one of six EMCs (**Figure 6-3**).

EMCs are prescribed or negotiated conditions that a river ecosystem may be maintained in and are also referred to as 'desired future state', 'ecological management category' or 'level of environmental protection' (Smakhtin and Eriyagama, 2008). The higher the EMC, more water will be needed to be allocated for ecosystems and more flow variability will need to be preserved. **Table 6-4** provides an explanation of each EMC. Once the desired EMC for a river is selected, its Environmental Flow Duration Curve can be converted into a flow time series, which can be maintained in the river as EF. Estimates using the Hydrological Method can be made at all 157 locations where modelled flow data is available (**Figure 6-4**).

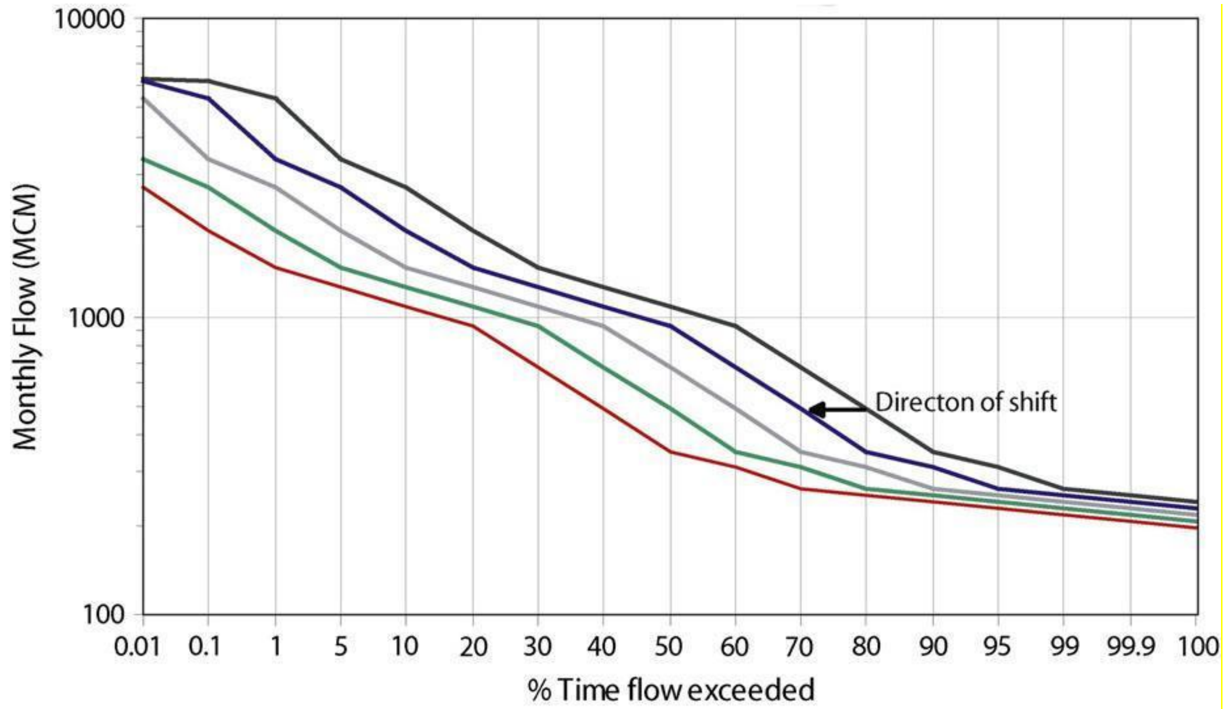

***Figure 6-3**: Procedure for shifting the Natural Flow Duration Curve to the left to produce Environmental Flow Duration Curves for different EMCs (Source: Smakhtin and Eriyagama 2008).*

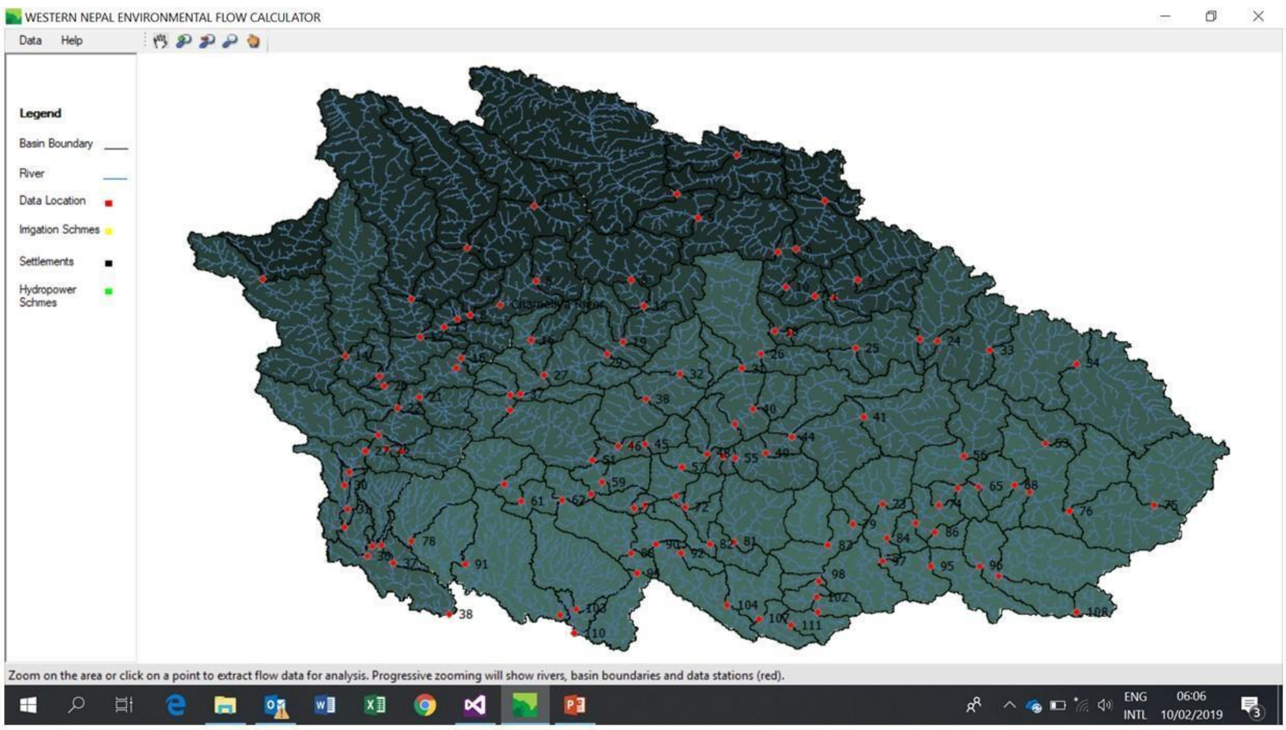

***Figure 6-4**: Locations (red circles) where estimates based on the Hydrological Method can be made shown on the Interactive map of the WENEFC.*

Table 6.4: *Environmental Management Classes (EMC)*

EMC	Most likely ecological condition	Management perspective
A	Natural rivers with minor modification of in-stream and riparian habitat	Protected rivers and basins. Reserves and national parks. No new water projects (dams, diversions) allowed
B	Slightly modified and/or ecologically important rivers with largely intact biodiversity and habitats despite water resources development and/or basin modifications	Water supply schemes or irrigation development present and/or allowed
C	The habitats and dynamics of the biota have been disturbed, but basic ecosystem functions are still intact. Some sensitive species are lost and/or reduced in extent. Alien species present	Multiple disturbances associated with the need for socio-economic development, e.g. dams, diversions, habitat modification and reduced water quality
D	Large changes in natural habitat, biota and basic ecosystem functions have occurred. A clearly lower than expected species richness. Much lowered presence of intolerant species. Alien species prevail	Significant and clearly visible disturbances associated with basin and water resources development, including dams, diversions, transfers, habitat modification and water quality degradation
E	Habitat diversity and availability have declined. A strikingly lower than expected species richness. Only tolerant species remain. Indigenous species can no longer breed. Alien species have invaded the ecosystem	High human population density and extensive water resources exploitation. Generally, this status should not be acceptable as a management goal. Management interventions are necessary to restore flow pattern and to 'move' a river to a higher management category
F	Modifications have reached a critical level and ecosystem has been completely modified with almost total loss of natural habitat and biota. In the worst case, the basic ecosystem functions have been destroyed and the changes are irreversible	This status is not acceptable from the management perspective. Management interventions are necessary to restore flow pattern and river habitats (if still possible/feasible) to 'move' a river to a higher management category

(Source: Smakhtin and Eriyagama 2008).

6.2.4.2. Holistic Method

The Holistic Method developed as part of the DJB project considers ecological and socio-cultural requirements in addition to hydrological considerations. **Figure 6-5** shows locations where river flow was generated with the SWAT hydrological model, and where ecological and social surveys were carried out.

Ecological Considerations

Based on analysis of macro-invertebrate samples collected from upstream reaches of Karnali-Mohana and Mahakali rivers, two flow thresholds (upper and lower) affecting the richness and abundance of the indicator species Trichoptera were identified (see section 6.3.1, **Figure 6-9**). The flow thresholds and the rationale for their identification are detailed below. Trichoptera were chosen due to the expertise within the project team and the recognition of Trichoptera are good indicators due to their importance in the food web.

i) River abstraction < 30% of Mean Annual River flow (MAR): Abundance of the indicator species is not affected if water abstractions are less than 30% of MAR, i.e., annual river flow is more than 70% of MAR.

ii) 30% of MAR < River abstraction < 80% of MAR: Abundance of the indicator species declines, but the impact is tolerable up to an abstraction level of 80% of the MAR, i.e., annual river flow is between 70% of MAR and 20% of MAR

iii) River abstraction > 80% of MAR: Abundance of the indicator species declines rapidly when water abstractions become larger than 80% of the MAR, i.e., annual river flow is less than 20% of MAR.

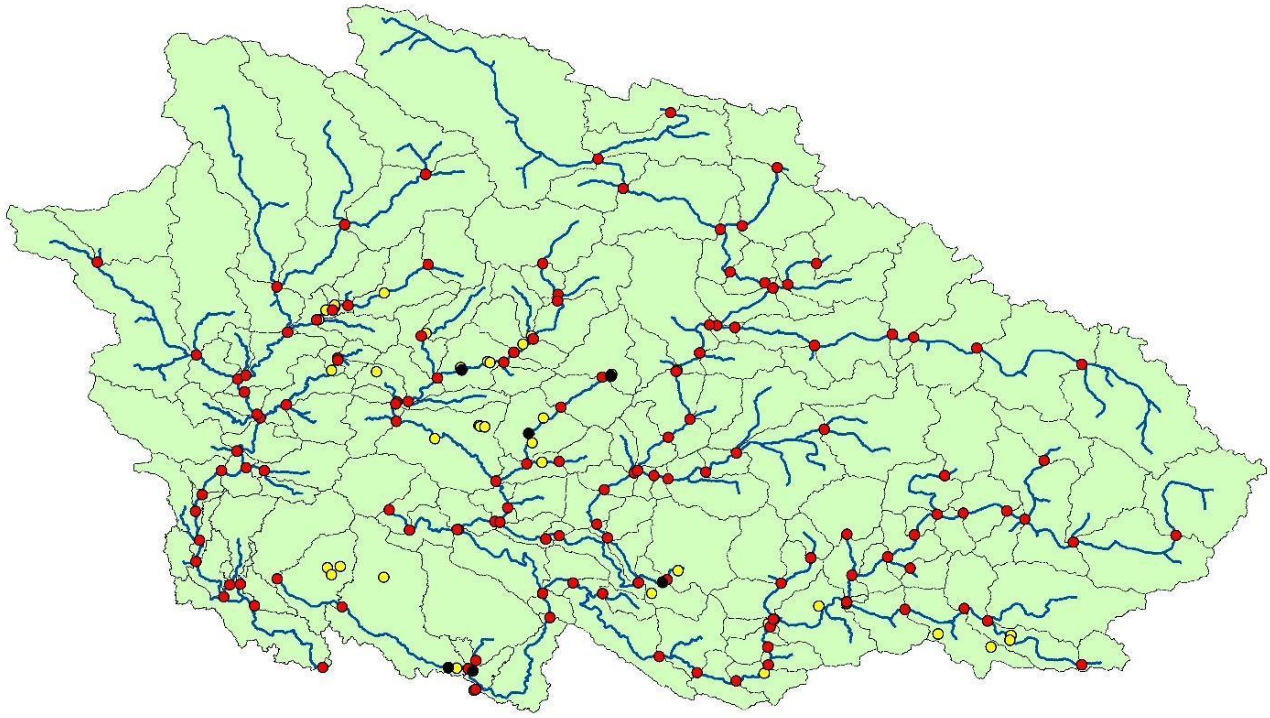

***Figure 6-5**: Locations with river flow was generated with the SWAT model (red), and where ecological (yellow) and social (black) surveys were carried out*

Flow Duration Curves corresponding to the two thresholds of 70% of MAR and 20% of MAR were then developed within the calculator. The low flow end of the Flow Duration Curve for the 20% of MAR threshold is adjusted to incorporate social/cultural requirements as detailed in the section on Social Considerations.

