Gandaki Province Government

Gandaki Province Policy and Planning Commission

Pokhara, Nepal

The Study on Status of Water Resources and Future Strategy of Gandaki Province

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EXECUTIVE SUMMARY

The "Study on Status of Water Resources and Future Strategy of Gandaki Province" is an extensive assessment undertaken by Nature Consult Nepal, commissioned by the Gandaki Province Government. The report aims to evaluate the current state of water resources in Gandaki Province, identify existing challenges and opportunities, and propose strategic measures for sustainable water management to ensure long-term water security and socio-economic development.

Methodology

We performed a comprehensive literature review, robust data collection, stakeholder engagement, and detailed analysis of current water management practices. These steps are elaborated as below.

- **Desk Study**: Reviewed existing literature, reports, and national strategies to understand current water demands and historical data.
- **Data Collection**: This study mainly depends on secondary data sources. We gathered secondary data from government reports and databases. Key data sources included government agencies, hydrological and meteorological records, and remote sensing and GIS data for mapping and trend analysis.
- **Stakeholder Discussions**: Engaged with government agencies, NGOs, local communities, and private sector entities to identify water management challenges and issues, and to review the effectiveness of past strategies.
- **Analysis of Current Practices**: Examined water management practices across agriculture, hydroelectricity, domestic consumption, and industry to understand water allocation and demand patterns.
- **Assessment of Water Resources**: Evaluated water availability considering population growth, climate change, and demand. Assessed potential climate change impacts on water resources, focusing on temperature and precipitation changes.

Key findings

Water availability and uses

Gandaki Province is characterized by its diverse geography, ranging from lowland plains to high mountain areas, and hosts several significant river basins including the Gandaki (Narayani), Trishuli, Marsyangdi, Daraudi, Madi, Seti, and Kaligandaki rivers. This geographical diversity leads to a wide range of climatic conditions from sub-tropical in lower regions to alpine in higher elevations, affecting water availability and distribution.

The province faces a significant disparity between water demand and supply. Water resources are primarily used for drinking, irrigation, hydropower generation, sanitation, and industrial purposes, but there is a need for improved management to balance these uses effectively.

Current Water Management Practices

Irrigation: Agriculture, which engages more than 60% of the province's population, is the main consumer of water. More than 90% of irrigation water is sourced from rain-fed rivers. However, current practices are insufficient to meet the increasing demand, especially in the face of erratic rainfall and climate variability.

Hydropower: Gandaki Province holds significant potential for hydropower, with the estimated feasible potential for Nepal being 45,610 MW. However, only a fraction of this potential has been harnessed. The development of hydropower infrastructure needs to consider climate change impacts, which may alter water flow patterns and availability.

Drinking water: As of the latest available data, approximately 91% of households in Gandaki Province have access to drinking water. This figure represents households that rely primarily on piped water sources for their daily water consumption. However, the functionality and reliability of these water supply systems vary, with many requiring rehabilitation, reconstruction, or minor repairs to ensure consistent and safe drinking water.

Challenges and Opportunities

Climate Change Impacts: The province is vulnerable to climate change, which manifests in altered rainfall patterns, increased temperatures, and more frequent extreme weather events such as floods and droughts. These changes threaten water availability, quality, and infrastructure.

Natural Disasters: The steep topography of the region makes it prone to landslides and floods, exacerbated by monsoon rains and glacial melt. These disasters pose risks to water infrastructure and resource management.

Agricultural Dependence: The heavy reliance on agriculture, coupled with traditional irrigation practices and limited technological advancement, challenges efficient water use and increases vulnerability to water shortages during dry seasons.

Hydropower Development: There is a substantial opportunity to expand hydropower generation, which can provide clean energy and support economic growth. However, this requires careful planning to mitigate environmental impacts and ensure sustainable water use.

Policy and Legal Framework

National Policies: The report reviews key national policies and legal frameworks, including the Constitution of Nepal 2015, Water Resources Strategy 2002, National Water Plan 2005, and the Water Resources Act 1992. These frameworks provide a foundation for water resource management but require effective implementation and integration at the provincial level.

Provincial Strategies: Gandaki Province must align its water management strategies with national policies while addressing local needs and conditions. This includes the development of provincial policies that promote Integrated Water Resource Management (IWRM) and climate resilience.

Strategic Recommendations

Integrated Water Resource Management (IWRM): Adopt IWRM approaches to ensure coordinated and sustainable management of water resources across various sectors and regions within the province. This involves enhancing data collection, monitoring, and information sharing among stakeholders.

Infrastructure Development: Invest in infrastructure to improve water storage, distribution, and treatment. This includes constructing dams and reservoirs, upgrading irrigation systems, and expanding water supply networks to meet growing demand.

Climate Resilience: Implement adaptive measures to cope with climate change impacts. Develop early warning systems, promote disaster risk reduction strategies, and ensure that water management plans are flexible to accommodate changing climatic conditions.

Policy Implementation: Strengthen institutional frameworks and coordination between federal, provincial, and local governments to ensure effective implementation of water management policies. Enhance capacity building and provide adequate resources for enforcement.

Public Awareness and Participation: Engage communities in water management practices through awareness campaigns, education programs, and participatory planning processes. Encourage sustainable water use behaviors and involve local stakeholders in decision-making.

Conclusion

Gandaki Province is endowed with substantial water resources, which are crucial for its socio-economic development. However, effective management is imperative to address the challenges posed by climate change, natural disasters, and increasing demand. The proposed strategic actions aim to foster sustainable water resource management, enhance climate resilience, and ensure equitable access to water. By integrating national policies with localized initiatives and engaging communities, Gandaki Province can achieve long-term water security and sustainable development.

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ABBREVIATIONS

ADPC: Asian Disaster Preparedness Center

DHM: Department of Hydrology and Meteorology

EIA: Environmental Impact Assessment

EWS: Early Warning Systems

GCF: Green Climate Fund

GIS: Geographic Information System

GLOF: Glacial Lake Outburst Flood

GoN: Government of Nepal

HI-AWARE: Himalayan Adaptation, Water and Resilience Initiative

ICIMOD: International Centre for Integrated Mountain Development

IMP: Irrigation Master Plan

IWRM: Integrated Water Resource Management

KGA: Kaligandaki 'A'

KK: Khimti Khola

ha: hectare

km: kilometer

kW: Kilowatt

MCM: Million Cubic Meters

M&E: Monitoring and Evaluation

MW: MegaWatt

NAP: National Adaptation Plan

NGO: Non-Governmental Organization

PDMA: Provincial Disaster Management Authority

PPP: Public Private Partnerships

PRA: Participatory Rural Appraisal

PWRC: Provincial Water Resources Council

RBCs: River Basin Committees

TACs: Technical Advisory Committees

WASH: Water, Sanitation and Hygiene

WECS: Water and Energy Commission Secretariat

WUA: Water User Associations

WRS: Water Resources Strategy

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INTRODUCTION

1.1 Background

Nepal has abundant water resources with an average annual rainfall of about 1600 mm. Thus, the availability of water resources can be considered a major factor in enhancing the pace of overall development of the country (WECS, 2011). Although it has been decades since Nepal has been focusing on proper water resource management to meet the people's basic water requirements and promote economic growth, the progress has been very slow. Every citizen of Nepal should have access to sufficient water to fulfill basic requirements like drinking, cooking, and sanitation. The population should benefit from the abundant water resources of Nepal through food and energy production at a reasonable cost (WECS, 2002).

Nepal is rich in water resources, but sustainable management of these resources has always been a matter of concern for governmental agencies working in the water sector. With years passing by Nepal's population is growing which increases the existing water demand and these demands increase the potential for future water conflicts. Changing climate scenarios such as diversity in rainfall patterns, increasing temperature, flash floods, severe droughts, heavy precipitation, and other factors limit the availability of clean water for the population. The amount of water available in Nepal is much higher than the amount used (Agrawala et al., 2003). The water resources are used mainly in drinking, irrigation, hydropower, recreation, sanitation, and industrial use. The medium and small rivers are mostly used for water-related activities and the larger and perineal rivers are usually left untouched.

The steep topography of Nepal contributes to natural disasters like landslides and flooding, which affect water resources. Increased monsoon rainfall, melting glaciers, and snowmelt due to climate change are expected to increase flood risks. On the other hand, droughts are becoming more common, reducing spring outflows and increasing forest fire risks. Surface and groundwater quality are being degraded by catchment destruction, agricultural runoff, and untreated residential and industrial wastewater. Nepal has one of the lowest dam storage capacities in Asia, which affects water storage and distribution, especially during the dry season. There is a lack of national integrated monitoring and coordination for water resource management. The continuation of subsistence agriculture practices and under-utilization of canal water are some of the challenges faced in irrigation development. These factors mainly impact the availability, quality, and management of water resources in Nepal, demanding a comprehensive and integrated approach to water resource management.