Social Considerations

Social/cultural requirements of riparian communities were assessed through a survey conducted among six communities living along the rivers of Western Nepal (please refer **Table 6-5** for details of locations). Water level requirements for each of their needs were identified under three categories as “Ideal”, “Acceptable” and “Poor” (**Table 6-6**). Noting that the minimum water level requirement is for irrigation (**Table 6-6**), this requirement of 0.10 m height was converted to a discharge value using corresponding river cross sections acquired during the ecological survey.

Table 6.5: *Details of locations where social surveys were carried out*

Settlement	District	Geographical Coordinates	
		Longitude	**Latitude**
Bauligad	Bajura	81.488069	29.452773
Deura	Bajhang	80.992053	29.471386
Drikeni	Achaam	81.21451	29.259744
Dungeshwor	Dailekh	81.663232	28.761611
Kuti	Kailali	80.946456	28.477730
Sunaphata	Kailali	81.027829	28.466650

Table 6.6: *Social/cultural requirements of riparian communities*

	Ideal Level (m)	**Acceptable Level (m)**	**Poor Level (m)**
Irrigation	**0.97**	**0.54**	**< = 0.10**
	The recommended ideal level allows all families in their village settlements to collect or divert sufficient water through canals for irrigation. This could reverse the impacts on adverse crop production and satiate household needs for consumption.	The proposed acceptable level allows families who wish to irrigate to continue to do so and should ideally reduce their reliance on rainwater. Families in the Tarai who grow crops on a commercial scale can continue to do so.	Levels below 0.10 meters could result in a negative rate of return for farmers, forcing even more of the population out of their villages in search for alternate sources of income. Additionally, water pumps and engines are most likely to not function or get damaged. Families who currently practice commercial farming may have to become fully reliant on underground water resources or find alternate sources of income.
Fishing	**1.52**	**0.97**	**< = 0.30**
	The proposed ideal level allows ample water for locals to find fish in, provided the water quality is acceptable. Nets, traditional *balchis* and fishing rods will all successfully work. This amount of water should provide enough space for the larger species of fish that locals say are no longer available.	The acceptable level still allows enough space for a variety of fish to comfortably swim in, allowing current fishing activity levels to be maintained. All popular fishing methods can still be practiced.	The poor level would not satisfy the current fishing activity, negatively affecting the livelihoods of the communities. Nets that require to be submerged in the water may no longer be as efficient. High levels of suspended sedimentation can also become more apparent with lower water levels and negatively affect aquatic habitat.

Socio-cultural and spiritual	**1.21**	**0.96**	**< = 0.50**
	The suggested ideal level is necessary to satisfy spiritual needs during various festivals. The additional water allows locals to fully immerse in the river to take part in cleansing and bathing rituals. Furthermore, the continuous flow of the river is very important in order to successfully complete the *Dahasanskar* ceremony.	The acceptable level leaves enough water to be able to submerge below the waist, in the river. A consistent flow is still very necessary. Additionally, there will be enough water in the river for all members of society to partake in their customs and practices. Marginalized communities will not have to find alternate solutions for the *Dahasanskar* ceremony.	The poor level does not allow locals to fully submerge and bathe in the water, nor does it guarantee the uninterrupted flow of the river to wash away the ceremonial blessings and offerings. At most, families can collect water in buckets to shower if they wish. Families may choose to bury their dead instead, affecting their traditional and cultural practices.
Household activities	**1.22**	**0.74**	**< = 0.40**
	The recommended ideal level guarantees that the remaining local water mills will function safely and well. Beyond this, there will still be enough water in the river for all community members' household activities.	The suggested acceptable level supports functioning of a water mill. It will provide families with enough water to carry out household activities.	Levels below 0.40 will not support water mills, as is the current condition in the Hills and lead to widespread closures. There will not be sufficient water to sustain an entire village's livelihoods activities without turning to other water sources. Taking care of livestock and showering larger cattle in the river may no longer be possible.
Tourism and recreation	**3.00**	**2.00**	**<= 1.5**
	The suggested ideal level will sustain the biodiversity, particularly of the endangered dolphins and the crocodiles present in the Karnali Basin. The flow of the water is also very important for activities such as rafting. to the local and neighbouring communities. Certain parts of the river, which do not have crocodile, will remain safe for swimming activities.	The proposed acceptable level allows dolphins and crocodiles to navigate the rivers. The environment by the river banks, where most of the mentioned picnic spots are located, will continue to be cherished and visited for recreational purposes.	The poor level does not support the endangered dolphin livelihoods and will likely drive them into the deeper rivers of India or harm them. Crocodiles may also migrate due to insufficient water levels. Water transport is no longer possible. Water levels so low may also reveal pollution and trash on the riverbanks, making picnic spots no longer appealing

In general, this minimum water height corresponded to 25-70% of the minimum flow value of the Natural Flow Duration Curve (MF) depending on the magnitude of the minimum flow value (MF). This relationship is further elaborated in **Table 6-7**. The low flow end of the Flow Duration Curve for the 20% of MAR threshold was then moved upwards to accommodate this minimum requirement during the low flow season (to make sure that the minimum end of the Flow Duration Curve is always above the required minimum flow).

Table 6.7*: Relationship between minimum water height of 0.1 m and the minimum flow value of the Natural Flow Duration curve*

Minimum flow value of the Natural Flow Duration Curve - MF (MCM/Month)	0.1 m height as a percentage of the minimum flow value of the Natural Flow Duration Curve - MF (%)
>=10	25
10>MF>=5	30
5>MF>=1	50
1>MF	70

This resulted in two final Flow Duration Curves, which were provisionally named as Class A and Class B in the context of the Holistic Method (**Figure 6-6**). The idea is to define E-Flows in such a way as to maintain river flows always above the Class B level, in order to maintain the health of the river ecosystems. Similar to the Hydrological Method, both Flow Duration Curves can be converted to flow time series which can be maintained in the river as E-Flows. However, application of the Holistic Method is currently limited to upstream reaches of Karnali-Mohana and Mahakali rivers – at locations where ecological sampling was performed and locations similar to them (**Figure 6-7**).

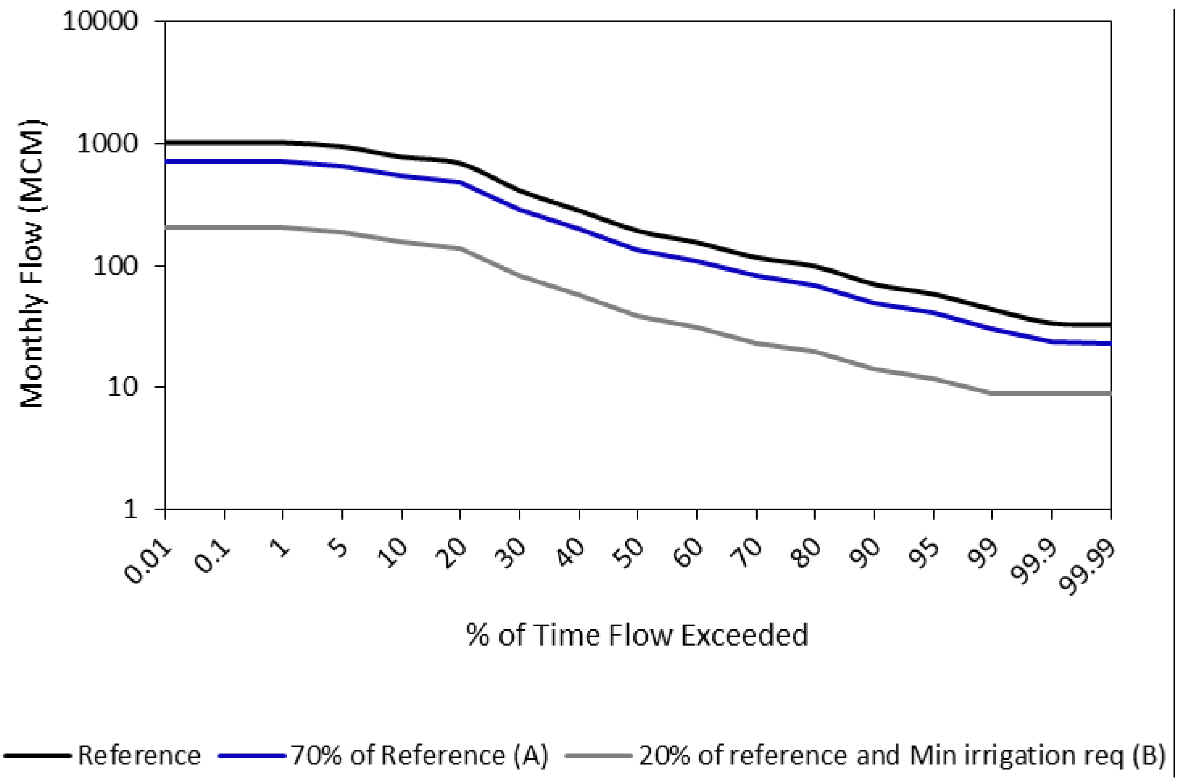

Figure 6-6*: Procedure for shifting the Natural Flow Duration Curve to generate Environmental Flow Duration curves for classes A and B under the Holistic Method*

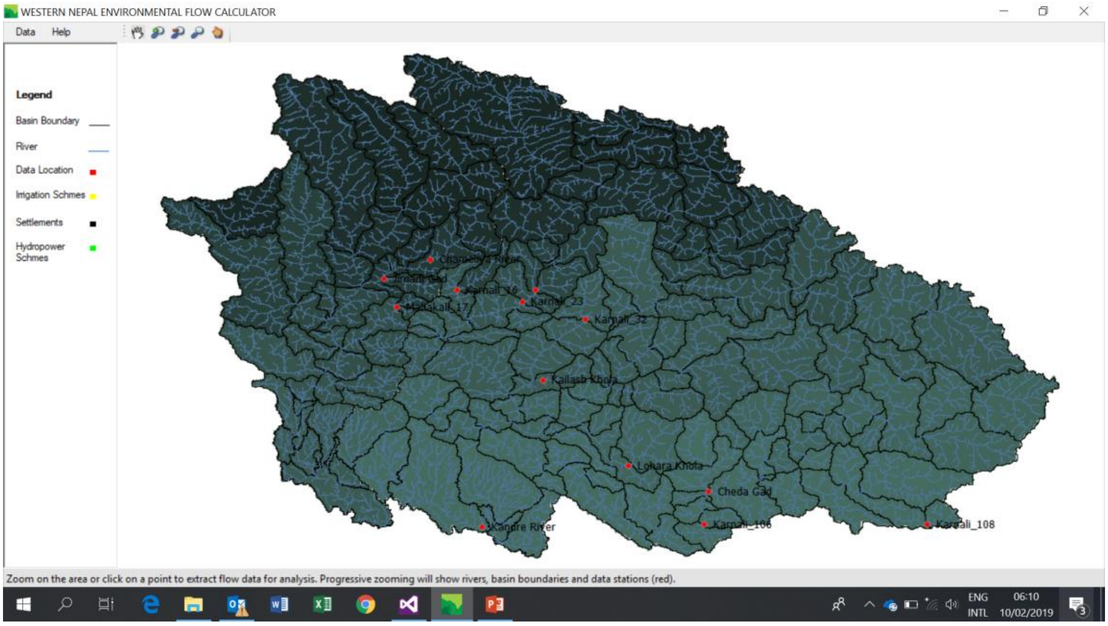

***Figure 6-7**: Locations (red circles) where estimates based on the Holistic Method can be made shown on the Interactive map of the WENEFC.*

6.3. Results and Discussion

6.3.1. River health status

The river quality class (RQC) was found to be changed from post-monsoon to pre-monsoon season in many of the sampling stretches (**Table 6-5**). All the study river stretches had high to good ecological status for the post-monsoon season while the quality deteriorated to fair and poor ecological status. Over 60% of sites were altered from high or good to fair class from post monsoon season whilst only 41% sites' RQCs changed from high or good to fair or poor/bad class. In general, the river quality classes seemed to change seasonally in the rivers of Mohana sub basin.