Nepal is predominantly an agricultural country and more than 60% of its population is engaged in agriculture as the main occupation. The agriculture sector is the main user of freshwater consumption and more than 90% of the irrigation water supply to the agricultural land is by freshwater mostly fed by medium or small rivers, which almost entirely depend on the rain. Due to extreme weather events like droughts, flooding, erratic rainfall, and others agriculture production is badly affected (WECS, 2011). Agriculture is not only the sector affected due to climate change's impact on water but also hydropower. The estimated hydropower potential of Nepal is 83,000 MW of which 45,610 MW have been identified as economically feasible (WECS, 2011). However, in the context of climate change the hydropower development scenario needs to be revisited in totality. The surface water available in the country is estimated to be about 225 billion m^3 (BCM) per annum out of which only around 15 BCM has been utilized. Around 95.9% of 15 BCM has been used for agriculture, 3.8% for domestic purposes, and only about 0.3% for industry (WECS, 2011). Therefore, effective management, climate resilience, and sustainable practices are needed to attain the potential of these available water resources. The water strategies and suitable plans at the local and provincial levels would be an added benefit for sustainable water resources management of the country.

Nepal went through a transformation from a centralized State to a three-tier federal system with the enactment of the new Constitution of Nepal in 2015. It became a Federal Democratic Republic with 7 Provinces, 77 districts, and 753 local levels. The seven provinces of Nepal are Koshi, Madhesh, Bagmati, Gandaki, Lumbini, Karnali, and Sudurpashchim. In this study, we conducted an assessment of water resources in Gandaki Province. Gandaki Province, located in central Nepal, is rich in water resources due to its diverse geography, including mountains, hills, and valleys. The province is home to several major rivers, including the Gandaki (Narayani) River, which is one of the major tributaries of the Ganges River. The tributaries of Gandaki rivers are Trishuli, Marsyangdi, Daraudi, Madi, Seti, and Kaligandaki, all of which provide crucial water supply for irrigation, industrial and domestic uses, and potential for hydropower generation.

The Gandaki Basin is a significant transboundary basin that stretches north-south in the central Himalayan region (Figure 1). The basin extends from China in the north to Nepal to India in the south originating from the Tibetan Plateau, flowing through central Nepal and draining into the Ganges River in India. The basin experiences a range of climatic conditions, from sub-tropical in the lower regions to alpine in the higher elevations which results in a wide range of hydro-meteorological phenomena.

The mean annual flow of the Gandaki basin is about 1583 m^3/s at Narayanghat, with the basin containing 1,340 glaciers and 116 glacial lakes within Nepal's boundary (CBS, 2019). The basin is vulnerable to water-induced disasters, particularly during the monsoon season. The Upper East Seti and Aandi Khola watersheds of the Gandaki basin are the most sensitive to climate change (Siddiqui et al., 2012). There is also concern about the possibility of the increase of extreme climate-related events such as landslides and floods threatening the livelihoods of people in Nepal's Gandaki River Basin region in the future.

The basin gets most of the annual precipitation (i.e. 78%) during the summer monsoon (Panthi et al., 2015a). Historical precipitation trends do not show any particular pattern. However, studies suggest that an increase in annual precipitation is projected in the Gandaki basin. Past studies based on Coupled Model Inter-comparison Project - Phase 6 (CMIP6) models suggest a 7-32% increase within a few decades (2021-2046) and an 18-45% increase in the far future (2074-2100) (Bajracharya et al., 2021).

The future precipitation is seen to be affected by seasonal variation as well. Precipitation increases during the pre-monsoon and monsoon seasons, and decreases in the post-monsoon and winter seasons. The dry parts and seasons of the basin could become dryer and the wet parts and seasons could become wetter. The study also suggests that although there is an increase in the total amount of monsoon precipitation, the number of rainy days does not increase. This suggests that the wet seasons are likely to face more precipitation-induced disasters such as landslides and floods during monsoon while the dry seasons might face soil moisture deficiency and the potential risk of future droughts (Panthi et al., 2015b). These precipitation trends might therefore have several socio-economic implications in the basin.