***Table 6.8**: River quality class of study river stretches using GRSbios. RQC stands for River Quality Class. Color bands: Blue= High Class, Green = Good Class, Yellow= Fair Class and Orange= Poor Class. "Grey light" and "Black" color band denote data missing and dried river for the particular season of the year, respectively.*

Basin	Name of River	Category	Latitude	Longitude	Post-monsoon		Base-flow		Pre-monsoon	
					RQC	Color Band	RQC	Color Band	RQC	Color Band
Mahakali	Surna Gad	A	29.46990	80.55585	II	Green	II	Green	III	Yellow
	Ghatte Khola	A	29.72651	80.72768	I	Blue	II	Green	II	Green
	Ghatte Khola	N	29.61219	80.49145	I	Blue	II	Green	II	Green
	Chameliya River	N	29.68128	80.56738	I	Blue	II	Green	III	Yellow

	Agari Gad	A	29.66703	80.54442	I		II		III	
	Jimadi Gad	A	29.63978	80.51373			II		II	
Karnali	Jjadi Gad	N	29.25977	81.21452	I		III		II	
	Jjadi Gad	D	29.25977	81.21452	II		II		II	
	Jjadi Gad	A	29.25977	81.21452	II		II		III	
	Ekri Gad	A	29.31126	81.26429	II		II		II	
	Ekri Gad	A	29.31166	81.26385	II		II		II	
	Bauli Gad	A	29.45277	81.48807	I		II		II	
	Bauli Gad	A	29.452956	81.488461			I		I	
	Bauli Gad	N	29.452357	81.489624			I		II	
	Aanai Khola	N	29.45723	81.491125			I		I	
	Kailash Khola	A	29.163088	81.259639			II		II	
	Chipke Khola	A	29.22849	81.22767	II		II		II	
	Phulaudi Gad	N	29.28322	81.05211	I		II		II	
	Phulaudi Gad	A	29.28112	81.05363	I		II		II	
	Ghandi Gad	N	29.28163	81.06762	I		II		III	
	Ghandi Gad	D	29.28143	81.06764	II		II		II	
	Ghandi Gad	A	29.28149	81.06776	I		II		II	
	Kala Gad	D	29.25743	81.09618	II		III		IV	
	Kala Gad	A	29.25743	81.09618	II		II		II	
	Kala Gad	D	29.25743	81.09618	II		IV		II	
	Kala Gad	N	29.24262	80.90311	II		II		II	
	Julei Khola	A	29.47394	80.98870	I		II		II	
	Julei Khola	N					II		II	
	Vagute Khola	A	29.47378	80.98810	I		II		III	
	Seti River	N	29.49635	81.08068	I					
	Sani Gad	N	29.48698	81.04872	I					
	Bahuli Gad	N	29.557515	81.195342			II		II	
	Suni Gad	N	29.585174	81.223894			II		II	
	Kalang Gad	N	29.593984	80.871659			II		II	
	Thulo Khola	N	29.470778	80.710478			II		II	
	Juge Khola	A	28.44374	81.81549	II		II		III	
	Cheda Gad	N	28.63873	82.03637	I		II		II	
	Pasakanda Khola	A	28.68358	82.18481	II		II		II	
	Palasangri Khola	A	28.45840	82.00153	II		II		III	
	Narsingh Khola	N	28.584663	82.827649			II		II	
	Rukumkot Khola	N	28.588491	82.584726			II		II	
	Sano Bheri	N	28.569519	82.824014			II		II	
	Kakri Khola	N	28.546827	82.760399			I		I	
	Lohara Khola	N	28.763145	81.662364			II		III	
	Lohara Khola	N	28.801594	81.715369			II		II	
	Vakule Khola	N	29.47378	80.9881			III		III	
Mohana	Godavari River	A	28.81081	80.54220	II		III		IV	
	Manahara Khola	N	28.81587	80.58382	II		IV		V	
	Chaumali River	N	28.78023	80.73283	II		III		III	
	Manahara downstream	A	28.78746	80.54764	IV		IV		IV	

	Pathariya River	N	28.46514	81.02916	III		III		V	
	Kandre River	N	28.47642	80.97456	II		IV		IV	

Clustering of sites across water abstractions

NMDS plot clustered sampling sites across different water abstraction categories (**Figure 6-8**). PERMANOVA differentiated sampling sites among 3 water abstraction categories i.e., none to slight abstraction (<30%), moderate abstraction (30-80%) and heavy abstraction (>80%) (p=0.047).

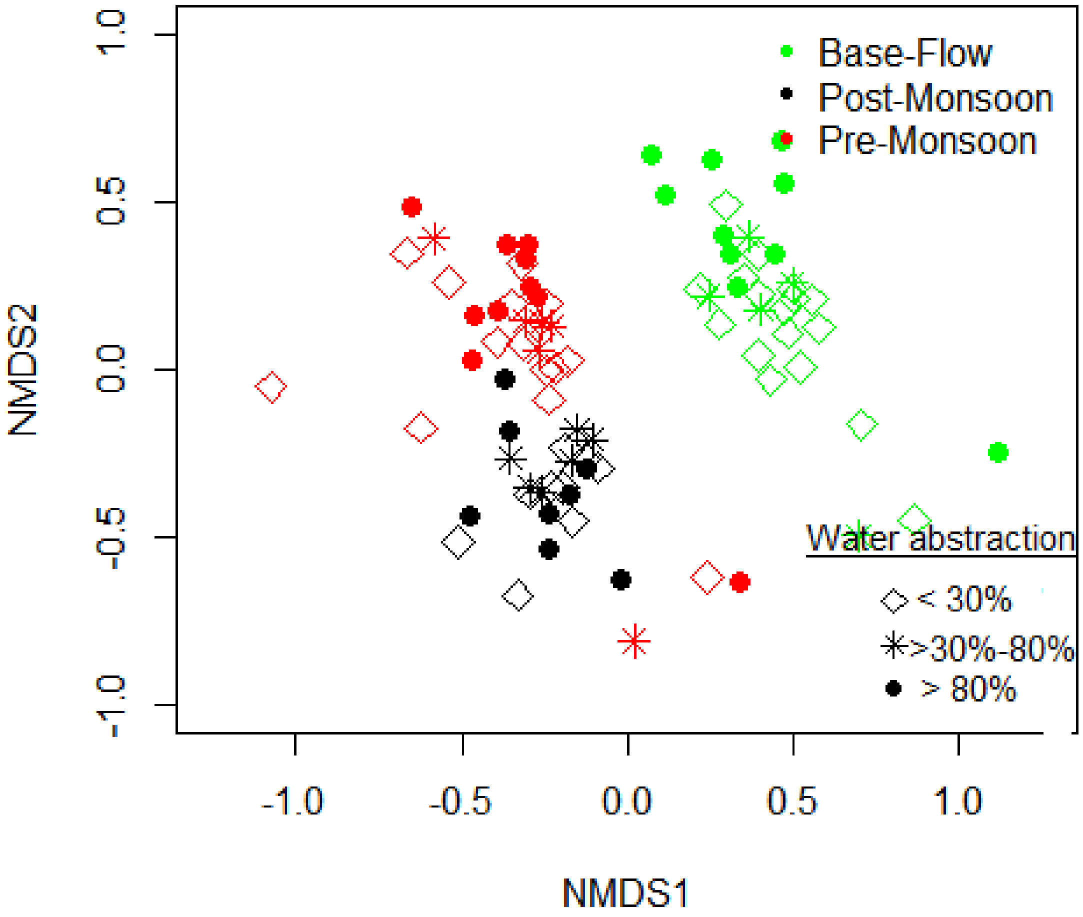

***Figure 6-8**: NMDS plot based on benthic macroinvertebrates composition. Sites are clustered into three water abstraction categories. In the figure, colours and symbols represent seasons and water abstraction categories, respectively.*

Response of faunal composition across water abstraction categories

Indicator species analysis identified four indicators, namely, relative Trichoptera abundance for “None to Slight water abstraction”, relative Coleoptera and Odonata abundance for “Moderate water abstraction” and relative Lepidoptera abundance for “Heavy water abstraction” for all seasons (**Figure 6-9**). For low flow season, i.e. pre monsoon season, relative Trichoptera and total abundance were identified as indicator groups for “None to Slight water abstraction” and Heavy water abstraction”, respectively from their high relative abundances. Only relative

Trichoptera abundance declined significantly from the least water abstraction to heavy water abstraction (**Figure 6-9**).

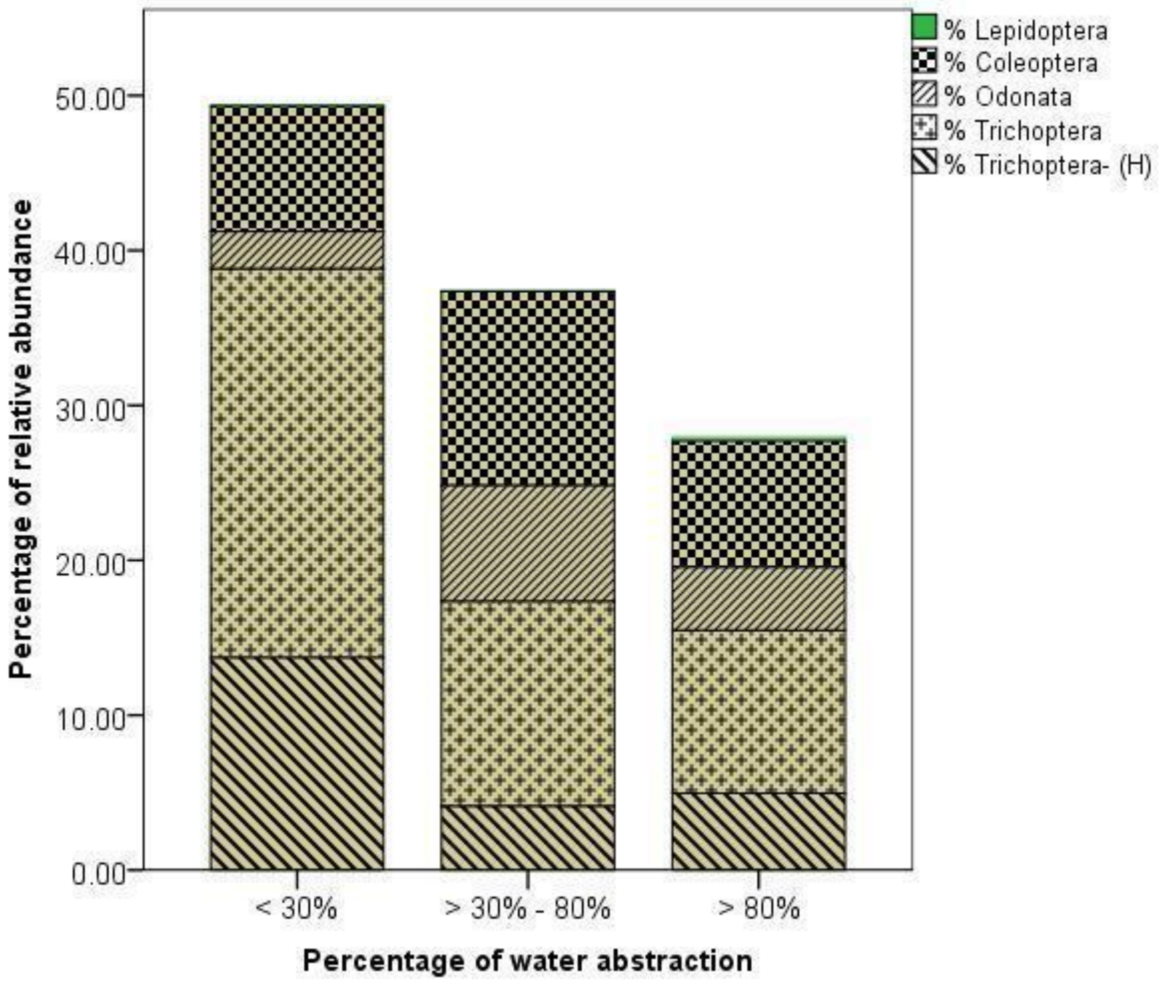

Figure 6-9*: Mean relative abundance of Trichoptera in three water abstraction categories.*

6.3.2. E-Flows assessment

The Western Nepal Environmental Flow calculator (WENEFC) has a user friendly map based interface with pan and zoom facilities. In addition to using the built-in flow data, users can also input their own river flow data into the calculator and obtain E-Flows estimates. **Figure 6-5** and **Figure 6-6** show the locations where estimates based on the hydrological and holistic methods respectively can be made with the built in flow data. The built in flow data can be retrieved by selecting the location of interest on the interactive map. The users' own data can be retrieved through a file open dialog. The procedure of estimating E-Flows involves four simple steps. E-Flows estimates at different locations are provided in terms of mean annual quantities, flow duration curves and flow time series (**Figure 6-10**). Facilities are also provided to save the results, while a help file too is available to assist users.

Figure 6-10*: Screens of E-Flows outputs from WENEFC in different formats*

Results from Hydrological Method

Tables 6-9 and 6-10 provide estimates of E-Flows requirements at the most downstream locations of the Karnali-Mohana and Mahakali basins as a percentage of their MAR. The Karnali-Mohana basin has an estimated MAR of 42224 MCM with an annual coefficient of variation of 0.087 while the Mahakali basin has a MAR of 25842 MCM with an annual coefficient of variation of 0.322. The Environmental Management Class (EMC) C is generally considered a fair condition for a river to be maintained in. The corresponding estimated E-Flows requirement for the Karnali-Mohana river is nearly 40% of its MAR while that for the Mahakli river is about 33% of its MAR. Based on estimates at 111 locations using the Hydrological Method, it is observed that in general it is necessary to maintain an E-Flows of approximately 70% of MAR to maintain a river segment in Class A while it is necessary to maintain an E-Flows of approximately 30% of MAR to maintain a river segment in Class C. Class D, considered the minimum acceptable level requires that E-Flows is maintained at 29% of the MAR for the Karnali-Mohana river and 23% of the MAR for the Mahakali river.

Table 6.9*: E-Flows estimates as a percentage of Mean Annual River Flow (MAR) for the Karnali-Mohana river*

Environmental Management Class (EMC)	E-Flows requirement as a percentage of MAR (%)
A	75.2
B	55
C	39.9
D	29.4
E	22.8
F	18.3

Table 6.10*: E-Flows estimates as a percentage of Mean Annual River Flow (MAR) for the Mahakali river.*

Environmental Management Class (EMC)	E-Flows requirement as a percentage of MAR (%)
A	70
B	48.2
C	33.1
D	23.1
E	16.4
F	11.9

Results from Holistic Method and comparison with the Hydrological Method

Table 6-11 shows the E-Flows requirements at a few locations estimated under both Hydrological and Holistic Methods. The estimates for Classes A and D from the Hydrological Method are compared against those for Classes A and B from the Holistic Method (considering that they represent the healthiest and the most degraded (acceptable) ecological conditions under each method). Although E-Flows estimates made with the Hydrological Method are slightly higher than those made with the Holistic Method at a majority of locations in **Table 6-9** to **Table 6-11**, their magnitudes are reasonably comparable. Considering both estimates at these locations it can be inferred that maintaining an E-Flows of 70% of MAR or above would leave the river in a Class A condition, while maintaining an E-Flows of at least 25% of MAR would leave the river in a Class D condition. However, comparison of estimates at a higher number of locations is necessary to verify these findings.

Table 6.11*: Comparison of E-Flows estimates under Hydrological and Holistic Methods for selected locations on the Karnali-Mohana and Mahakali rivers (Location names are indicative only)*

River	Location	MAR (MCM)	Hydrological Method (%)		Holistic Method (%)	
			Class A	Class D	Class A	Class B
Karnali-Mohana	Kandre River	2794	73.5	29.1	70	20
Karnali-Mohana	Karnali_108	241.6	72.9	24.1	70	20.1
Karnali-Mohana	Lohara Kola	1491	67	19.4	70	20
Karnali-Mohana	Suni Gad	398.3	76.8	32.8	70	20
Mahakali	Chameliya River	1091	74.6	31.1	70	20
Mahakali	Jimadi Gad	225.6	70.1	22.1	70	20
Mahakali	Surna Gad	151.6	67.1	17.7	70	20.1

6.3.3. Institutionalization of E-Flows in Nepal

Sustainable water resources development should be carried out maintaining ecosystem health while maximizing economic development. Extensive workshops are required to sensitize concerned departments and agencies during implementation or operation of water resources development in a basin. As most of the water withdrawals are associated with hydropower and irrigation developments, making E-flows requirements mandatory for obtaining hydropower licences and/ or irrigation project approvals would be a good way to ensure the institutionalization of E-flows in Nepal. Adjustment in policies for monitoring E-flows releases is also necessary.

6.4. Conclusions

The benthic macroinvertebrates are a fundamental component of aquatic ecosystems. They are a reliable indicator of river ecosystems as they live continuously in the systems integrating environmental conditions and show response by altering faunal composition to its degree of perturbation caused by river flow modification, morphological degradation or intensity of organic pollution. Therefore, these biotas based assessment tools are believed to reflect actual state of river ecosystems. Integrating instream biota richness and abundance into the flow duration curve determination provide a holistic assessment tool that ensures preservation of aquatic biodiversity and river flows required for social activities in downstream.

Although relatively less developed, the rivers of Western Nepal are prime candidates for new developments, especially considering their large hydropower potential. Therefore, scientific tools are essential for proper planning of these developments beforehand. The WENEFC caters to the need for planning level estimates of environmental flows to inform decisions on optimising the compromise between human, ecological, social and cultural demands for water. It can be used in environmental impact assessments and water infrastructure planning to define the quantity and timing of water flows required to sustain river biodiversity, ecosystem services and livelihoods.

This is the first E-Flows assessment tool for Western Nepal. It links ecological, social and cultural requirements with hydrology in order to estimate E-Flows. Advantages of the WENEFC are its user friendly map-based interface, the facility to extract flow data by selecting locations on the map, and its ability to provide quick estimates of E-Flows in a few simple steps. This is a first step in a continuous process to provide a simple user friendly tool for rapid analysis of environmental flow requirements for Western Nepal, before any major water resources development projects are initiated in this region. However, there is ample scope for improving the calculator by extending the ecological surveys to larger river segments of the Karnali-Mohana and Mahakali rivers and conducting a series of workshops with expert groups to verify and expand the identified relationships between river flow and ecosystems, livelihoods, society and culture. This action would enable the WENEFC to make better estimates of E-Flows requirements.

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6.6. Annexes

Annex 6-1: Tachamo Shah, R.D., Sharma, S. et al. (2019). Water-diversion induced changes in aquatic biodiversity in monsoon-dominated rivers of Western Himalayas in Nepal: Implications for Environmental Flows. Ecological Indicators, 108: 105735. (https://doi.org/10.1016/j.ecolind.2019.105735)

7. Future Development Pathways: Trade-offs and Opportunities

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7.1. Introduction

Water resources development and management present important opportunities and challenges for national governments and local communities. Effective balancing of domestic needs with international prospects, and economic growth with resource preservation, requires careful and consultative planning processes. Especially in low-income countries, the careful management of resource wealth can serve as the basis for local development – providing individuals and communities with inputs necessary for sustenance, livelihood, or energy – or bring in needed foreign exchange from sales of energy or valuable commodities (Pakhtigian et al., 2019). Water resources provide options for energy generation, agricultural production, industrial development, and navigation. Importantly, though, these various productive uses often entail complex and inter-sectoral trade-offs, including with non-market purposes such as support of basic livelihoods activities and environmental conservation. For example, water stored and released for steady electricity generation may conflict with release patterns desired by irrigators (Bekchanov et al., 2015); waterways preserved for navigation or ecosystem services may be ill-suited for infrastructure development (Arias et al., 2014; Palmer, 2010); export-focused production may discount or disregard local resource dependence (Pokharel, 2001); and upstream abstractions may threaten the water security of downstream users (Waterbury and Whittington, 1998; Wu et al., 2013). Development of water resources has often been considered a threat to environmental quality, and many argue that environmental costs are too often ignored (Ansar et al., 2014; Richter et al., 2010). The possibility of acute resource use trade-offs highlights the need for careful consideration of competing water demands within a given river system, using tools that are appropriate for this task. Without such tools, inefficient decision-making – in terms of infrastructure choices and sectoral prioritization – appears likely. Though trade-offs may be inevitable, a basin-wide perspective is essential to evaluate the magnitude of such concerns and to adequately account for cross-sectoral interdependencies.

Water resources planning, development, and management is particularly important in Nepal's western river basins, which comprise the lowest-income regions of the country. The region is on the cusp of economic development, and enhanced management of its vast water resource wealth provides a rich set of options for investment to advance economic growth objectives. The region has opportunities to grow and develop through harnessing of its water resources for productive uses such as hydro energy generation or irrigated agriculture. Opportunities for development also exist through environmental preservation and the strengthening of associated eco-tourism, rafting, and trekking opportunities. Given these overlapping yet somewhat divergent pathways, planners and policy makers in the region need tools to consider the trade-offs associated with prioritizing different water use opportunities. This chapter describes approaches used in identifying and evaluating trade-offs among various water development pathways and associated results for the river basins in the Western Nepal.

7.2. Materials and Methods

7.2.1. Study design

We utilized a three-study approach to examine trade-offs among various water development pathways. First, we took a holistic approach to defining development pathways by combining priorities laid out in national and regional policies, local water demands, and discussions with over ninety local and national stakeholders in water-related sectors. Second, we delved into environmental valuation among inhabitants of Western Nepal to contextualize regional demands for ecosystem services and reliance on water resources. Finally, we developed a hydro-economic model, which we applied to the Karnali and Mahakali River Basins in Western Nepal, to quantitatively compare across development pathways in the region. As policy makers and planners in Western Nepal are currently debating how to prioritize among overlapping demands for water resources in the region, these studies provide timely and policy-relevant analysis.

Study one – "The role of hydropower in visions of water resources development for rivers of Western Nepal"

This study drew on policy documents, planning processes, primarily data collection, and stakeholder consultation to define possible development pathways for Western Nepal. National planning policies such as master plans for irrigation and hydropower and water plans and policies highlight central priorities for regional development of infrastructure for energy generation and irrigation (Department of Irrigation & Groundwater Resources Development Project, 1994; Japan International Cooperation Agency [JICA], 1993, 2014; Ministry of Water Resources & Department of Irrigation, 1990; WECS, 2005). Water User Master Plans (WUMPS) are Village Development Committee (VDC) developed plans regarding local water priorities, which demonstrate and catalogue local demand for drinking water schemes, small-scale, community-managed irrigation, and environmental preservation. These WUMPS, in tandem with information from a representative basin-wide survey conducted for the Digo Jal Bikas (DJB) project, provide a comprehensive overview of local reliance on water resources. Finally, consultation with stakeholders representing local and national institutional interests and a variety of water-related sectors including irrigation, energy, watershed management, fisheries, environment, and social inclusion, among others, provided insight into development priorities across sectoral interests.