There is also an observed increasing trend of temperature at annual and seasonal scales. The cold-related temperature extremes were projected to decrease while warm-related extremes are likely to increase in the Gandaki basin. This projection of warmer summers in the future is likely to accelerate the melting of glaciers and snow, severely impacting the mountain ecosystem, irrigation, and water resource management over the basin (Sigdel et al., 2022).

The snow and glacier melting also play a significant role in terms of water resources and potential hazards. Snow and glacier melt contribute to the seasonal pattern of river flows and provide essential water during periods when rainfall is scarce, which is crucial for agriculture and other uses (Biemans et al., 2019). The Gandaki basin consists of 1,340 glaciers and 116 glacial lakes (Bajracharya & Shrestha, 2011) which suggests that snow and glacier melt play an important role in the Gandaki basin, especially during dry periods when other sources of water are limited.

Projections indicate that with climate change, the patterns of snow and glacier melt in the Narayani Basin will change. Initially, there may have been an increase in river flows due to an increase in snowmelt but as time passes and glaciers continue to melt, by the end of the century the long-term trend is likely to show a decrease in river flows (Lutz et al., 2016). This can lead to significant impacts on water availability for agriculture, hydroelectric power generation, and domestic use. Studies also suggest that high-altitude areas in the Gandaki basin can contribute to river flows through snow and glacier melt but with climate change, the rate of glacial melt is increasing leading to the formation of glacial lakes which pose a risk of Glacial lake outburst floods (GLOFs) (Biemans et al., 2019). These events of GLOFs can have significant effects downstream, affecting lives, infrastructure, and ecosystems. Moreover, changes in the timing and intensity of snow and glacier melt can affect the seasonality of river flows, which can lead to more extreme water-related events such as floods and droughts. Therefore, water balance in glaciers should be assessed properly to evaluate the potential risks of GLOFs and implement early warning systems to mitigate these risks. The role of snow and glacier melt in the Gandaki Basin is a critical factor in water resource management and planning for future climate change adaptation strategies.

The projections suggest a decrease in flow during the dry months of December, January, and February and there could be an increase in flow during the pre-monsoon months of March, April, and May (Sharma et al., 2024). This decrease in flow during pre-monsoon can likely cause a potential risk of future droughts and also hint at an early onset of the monsoon with an increase in flow during pre-monsoon.

Additionally, water resources in Gandaki Province have been facing significant challenges related to managing water, primarily due to climate changes and seasonal variations in rainfall. The province heavily relies on water resources for various essential purposes, making it vital to manage them efficiently. Therefore, it becomes crucial to develop and implement proper water resource strategies to address these issues and ensure sustainable water management.

Agriculture is a primary sector in the province, and a reliable water supply is essential for irrigation to support crop growth and increase agricultural productivity. Proper water management through irrigation facilities can lead to better crop yields, food security, and livelihood improvement for farmers. Furthermore, the province recognizes the potential of hydropower generation to meet national energy demands. By strategically harnessing its rivers' hydroelectric potential, the province can contribute significantly to the country's energy production, reduce dependency on fossil fuels, and promote clean and renewable energy sources. In addition to agricultural and energy needs, access to safe and clean drinking water is critical for the well-being of the province's population. Adequate drinking water supply enhances public health, reduces waterborne diseases, and improves overall living standards.

The industrial sector also relies on water resources to support manufacturing and other production processes. Efficient water management is necessary to balance industrial demands while preserving the natural ecosystem and ensuring water availability for other sectors. Therefore, the hydro-meteorological dynamics of the Gandaki River basin are essential for developing adaptation strategies and sustainable management, particularly in the face of climate change.

1.2 Purpose of the study

The primary goal of this study is to evaluate the existing state of water resources and devise a comprehensive strategy for their future utilization in Gandaki Province. The specific objectives are outlined as follows:

- Conduct an assessment of water resources in Gandaki Province.
- Analyze the current water uses and management practices in the region, including agricultural, industrial, domestic, and hydroelectricity generation.
- Identify and comprehend the prevailing challenges and issues about water resources in Gandaki Province, taking into account factors like climate variability, population growth, and competing demands.
- Formulate well-defined water resources strategies tailored for the region, encompassing sustainable water allocation, conservation, and efficient use practices.