This study then worked to synthesize views of and priorities among water-related development pathways in Western Nepal. It utilized a variety of methods and data sources to provide a comprehensive overview of opportunities for water management in the region. We developed a framework for constructing development visions, which we then applied to Western Nepal to outline three visions of development: (i) state-led development; (ii) demand-driven development; and (iii) preservation of ecosystem integrity. Full study report is provided in **Annex – 7.2**

Study two – "Valuing the Environmental Costs of Local Development: Evidence from Households in Western Nepal"

The second study used nonmarket valuation techniques to examine how households in the Karnali and Mahakali River Basins value environmental quality. A targeted review of stated preference techniques for environmental quality valuation in resource-constrained settings reveals a large gap in this literature. There are several potential explanations for this lack of sufficient evidence on environmental quality valuation in developing countries. First, as Nunes and van den Bergh (2001) argue, the ecological mechanisms underpinning environmental quality can be challenging to understand even among the most well-informed of respondents. Thus, elicitation of valuations in resource constrained settings where environmental quality information is generally inaccessible can yield results that are of questionable relevance. Yet, assuming away indigenous knowledge about the environment seems problematic. Barkmann et al. (2008) empirically test the concerns of information and methodological misspecification biases using a choice experiment in rural Indonesia and find that respondents are highly attuned to their ecological surroundings. The authors conclude that careful valuation elicitation design informed by extensive ex ante study contextualization and field testing of stated preference survey instruments can overcome potential bias and yield more accurate estimates of the value of environmental quality in information-constrained settings. Second, standard concerns about "yea-saying", hypothetical bias, strategic behaviour, and framing yielding biased valuations from stated preference methods remain problematic within the context of environmental quality valuation (Diamond and Hausman, 1994; Hausman, 2012). Full study report is provided in **Annex – 7.3.**

In the face of these knowledge gaps, we designed and implemented a contingent valuation questionnaire as part of the DJB project basin-wide survey. This method was selected as a way to collect and analyse data related to environmental valuation among inhabitants of Western Nepal, which could inform the role of municipal and environmental demands for water and other resource access in the region. While infrastructure and production (of energy or agriculture, for example) are often first considered as inputs for development in the region, previous work in Western Nepal and interactions with stakeholders from the region suggested that the environmental trade-offs associated with infrastructure development may incur large costs, particularly for vulnerable populations or to valuable and unique ecosystems. Thus, in this study we aimed to estimate a value of land conservation, to inform the ways in which future development pathways should incorporate plans for environmental conservation. Furthermore, as many development pathways in the region would entail some level of environmental degradation through infrastructure development, this study demonstrates the values associated with such environmental loss.

Study three – "Hydro-economic modelling of water use trade-offs in Western Nepal"

This third study utilized a hydro-economic model (HEM) to optimize water resource use and management throughout the Karnali and Mahakali River Basins under development scenarios that align with the pathways for development outlined in study one. In providing an economic perspective on more efficient water use, HEMs represent an important tool for river basin planning. They offer a way to compare the economic benefits of potential competing water use allocation schemes or infrastructure choices, within a flexible and customizable framework that accounts for system interdependencies (Harou et al., 2009). Such models help to inform policy makers regarding the efficient use and distribution of water resources and benefits throughout a system, incorporating tools and principles from engineering, hydrology, and economics. A major strength of such models is their usefulness for analysing the sectoral, locational, and temporal trade-offs inherent in water resource use decisions.

This study implemented a new HEM, namely, the Western Nepal Energy Water Model (WNEWM), that spans two river basins and crosses two regions in Nepal – the Mid- and Far-West. By specifying the spatial scope of the model in this way, multiple sectors—agriculture, energy, municipal, and environmental—can be modelled and linked to hydrological and governance systems in parallel, with linkages between sectors (e.g., energy flows to agriculture) and between each sector and river hydrology (e.g., water flows to agriculture). We additionally incorporate political constraints based on existing water sharing agreements between India and Nepal, as well as linkages that allow for energy export from Nepal. We considered several specific questions in our analysis of these different water resources development visions. They are:

- What are the economic benefits associated with various development pathways for western Nepal?
- How does incorporation of environmental and municipal water demands constrain the benefits derived from energy generation and irrigation development?
- How are benefits distributed across space and sectors?

Full study report is provided in **Annex – 7.1.** Additionally, a framework working paper, "*Hydro-economic Modelling Framework to Address Water-Energy-Environment-Food Nexus Questions at the River Basin Scale*", which outlines the complete model used in the WNEWM application is provided in **Annex – 7.4**. (Sood et al., 2019).

7.2.2. Methodology

Figure 7-1 provides a schematic flow chart of the materials and methods utilized in our examination of future development pathways in Western Nepal. Grey-filled text boxes represent inputs incorporated in the analysis, but not generated, by the DJB project. These include national and local plans and policies, which help to frame priorities for water resource use at different institutional levels in Nepal. Dashed text boxes represent inputs generated by the DJB project, including a representative, basin-wide survey and consultations with stakeholders during a workshop and additional meetings. Lined text boxes represent intermediate outputs that identify priorities for water resources management. Finally, thick-lined text boxes represent the final outputs related to the examination of future development pathways.

The examination of future development pathways can be split into four main categories, according to the colour scheme specified for **Figure 7-1**. First, we utilized a document review process to bring together relevant policies, plans, literature, and reports related to water resources management and planning in Western Nepal. These documents were used in several ways—they provided the basis for establishing the priorities for water resources management within both the national government and local municipalities; they were used to guide development of the model framework for the WNEWM; and they were used to complete a parameter template necessary for implementing the WNEWM. Second, we collected primary data in combination with efforts from the broader DJB project. We added questions to the basin-wide survey to collect information about how basin inhabitants use water resources and value environmental quality. Further, we held a series of meetings with stakeholders, starting with a large workshop during which 50 relevant stakeholders completed surveys and participated in visioning activities to establish possible development pathways for the region. This workshop was followed by a series of stakeholder consultation meetings with approximately 40 stakeholders during which we presented initial development pathways and modelling work for stakeholder feedback. Third, we generated a set of intermediate outputs, namely a compilation of water resource management and use priorities from plans and policies, from basin inhabitants, and from sectoral stakeholders and a parameter template for the HEM. Finally, we produced our project outputs: three studies and the HEM framework working paper. Each of the studies applied a different set of methods, as detailed hereunder.

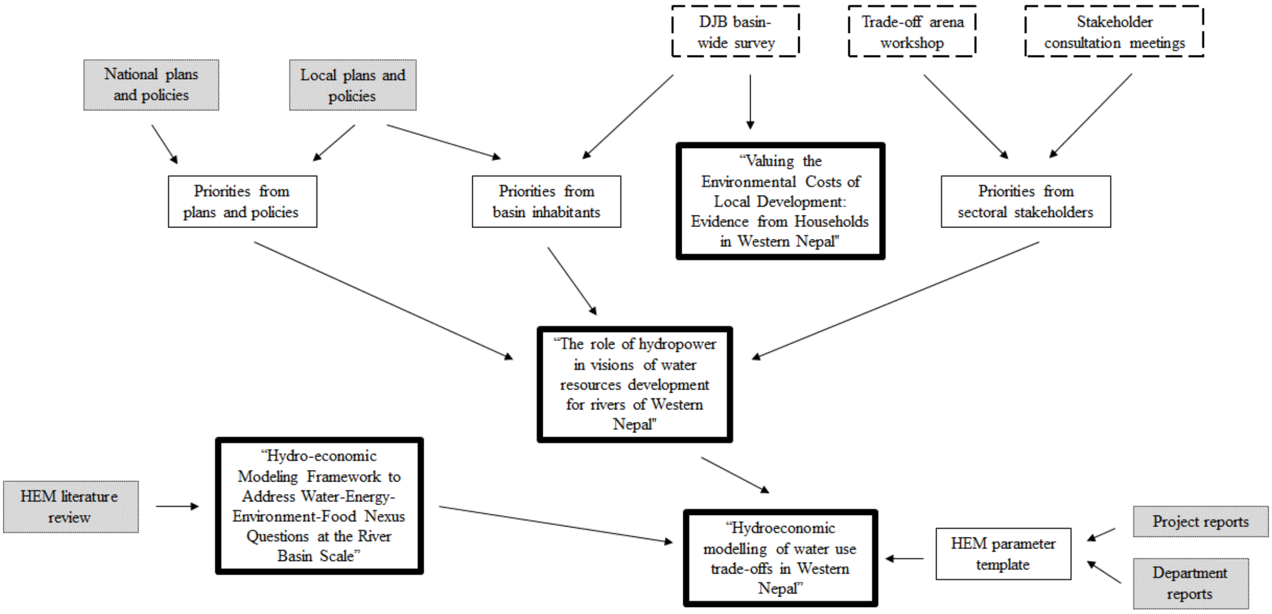

***Figure 7-1**: Schematic of work plan for examining development pathways in Western Nepal. Gery-filled text boxes indicate review of materials external to the DJB project; dashed text boxes represent primary data collection as part of DJB project; lined text boxes represent intermediary outputs; and thick-lined text boxes represent outputs associated with future development pathways.*

Study one

In this study, we combined data from existing plans and policies, stakeholder interactions, and the basin-wide survey to examine trends, consistencies, and divergences across priorities for water resource management. We generated policy summaries from existing documents to characterize priorities from these materials. We utilized basic statistical methods to analyse priorities among sectoral stakeholders as identified by individual surveys. While the sample size was insufficient for extensive quantitative analysis, descriptive statistics provided insight into the priorities among our group of stakeholders. Finally, we used descriptive analysis of data from the basin-wide survey to characterize households and natural resource reliance in the basin. With these data inputs, we develop three visions of development for the basins of Western Nepal.

Study two

In this study, we used quantitative analysis to estimate the ability and willingness to pay (WTP) for a land conservation program that would prevent future development in and around inhabitants' villages in Western Nepal. We derived these values using both nonparametric methods (Turnbull lower bounds and Kriström mid-point estimates) and using the Stata-generated double command for analysing double bounded dichotomous choice contingent valuation data. We also used regression analysis to examine the relationships between household characteristics and WTP for land conservation.

Study three

In this study, we implemented the HEM framework (as described in Sood et al., 2019) using the non-linear CONOPT solver in the General Algebraic Modeling System (GAMS) software package. We ran the base model for four development scenarios—status quo, infrastructure development, limited infrastructure development, and environmental development; the different scenarios are depicted in maps in **Figure 7-2**. The status quo scenario contains existing hydropower and irrigation infrastructure in the region. Infrastructure development expands infrastructure to include all currently licensed hydropower projects (both storage and run-of-the-river) and all licensed irrigation schemes. Limited infrastructure development expands infrastructure to include all licensed run-of-the-river hydropower projects and all licensed irrigation schemes. Finally, environmental development follows the same infrastructure strategy as limited infrastructure development; however, it maintains two river stretches near conservation areas in their natural state. We also conducted sensitivity analyses that utilize alternative parameters for environmental flows, institutional constraints, and energy demand and prices.

7.2.3. Data

The data utilized in these studies include of existing data from project plans, government documents, and reports; data collected as part of the DJB project through the basin-wide survey or interactions with stakeholders; and data from models. The main data sources are summarized in **Table 7-1**.and described below for each study.

Table 7.1*: Summary of data used for analysis*

	Data used	Source
Study one – "The role of hydropower in visions of water resources development for rivers of Western Nepal"		
National policy documents	Identification of national priorities for water use	DIGRDP, 1994; GON, 2003-04; JICA 1993, 2014; MWRI, 1990; WECS, 2005
Local policy documents	Identification of local priorities for water use	62 Water User Master Plan reports conducted by Helvetas and RVWRMP
Stakeholder meetings	Identification of national and local priorities; identification of sectoral priorities	Trade-off Arena Workshop (August 2017); DJB stakeholder meetings (June 2018)
DJB basin-wide survey	Natural resource reliance	DJB project survey, July 2017
Study two – "Valuing the Environmental Costs of Local Development: Evidence from Households in Western Nepal		
DJB basin-wide survey	CV questionnaire, household demographics, natural resource use, community involvement	DJB project survey, July 2017
Study three – "Hydro-economic modelling of water use trade-offs in Western Nepal"		
Hydrology module	Natural river flows, precipitation, institutional withdrawal constraints, reservoir parameters	Mahakali River Treaty; Pandey et al., 2019a, b; Project-specific documentation
Energy module	Energy prices, generation efficiency, production cost, installed capacity, transmission cost, transmission distances	GIS tools; NEA, 2016; PHD 2013; Project-specific documentation

Agriculture module	Irrigation efficiency, crop yields, cropping patterns, potential agricultural areas, potential irrigable areas, production costs, crop prices, PET, water stress coefficients, crop coefficients, energy demands	CROPWAT, DJB project survey, July 2017; MAD, 2014; MRSMP 2015a, b; Project-specific documentation; WECS, 2005
Municipal module	Energy and water demands, population, surface water reliance	DJB project survey, July 2017; Nepal census, 2011; WB, 2014; WHO, 2005
Environmental module	E-flow requirements	MWR, 2001; Western Nepal Environmental Flow Calculator

Study one

This study used three main data sources, as summarized in **Table 7-1**. First, we reviewed policy documents. These included central government planning documents such as river basin and sector master plans, natural resource policy documents, and project-specific studies and local planning documents—specifically, 62 Water User Master Plan reports (WUMPS). Second, we held four stakeholder meetings—one large meeting with approximately 50 attendees representing national and local institutional levels and a variety of water-related sectors and three meetings with 10-15 stakeholders (each) which were focused on national and local level planning. Third, we used data from the DJB basin-wide survey of 3660 households to incorporate visions from basin inhabitants.

Study two

This study relied on data from the DJB basin-wide survey of 3660 households. We utilized the data related to contingent valuation, household demographic, community involvement, and information on natural resource reliance for this analysis as summarized in **Table 7-1**.

Study three

This study used a variety of data to parametrize the HEM and establish appropriate development scenarios and sensitivity analyses, as summarized in **Table 7-1**. For the hydrology module, we used hydrology inputs generated for the Karnali and Mahakali River basins for the 12-year period covering 1996-2007. This model is described in Pandey et al. (2019, 2020a, 2020b). In addition, we generated institutional water constraints based on the Mahakali River Treaty and referenced project-specific document (when available) related to reservoir parameters including area, height, volume, and operating capacities. For the energy module, we based domestic and export prices based on tariff structures explained in NEA (2016) and PHD (2013). The Nepal Electricity Authority annual reports also provided data related to production costs, generation efficiency, and transmission costs. We used GIS to generate distances between energy site locations and the energy markets established in our model. Finally, we used data from planning documents and project licenses to establish projected energy site locations and capacities. For the agricultural module, we used information from water policies and planning documents from the Ministry of Agriculture and Water and Energy Commission Secretariat to parameterize irrigation efficiency, return flows, potential yields, agricultural areas, crop prices, and production costs (MAD, 2014; MRSMP, 2015a, b; WECS, 2005). We also used FAO tools (CROPWAT and CLIMWAT) to generate water stress and crop coefficients. Finally, the DJB survey data were used to parameterize energy demands in agriculture and cropping patters. For the municipal model, we used projected energy demands from the World Bank (WB, 2014) and water demands from the World Health Organization (WHO, 2005). We also used population data from the 2011 census and data on surface water demands throughout the basin from the DJB basin-wide survey. Finally, for the environmental module, we implemented two e-flow constraints. First, we utilized a 10 percent e-flow constraint as specified in (MWR, 2001). Second, we utilized e-flows for slightly-modified rivers as calculated by the Western Nepal Environmental Flows calculator.

7.3. Results and Discussion

While the studies described above all examine various aspects of future development pathways for Western Nepal, we provide a summary of the results and discussion of each study separately.

7.3.1. Development visions and priorities

Three specific visions emerged, differing in governance, priority sectors and interests, and implications for trade and the growth of industry. They are;

- State-led development: cohesive infrastructure investment
- Demand-driven development: local management
- Preservation of ecosystem integrity

7.3.1.1. State-led development:

Cohesive infrastructure investment makes large-scale infrastructure its main focus and implies export of excess energy and agricultural products. Local management is primarily aimed at satisfying local consumption and production needs. Finally, preservation of ecosystem integrity values environmental conservation and preservation of vulnerable and unique ecosystems. Cohesive infrastructure investment rests on a premise of state-led development with streamlined planning and consistent implementation across potentially disparate regions. This vision, which incorporates large-scale infrastructure development, was imagined by several national-level and sector-focused stakeholder groups and is consistent with priorities found in national planning documents. Small localities lack the resources for implementation of this vision, corroborating its state-led character. While large hydropower and irrigation projects are among this strategy's priorities, the holistic vision includes investment in complementary transportation and communication systems to improve rural market access, and in health and education.

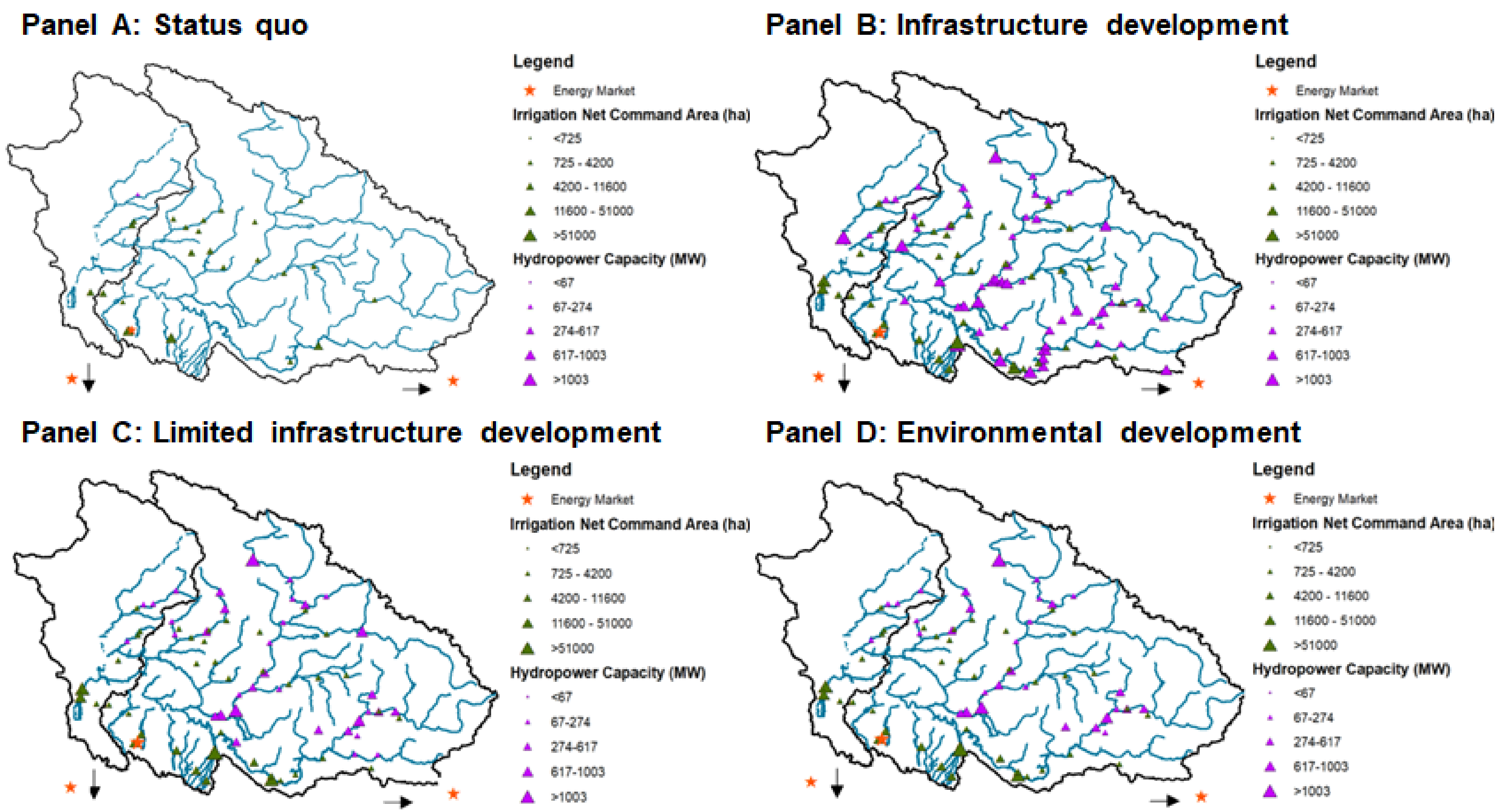

***Figure 7-2**: Maps of scenarios modelled in HEM depicting infrastructure development. Panel A shows the status quo scenario, and thus incorporates the hydropower projects and irrigation demands existing in the basin at the time of modelling. Panel B depicts the infrastructure development scenario, and includes all licensed hydropower projects proposed in the region plus all extensions and proposals for irrigation infrastructure. Panel C show limited infrastructure development, and includes only run of the river licensed hydropower projects plus all extensions and proposals for irrigation infrastructure. Finally, Panel D depicts the environmental development scenario, and thus largely matches the limited infrastructure development scenario (panel C) but with projects in sensitive river stretches omitted. Energy markets in all cases are in the Far Western Region, in India, and in Kathmandu.*

7.3.1.2. Demand-driven development

An alternative to the state-led vision is a local approach geared to demand-driven development. This vision was also developed by some stakeholder groups and corroborated by priorities identified in the WUMPs and the basin-wide survey. It identifies numerous challenges with large-scale infrastructure—high fixed costs, environmental degradation and destruction of unique ecosystems, and dependence on export agreements—and prioritizes water access for municipalities, small-scale hydro and farmer managed irrigation. As with the first vision, this alternative development paradigm emphasizes access to education and healthcare.

7.3.1.3. Preservation of ecosystem integrity

An environmentally minded vision of development surfaces as a third type of pathway. While conservation plays a role in the development visions outlined above insofar as environmental quality is incorporated into infrastructure planning, this vision considers it paramount. Stakeholders involved in tourism and representing national parks and conservation interests placed dual emphasis on environmental conservation and development, arguing that maintaining natural assets in Western Nepal is essential to sustainability. Water Use Master Plan (WUMP) reports and basin inhabitants similarly cited the importance of environmental conservation and relies on preserving ecological wealth.

Understanding the visions for development of Western Nepal from the perspectives of stakeholders and basin inhabitants is a necessary first step towards sustainable planning. Voices from the basins provide the local knowledge required to develop feasible and actionable plans, while sectorally and institutionally diverse stakeholders identify the tension between priorities and trade-offs for water resources use and management. Bringing together these different voices reveals there is no singular, cohesive vision of development and water resource management for Western Nepal; rather, three visions provide a more comprehensive representation of potential development pathways, with the region’s development trajectory likely lying somewhere in the intersection. That is, while cohesive infrastructure development may prioritize the built environment; local management, the strengthening of local institutions; and preservation of ecosystem integrity, the opportunities of conservation and eco-tourism, there are unifying threads across these visions.

7.3.2. Valuing environmental costs of local development

A key output of the valuation study is an estimate of the value of land conservation (as an alternative to its development). We estimated a lower bound on monthly Willingness to Pay (WTP) of 165 NRs (US$1.60) and an average monthly WTP of 202 NRs (US$1.96) per household for environmental conservation. Across the basins, these WTP values correspond to about 1% of households’ monthly income. Given the limited resources of many of the inhabitants of the Karnali and Mahakali River Basins, 1% of monthly income suggests a relatively high prioritization of environmental conservation, which should not be ignored as tradeoffs with land development for various purposes are used. We observed some variation in WTP estimates when dividing the sample by river basin. Valuation for environmental quality is highest in the Mohana River Basin and lowest in the Mahakali River Basin, regardless of the estimation method used. There was also variation in the WTP estimates across the Terai, hills, and mountain zones, as depicted in **Figure 7-3**. Respondents in the mountain regions had the highest monthly WTP for environmental conservation, and respondents in the mid-hills had the lowest. While these results do demonstrate some variation in monthly WTP for environmental conservation based on location and terrain, they also reveal a consistently positive valuation for environmental quality among this representative sample of respondents.

While providing insight into conservation priorities in the Karnali and Mahakali River Basins, it should be noted that the valuation exercise indicated that value is conditional on the mobilization of a community-wide conservation effort. Thus, considering the community-level WTP for environmental conservation is informative regarding the scale of conservation that may be feasible in the region. While 30 households from each of the 122 VDCs visited were included in the sample, VDCs vary considerably in both area and population; the smallest VDC has only 124 households, whereas the largest has over 34,000. Thus, comparisons of VDC-aggregated monthly WTP for environmental conservation will be skewed based on population size and demonstrate substantial variation. Nevertheless, we find that the median VDC-aggregated WTP for environmental conservation is 32,707 NRs per month (US$318). Of course, the natural land area available for conservation programs also varies by VDC; however, we can think of these aggregated values as the additional income that development would have to generate to fully compensate for loss of these preserved lands. In reality, it is also worth noting that VDCs with greater population may face larger challenges in averting development, as collective action for land conservation becomes harder to maintain in larger and more heterogeneous groups.