1.3 Scope of the study

1.3.1 Water Resources Assessment

It includes a systematic evaluation of the quantity of water available in Gandaki province. These assessments are essential for understanding and managing water availability, distribution, and usage, especially in the face of increasing population, climate change, and growing demands for water resources.

1.3.2 Current Water Management Practices

Currently, water resources are being utilized across various sectors, including agriculture, hydroelectricity generation, domestic consumption, and industrial applications. To plan effective water use strategies for the future, it is essential to summarize and analyze the current allocation and demands in each sector. Understanding these usage patterns will allow for informed decision-making and sustainable management of water resources going forward.

1.3.3. Water Resources Challenges and Opportunities

Challenges arise from the dynamic interplay of factors such as changing climate patterns, altered rainfall distributions, escalating demands for domestic and irrigation purposes, and the proliferation of hydroelectric plants within river systems. These complexities underscore the critical importance of ensuring proper and effective utilization of our water resources.

1.3.4. Water Resources Strategies

Given the present state of water resource availability and the myriad challenges already faced or potentially looming, it becomes imperative to formulate well-considered strategies for water resource development in Gandaki Province. These strategies should address both immediate concerns and long-term sustainability, enabling us to harness water resources effectively while safeguarding the delicate ecological balance and meeting the needs of current and future generations.

1.4 National Context of Water Resources Planning

The Constitution of Nepal 2015 has established a framework for managing water resources across all three levels of government: federal, provincial, and local. It emphasizes the importance of the multi-dimensional and sustainable development of water resources. The National Water Resources Policy of 2022 further supports this framework by providing a strong foundation for the sustainable development of water resources through national policy. The constitution ensures that every citizen has the right to access clean water and hygiene. This is supported by several national policy frameworks, including the Water Resources Strategy 2002, National Water Plan 2005, and the Water Supply and Sanitation (WASH) Act 2022, among others.

Nepal is rich in water resources and has around 225 BCM of water available annually. Only a small part of this available water is being used for social and economic purposes, which is around 15 BCMM. Thus, to meet the country’s water supply needs and achieve long-term sustainability, the Government of Nepal (GN) through the Water and Energy Commission Secretariat (WECS) started formulating the Water Resources Strategy (WRS) for Nepal in 1996 and approved it in January 2002 (WECS, 2002). The goal defined by the WRS for Nepal is to improve the living standard of Nepalese people by developing and managing of country’s water resources sustainably (WECS, 2002). The specific objectives outlined in WRS are as follows:

1. Help in reducing poverty, unemployment, and under-employment by effectively utilizing water resources.
2. Provide access to safe and adequate drinking water and sanitation, ensuring health security for all citizens.
3. The strategy aims to increase agricultural production, thereby contributing to the nation's food security.
4. The strategy focuses on generating hydropower to satisfy national energy requirements and allow for the export of surplus energy.
5. It aims to supply water to the industrial sector and other segments of the economy.
6. The strategy seeks to facilitate water transport, particularly connecting to a seaport.

7. It aims to protect the environment and sustain the biodiversity of natural habitats.
8. The strategy focuses on measures to prevent and mitigate water-induced disasters.

The WRS aims to balance economic development, environmental conservation, and social well-being through effective management and utilization of available water resources. Following the formulation of the WRS of Nepal, The National Water Plan (NWP) was prepared to operationalize the WRS. The NWP formulated by the Water and Energy Commission Secretariat (WECS) includes social, environmental, and institutional development aspects as critical factors in the policy framework for achieving targeted national goals. It has several key objectives that contribute to the overall development and well-being of the country. These objectives address various aspects related to water resources management. The main objectives are as follows:

1. The NWP aims to contribute to the overall national goals in a balanced manner which includes:
   - Economic Development
   - Poverty Alleviation
   - Food Security
   - Public Health and Safety
   - Decent Standards of Living for the People
2. Integrated water management and use has been adopted as the main theme of NWP. It seeks to ensure equitable development and utilization of water resources while preventing water-related conflicts.
3. By promoting sustainable water resource development, the NWP aims to enhance the pace of overall development in Nepal. It recognizes that sustainable water management can significantly reduce poverty and economic growth (WECS, 2002)