Figure 7-3: *WTP for land conservation in Western Nepal. Values calculated using double-bounded MLE parametric approach.*

In addition to locational heterogeneity in WTP among respondents throughout the Karnali and Mahakali River Basins, household characteristics were found to be related to WTP for land conservation. Households with at least one migrant household member demonstrated a lower probability of WTP for land conservation programs. This could indicate that such households are more mobile or view migrant family members as a source of income outside of the community and are thus less dependent on natural resources as a form of insurance or less willing to invest in their community. We also found a positive, statistically significant relationship between the amount of land owned by a household and WTP for environmental conservation. Households owning higher amounts of land in a village may exhibit higher WTP because they are more invested in the village and its resources, or because conservation for them delivers more substantial private benefits. Alternatively, these households may have higher wealth, and environmental quality may be a normal good. Similarly, we find a positive, significant relationship between household WTP for environmental conservation and experienced negative environmental shocks. This positive correlation could be indicative of a better understanding among these households of the relationship between environmental degradation and development of natural lands and incidence of environmental shocks (ex., landslides or erosion resulting from road building or deforestation).

We also considered relationships between household WTP for environmental conservation and various measures of community participation. There was a positive and statistically significant relationship between a household's membership in community groups not related to natural resource use or conservation and WTP as well as between stated participation in community collective action and WTP. These relationships provide suggestive evidence that households that participate more in community activities also place a higher value on land conservation. As the benefits of such a program would be shared by the community, these relationships demonstrate consistency between reported behaviours and stated responses to the contingent valuation (CV) questionnaire. We found a negative, statistically significant relationship between WTP and familiarity with local NGOs, which may reflect a lack of confidence in NGO-implemented conservation programs or a belief that existing NGO conservation programs already provide the necessary protection in their communities.

From a policy perspective, the prioritization of environmental conservation over other development opportunities among respondents suggests that environmental concerns should continue to be an important factor in development planning in Western Nepal. Households rely on natural resources for household consumption and to maintain agricultural productivity and income, as well as for preserving ecosystem balance and reducing the instance and severity of hazards such as landslides. Infrastructure building and other development initiatives must take into account their potential environmental costs, if such livelihoods were to be displaced. Informed benefit-cost analysis of such projects would account for the nonmarket values associated with environmental impacts, as well as their distributional implications for local populations.

7.3.3. Evaluating water development pathways

We modelled the status quo scenario along with three development scenarios—infrastructure development, limited infrastructure development, and environmental development—in the WNEWM. A summary of results from the model is provided in **Table 7-2**, which shows the economic benefit from the energy sector, the agriculture sector, and the value of the objective function across the development scenarios modelled and sensitivity analyses.[8] Across the 12-

[8] The objective function reflects the solution to the economic optimization across the energy, agriculture, municipal, and environment sectors as included in the WNEWM. Note that as environmental and

year time horizon (using available hydrology data from 1996-2007), the expansion of Western Nepal's agricultural and energy sectors through irrigation and hydropower infrastructure would yield between 9.1 and 28.4 billion US$, depending on the extent of infrastructure development. Any of the development visions would lead to substantial increases in benefits over those produced with existing infrastructure (status quo scenario), which are just above 1 billion USD over the 12-year period (see **Figure 7-4** "based" model). The upper bound of this range of economic benefits corresponds to the large infrastructure vision, in which all proposed hydropower and irrigation projects would be developed (infrastructure development). Of course, these economic benefits would require establishment of an export energy market between Nepal and India, as the annual electricity generation in the infrastructure development scenario eclipses demand in Western Nepal by a large amount. Unsurprisingly, the economic benefits generated from this high-infrastructure scenario are not distributed evenly across the energy and agricultural sectors: About 80 percent is generated by the energy sector.

Scenarios with more conservative infrastructure approaches (limited infrastructure and environmental development) provide lower economic benefits, yet each generate over 9 billion US$ in productive benefits over the 12-year period. The decreased economic benefit in these scenarios is driven entirely by the energy sector, with these scenarios generating only 15-17 percent of the electricity that would be generated under the high-infrastructure storage-backed hydropower scenario modelled in scenario 2. The distribution of economic benefits across sectors is thus more evenly distributed, with just over 40 percent of monetized benefits coming from the energy sector and the rest of the benefits originating in the agricultural sector.

***Table 7.2**: Summary of WNEWM economic output*

	Status quo	Infrastructure development	Limited infrastructure development	Environmental development
Panel A. Base model				
Energy sector (billion US$)	0.03	22.9	3.88	3.63
Agriculture sector (billion US$)	1.05	5.5	5.51	5.51
Objective function (billion US$)	1.08	28.4	9.39	9.14
Panel B. E-flows sensitivity analysis				
Energy sector (billion US$)	0.03	22.9	3.88	3.63
Agriculture sector (billion US$)	1.00	5.1	4.94	4.94
Objective function (billion US$)	1.03	28.0	8.82	8.57
Panel C. Institutional sensitivity analysis				
Energy sector (billion US$)	0.03	23.10	3.88	3.63
Agriculture sector (billion US$)	1.05	3.27	3.27	3.27
Objective function (billion US$)	1.08	26.37	7.15	6.90
Panel D. Energy demand sensitivity analysis				
Energy sector (billion US$)	0.03	22.60	3.69	3.44
Agriculture sector (billion US$)	1.05	5.51	5.51	5.51
Objective function (billion US$)	1.08	28.11	9.20	8.95

Notes: Author's calculations. Values reported are results from the GAMS model solved for optimal solutions using the CONOPT solver. For the infrastructure development scenario, the objective function is quite flat near the optimal solution, suggesting there are many near optimal solutions when a large number of projects is used in the model.

municipal water demands were modeled as constraints, the objective function captures benefits generated in energy and agriculture.

Sensitivity analyses revealed that more stringent Environmental Flows (E-Flows) constraints and limits to water diversion for use in Nepal would entail economic trade-offs. With more stringent E-Flows, overall economic benefits decline between 2 and 6 percent, with the greatest declines coming in scenarios with moderate development and limited water storage (see **Figure 7-4** "e-flows" model). The majority of these declines come from reductions in agricultural output—due to reduced water availability for irrigation—though there are minimal reductions in energy generation as well. A second sensitivity analysis limited water withdrawals for both basins in Nepal in accordance with those implied in the Mahakali River Treaty. We found that these constrained withdrawals led to a reduction in productive benefits by 7 to 24 percent, with the largest losses among scenarios that did not include water storage (see **Figure 7-4** "institutional" model). The cost of the trade-off between water use in Nepal and water flowing downstream is entirely borne by the agricultural sector, where agricultural output is reduced by 45 percent, while the energy sector bears no burden. The third sensitivity analysis applied different assumptions regarding future energy demand in Western Nepal compared to the base model. Here, we assumed that future demand would remain consistent with current demand at current prices and beyond current energy demand, the value of energy in the region would decrease linearly to zero. In this scenario, export markets became more lucrative given these changing prices, leading to a different distribution of energy to local and export markets. Overall, this lower local demand scenario reduced energy generation benefits by 2 to 3 percent (see **Figure 7-4** "energy demand" model). The agricultural sector remained unaffected by these changes in energy demand and pricing.

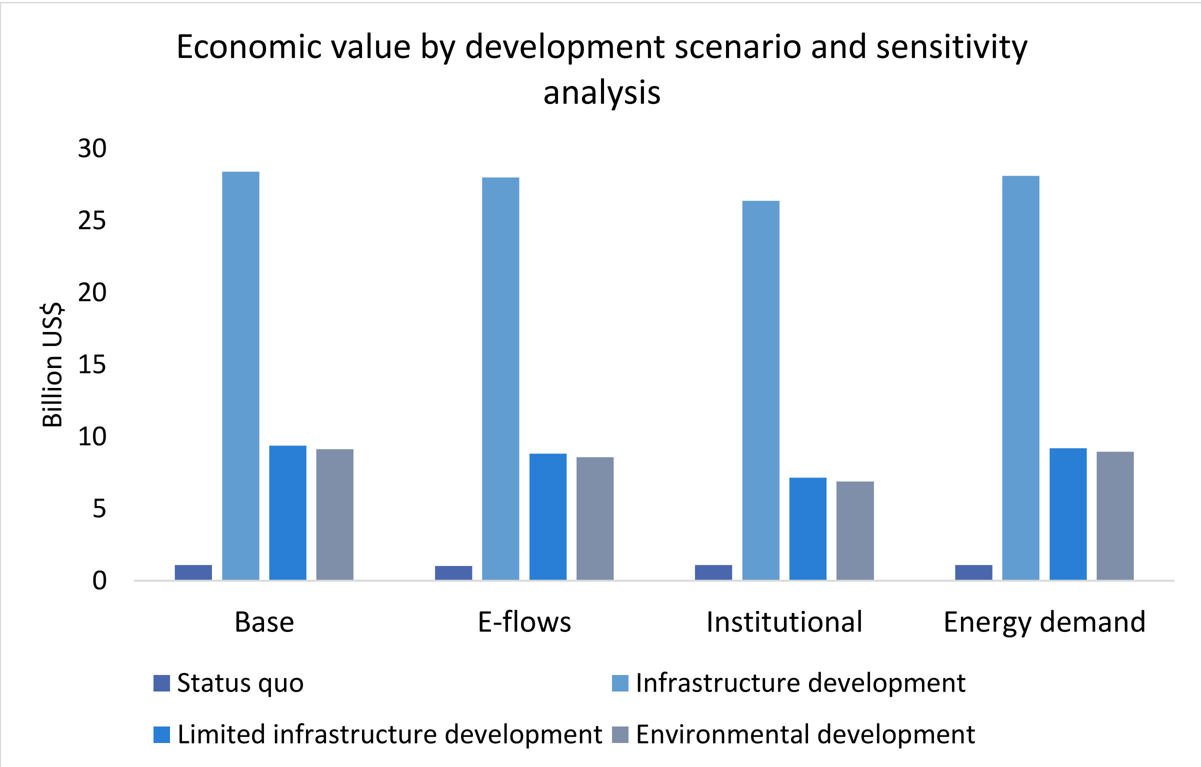

***Figure 7-4**: Total economic value (including value from energy generation and agricultural production) of each development scenario. Base refers to the main analysis; e-flows, institutional, and energy demand refer to the economic values from sensitivity analyses.*

7.4. Conclusions

Water resources in Western Nepal provide the basis for many development pathways, yet prioritization amongst competing water demands poses challenges for policy makers interested in fostering economic development in the region. We examined future development pathways in Nepal using a three-study approach in which we synthesized existing materials, generated and analysed new data, and developed a hydro economic model. Our first study identified development and sectoral priorities for water management and created a framework of development pathways for Western Nepal. These visions included state-led development, demand-driven development, and preservation of ecosystem integrity. Not only did this study provide a comprehensive overview of water resources management and visions of regional development from a variety of data sources and perspectives, it also established the visions framework that guided our subsequent work. Convergences across these visions suggest that a mixture of infrastructure development and environmental conservation would provide a viable pathway; however, divergences between them suggest that even within such a framework, difficult choices between productive uses and between infrastructure and land preservation will have to be made.

Study two contributes to the overall goal of characterizing future development by providing estimates of environmental quality valuation in Western Nepal. As the visioning process made clear that environmental concerns were top priorities among certain sectoral interests and the WUMP reports demonstrated the reliance of local communities on their natural surroundings, we wanted to include these local environmental concerns in our framework for investigating future development pathways. The results from this study demonstrates that even among the resource-constrained inhabitants of the Karnali and Mahakali River Basins, there is significant demand for environmental conservation, demonstrating, once again, the importance of including environmental costs in any trade-off analysis.

Study three built on studies one and two as well as the HEM framework working paper to model optimal water distribution throughout the river basins under several development scenarios. Specifically, it demonstrated how water resources could be used to meet demands in energy, agricultural, municipal, and environmental sectors. We found evidence of trade-offs between the most infrastructure-intensive development scenarios and environmental quality and between agricultural production and stringent, institutional withdrawal constraints. Furthermore, the framework established for the WNEWM was flexible enough to be expanded to incorporate groundwater or consider different development scenarios if they became relevant options for policy makers.

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7.6. Annexes

Annex – 7.1: Pakhtigian E.L., Jeuland M., Dhaubnjar S., Pandey V.P. (2019). Balancing intersectoral demand in basin-scale planning: The case of Nepal's western river basins. Water Resources Economics. In Press. https://doi.org/10.1016/j.wre.2019.100152

Annex – 7.2: Pakhtigian, E. L., Jeuland, M., Bharati, L., & Pandey, V. P. (2019). The role of hydropower in visions of water resources development for rivers of Western Nepal. *International Journal of Water Resources Development*, 1-28. (https://www.tandfonline.com/doi/abs/10.1080/07900627.2019.1600474?journalCode=cijw20)

Annex – 7.3: Pakhtigian, E. L., & Jeuland, M. (2019). Valuing the Environmental Costs of Local Development: Evidence from Households in Western Nepal. *Ecological Economics*, *158*, 158-167. (https://www.sciencedirect.com/science/article/pii/S0921800918308085)

Annex – 7.4: Sood, A., Pakhtigian, E.L., Bekchanov, M. & Jeuland, M. (2019). Hydro-economic Modeling Framework to Address Water-Energy-Environment-Food Nexus Questions at the River Basin Scale.

8. Conclusions

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The United Nations Sustainable Development Goals (SDGs) are pushing for more holistic and integrated planning. The main goal is to promote human dignity and prosperity while safeguarding the Earth's vital biophysical processes and ecosystem services. The SDGs recognize that ending poverty and inequality must go hand-in-hand with strategies that support sustainable economic growth, peace and justice; address fundamental social needs, including education, health, social protection and job opportunities; and achieving these while also tackling climate change and enhancing environmental protection. Water management will play an important role in implementing the SDGs as water cuts across many of the goals and targets. Therefore, water resources development should ideally *balance* multiple sectoral demands, achieve various societal objectives and be *robust* under a wide range of plausible futures. However, there are many challenges for holistic water resources planning in Nepal. There is a lack of data and comprehensive analysis of water resources at basin/country levels integrating multiple sectors. Water resources development and planning is sectoral and fragmented, and current governance structures and processes do not facilitate reaching a shared vision to develop a basin/country. In addition, there is a lack of clarity on the direction and magnitude of future changes, and risks including environmental, societal and economic. The research conducted by the IWMI-led DJB project over the last 3 years has aimed to address these challenges, and is striving to achieve robust and balanced water resources development in Western Nepal.

Achievement of very divergent societal objectives such as economic growth, social justice and maintenance of healthy ecosystems will not always be possible. Trade-offs will need to be considered and compromises made. Currently, the shift in focus from productivity focused growth to also considering equity, social justice, environmental health and sustainability has brought development discourses at the crossroads. New targets and indicators are changing the ways success is measured. As we move into a world where water for individual sectors, such as health and sanitation, is managed in isolation from water for irrigation, hydropower, municipal supply and ecosystems, it would be more effective to integrate water management equitably across multiple demands and uses. Therefore, the boundaries of water management continue to expand and stretch beyond the river basin boundaries and even the water realm. In this context, polycentric governance approaches, in which multiple governing bodies interact to create and enforce rules within a specific policy arena or location, could be one of the best ways to achieve collective action in the face of disturbance and change.

There is an urgent need to address water resources development and management plans in Western Nepal, a region that has much potential for economic development but is highly vulnerable to climate change impacts. It is also rich in natural resources, with many biodiversity hotspots and much scope for ecotourism. The DJB project, funded by USAID, sought to promote sustainable water resources development in the region by conducting multidisciplinary studies with numerous stakeholders, and by producing knowledge and tools aimed at helping decision-makers develop policies and plans that balance economic growth, social justice and healthy ecosystems. IWMI, along with Duke University, Kathmandu University, and the Nepal Water Conservation Foundation, worked in three river basins in the Karnali and Sudurpaschim provinces of Nepal – the Karnali, Mohana and the Mahakali. The following sections highlight the tools developed and the key lessons learned by the project.

8.1. Tools for Decision-makers and Implementers

- Hydrological models to assess temporal and spatial water balances and availability in the Mahakali, Karnali and Mohana basins.
    - The models have already been used to assess water availability in the National Irrigation Master Plan developed by the Department of Water Resources and Irrigation and the Government of Nepal.
    - These models will be accessible through the IWMI water data portal and can be used for basin-wide and project-specific planning (http://waterdata.iwmi.org/).
- Eighteen Climate Future (CF) matrices for Western Nepal.
    - Projections from 19 Regional Climate Models (RCMs) have been visualized into CF matrices for three regions (mountains, hills, Tarai), two global Representative Concentration Pathways (RCPs 4.5 and 8.5) and three 25-year future time frames. The CF matrices can be used to prepare a tailored ensemble of climate projections to fit the need to any impact assessment.
    - Ten bias-corrected future climate scenario projections have been prepared. These can be directly applied to relevant climate impact assessment studies in the region.
    - The projected climate data and scenarios will be accessible via the IWMI water data portal (http://waterdata.iwmi.org/).
- Environmental flows (E-Flows calculator for Western Nepal.
    - This software package simulates E-Flows requirements in the Karnali-Mohana River Basin at 157 locations, using both holistic as well as hydrological methods.
    - E-Flows can be used in environmental impact assessments and water infrastructure planning to define the quantity and timing of water flows required to sustain river biodiversity, ecosystem services and livelihoods.
    - The E-Flows calculator can be customized to generate E-Flows requirements at rivers outside of the study basins.
    - The E-Flows values from the calculator will be incorporated in the National Irrigation Master Plan developed by the Department of Water Resources and Irrigation and the Government of Nepal.
- Hydro-economic Model (HEM) to explore multiple scenarios for basin development.
    - Modelling examined the environmental, social, and economic benefits and trade-offs resulting from different pathways for water resources development.
    - HEM can be modified to simulate and analyze additional scenarios to inform local- or basin-level water resources development.
- Biophysical, socioeconomic and livelihoods database for Western Nepal.
    - Rich dataset can be utilized for planning purposes (http://waterdata.iwmi.org/).

8.2. Key Lessons Learned

Biophysical assessment

- The basin's diverse agro-ecological zones (i.e., Trans-Himalayan zone, mountains, hills and Tarai) have different biophysical characteristics. Precipitation, for example, ranges from less than 500 mm in the Trans-Himalayas to over 2,000 mm in the mountain and hill regions.
- Similarly, net water yield ranges from less than 400 mm in the Trans-Himalayas to more than 1,000 mm in the mountains and hills.
- Despite spatial and temporal heterogeneity and variability, the Karnali, Mohana and Mahakali basins have high water availability and high potential for water resources development.

Preparing for the future climate

- Use of location- and application-specific climate projections in any climate change planning is necessary as projections vary spatially across Western Nepal and local values are higher than projections for South Asia.
- Average temperatures and rainfall variability will both increase with climate change.
- Prolonged monsoon rains and sporadic rainfall events in the drier months are projected. These changes and associated uncertainty should be incorporated into strategies and future plans for disaster risk reduction, infrastructure development and livelihood improvement.
- Current dependency of agriculture on rainfall should be reduced given the projections for increased variability and uncertainty in rainfall. Interventions should emphasize on integrated measures to increase natural and artificial recharge, and storage of water.

Institutions and policy

- In the context of federalism, river basin planning would serve not only as a platform to coordinate cross-sectoral development activities, but also as an institutional mechanism to prevent and resolve conflicts between different key stakeholders across scales. In the past, river basin planning processes involved mainly sectoral ministries and relevant government agencies at national level, with some involvement of local authorities within particular basins. Therefore, at present, river basin planning processes need to be fine-tuned with ongoing processes of federalism.
- Conceptually, this requires the incorporation of a bottom-up approach in river basin planning processes to ensure the defined plan represents local communities' diverse development needs and aspirations. While formulating the Water Resources Policy, WECS has initiated this process through a series of consultations with local governing bodies in various basins.
- In practical terms, this bottom-up approach would work effectively when supported by systematic capacity building programs targeting the newly elected local governing bodies,

while ensuring that they incorporate water resources management as an important cross-sectoral theme in their mandates.

- Research linking politicians and bureaucrats in the water governance diagnostic shows that political competitions centered on power interplay between the major political parties drive the overall performance of administrative government. Therefore, ensuring that national development planning processes (or the lack thereof) follow the defined political agendas, neither incorporating the country's long-term development vision nor coinciding with local community's and the wider society's development needs and aspirations.
- Hence, the country's scattered, inconsistent national development plan as well as its overlapping and disjointed development activities should not be viewed as an indication of severe lack of governance. On the contrary, it resembles how governance structures, processes, and outcomes are produced and reproduced through power relations and power interplay.

Gender equality and social inclusion

- Revamp organizational policies, structures and culture by allocating adequate resources and incentives towards GESI goals, and institutionalizing values that promote positive masculinities of empathy and respect within organizations.
- Create more opportunities for women to play technical and non-technical roles in organizations and projects; rural women will feel more comfortable to create social relations with female staff members, thereby extending their social network beyond their community.
- Introduce incentives for organizations and projects to take into account in their planning, implementation and monitoring how intra-household and intracommunity social relations shape access to water along gender, class, caste and age lines, and to conduct affirmative actions with the aim of diminishing the influence of these factors.
- Address intra-household gender relations through group methods (e.g., creating safe spaces to discuss local gender and social norms). Without this support, a young married woman with a migrant husband and young children will find it difficult to take part in decision-making, even if she is literate and entirely capable of contributing to local water governance.
- Design policies and activities that enhance collective action in rural communities, based on increased trust and social well-being.

Water sources and access

- Pilots in Mellekh, Doti and Kunebata aimed to improve dry-season irrigation through formation of collectives, rehabilitation of ponds, gender training, and provision of solar pumps and piping.
- The analysis suggested that ensuring access to sustainable water resources for rural communities also requires mitigating and preventing land degradation, as the biophysical processes driving water resources are connected to land use practices
- Recognizing the multi-functionality of agricultural land and managing agriculture as part of the larger landscape are recommended.

- Farmers can increase water productivity and profitability by adopting proven agronomic and water management practices such as collective approaches (in the case of marginal and tenant farmers); and where possible, integrated and multiple use of water (e.g., for crops, fish, livestock and domestic purposes).
- As Western Nepal is still very behind in terms of agricultural practices, technological interventions, capacity building, market linkages, and regular engagement and monitoring are likely to bring positive and long-lasting transformations, including up-scaling and out-scaling.

Environmental flows (E-Flows) assessment

- There is an urgent need to incorporate E-Flows in the development and management of hydropower and irrigation infrastructure to sustain river biodiversity, ecosystem services and livelihoods.
- The E-Flows requirement should mimic the natural flow of the river, including both high and low flows.
- The E-Flows calculator for Western Nepal, developed in the project, can be applied to generate E-Flows values for any river stretch.
- Based on estimates at 111 locations using the Hydrological Method, it was observed that, in general, it is necessary to maintain E-Flows of approximately 70% of Mean Annual Runoff (MAR) to maintain a river segment in Class A condition, while it is necessary to maintain E-Flows of approximately 30% of MAR to maintain a river segment in Class C condition.
- Results from the holistic E-Flows method show that maintaining E-Flows of 70% of MAR or above would leave the river in a Class A condition, while maintaining E-Flows of at least 25% of MAR would leave the river in a Class D condition, which is not acceptable to maintain river health.

Future pathways: Trade-offs and synergies

- Water resources in the study area can be used to meet the demands in the energy, agriculture, municipal and environmental sectors.
- The trade-off between hydropower and irrigation is limited, because storage improves year-round water availability for agricultural production.
- Large-scale plants generate more power and revenue than small plants designed for domestic demand and rural electrification, but there is a trade-off between exporting energy to India versus using water for irrigation in the Tarai.
- Trade-offs exist between large infrastructure projects and E-flow releases.