The Department of Water Resources and Irrigation has developed a long-term strategy called the Irrigation Masterplan 2019 with the aim of developing and management of the irrigation sector based on the available resources in the country (ADPC, 2021). The Irrigation Master Plan aims to expand irrigated areas and introduce efficient technologies to support agricultural productivity. The plan emphasizes the development of both surface and groundwater projects, including multipurpose large-scale and small-scale initiatives. It also focuses on decentralizing management to local government or water users’ cooperatives, financial planning, and capacity building at various levels. Through these efforts, the plan aspires to contribute significantly to Nepal’s economic growth, food security, and poverty reduction (Irrigation Master Plan, 2019).

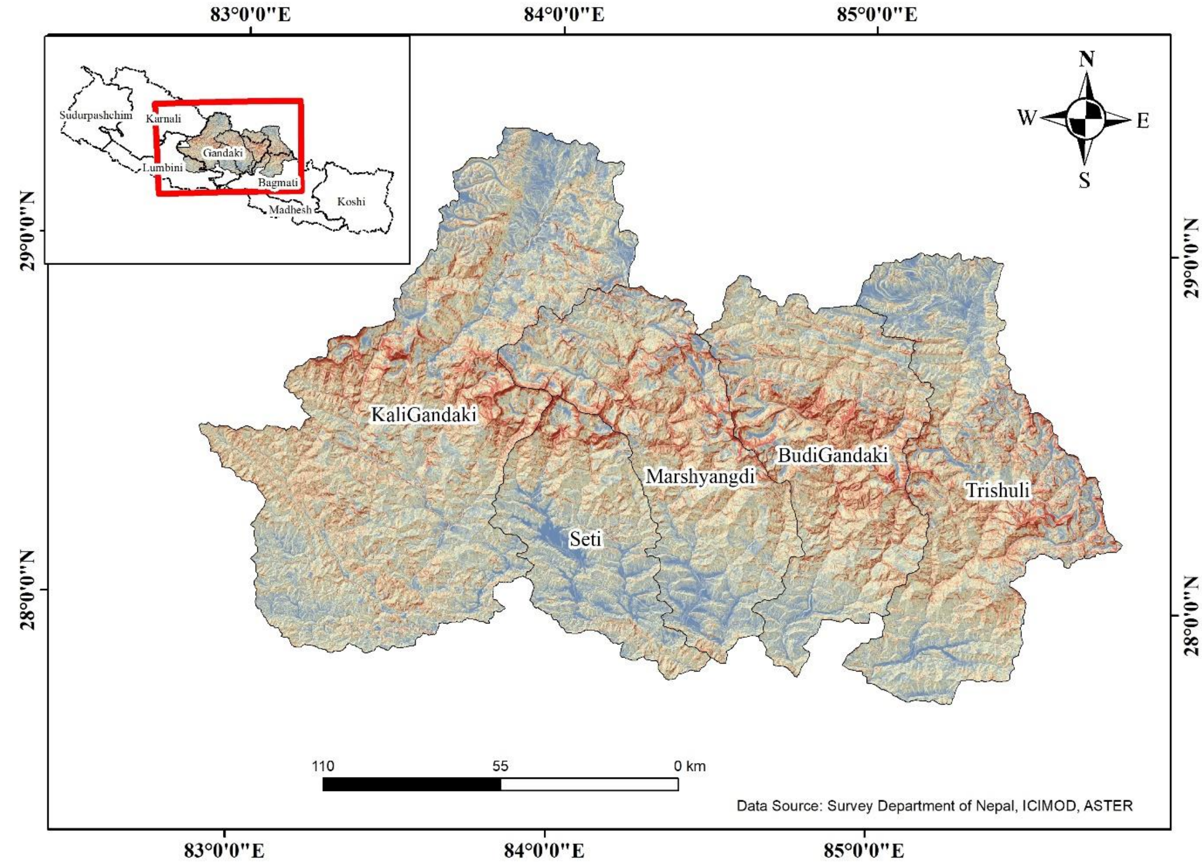


Figure 1: River basins in Gandaki Province.

1.5 Methodology

1.5.1 Desk Study

The desk study for the water management strategy in Gandaki Province involved conducting a comprehensive analysis of existing information, data, and literature related to water resources and management in the region. The goal of the desk study was to gain a thorough understanding of the current water situation and identify potential strategies and solutions for sustainable water management. Here are the key steps to perform a desk study:

Begin by collecting and reviewing all available literature, reports, academic papers, national water resources strategies, irrigation master plans, and documents related to water resources in Gandaki Province. This included studies on hydrology, rainfall patterns, groundwater availability, river flow data, water demand, water quality, and past water management initiatives. Additionally, explores historical data and trends in water availability in Gandaki Province. Study the current water demands in different sectors, such as agriculture, industry, domestic use, and the environment, from the literature. We examined past literature to explore the potential impacts of climate change on water resources in the province, as projected changes in temperature and precipitation patterns can have significant implications for water availability. We identified the key challenges and issues related to water management in Gandaki Province, including water scarcity, pollution, conflicts over water use, and inefficient water use practices. Similarly, explored the effectiveness of past water management strategies and projects in the region to understand their successes, failures, and lessons learned and identify the key stakeholders involved in the province, including government agencies, NGOs, local communities, and private sector entities.

1.5.2. Data collection

We collected accurate and relevant data for the development of an effective water management strategy in Gandaki Province. To ensure comprehensive data coverage, we clearly defined specific data requirements through a combination of desk study and expert consultations. The data encompassed vital aspects such as water availability, water demand, hydrological information, climate data, land use, population statistics, and relevant socio-economic indicators. These data sources included a few primary data gathered through direct surveys and observations and mostly secondary data that will be obtained from existing literature and reports and relevant sources, such as government agencies, research institutions, NGOs, and international organizations. We explored reports, publications, databases, and online portals that contain relevant data on water resources in the province.

- **Government Agencies**: We contacted the relevant government departments responsible for water resources management, such as the Department of Water Resources and the Department of Irrigation. They had data on river flow, water infrastructure, and water use permits.
- **Hydrological and meteorological data:** We obtained this data from secondary sources. This data was essential for understanding water availability and seasonal variations. Additionally, we gathered climate data, including historical and current temperature and precipitation records, to understand the potential impacts of climate change on water resources.
- **Remote Sensing and GIS Data:** We utilized the satellite imagery and GIS data to map land use, vegetation cover, and changes in water bodies over time. Remote sensing can provide valuable insights into the dynamics of water resources in the region.

1.5.3 Stakeholder Discussion

We organized a focus group discussion (FGD) centered on the future strategy of water resources management, providing a valuable platform for gathering insights and ideas from a diverse group of stakeholders. The primary objective of this FGD was to engage key stakeholders in a collaborative dialogue aimed at exploring and defining a comprehensive strategy for the sustainable management of water resources in the future. Stakeholders from various sectors participated, including government representatives, environmental experts, hydrologists, local community leaders, industry professionals, NGOs, researchers, and other concerned authorities/personnel.

The goal of this discussion was to harness the collective expertise and experiences of these diverse stakeholders. By addressing current challenges, establishing clear objectives, and outlining practical strategies, this collaborative effort significantly contributed to the sustainable and efficient management of water resources in the future. The insights gathered played a pivotal role in shaping policies and practices that ensure water security and environmental sustainability for generations to come.

SITUATION ANALYSIS OF GANDAKI PROVINCE'S MAJOR RIVER BASINS

Nepal is the second richest country in water resources in the world and has more than 6000 rivers flowing to the Ganges River system of Indian Subcontinent. All these rivers are categorized into four major river basins namely: Koshi Basin, Narayani (Gandaki) Basin, Karnali Basin, and Mahakali Basin. Among them Koshi is the largest basin with 34960 km^2 catchment area while Gandaki is third largest with 34960 km^2 catchment area. Table 1 illustrates the details information on these basins.

The Koshi river systems are the trans-boundary river system originating from the Tibetan Plateau. It flows through the Mahabharat range and Siwalik hills, reaching the plains of eastern Nepal, and meets the Ganges in India at the end. Based on the elevation and topography, the basin is divided into Trans-Himalayan Zone, High Himalayan zone, Middle Mountains, and Terai zone from north to south with different climates and vegetation. About 45% of the total area (87,970 sq. Km) of Koshi basin lies in Nepal (Shrestha et al., 2017) . Koshi basin is the largest river basin of Nepal and consists of several rivers originating from glaciers and snow-fed lakes. The major tributaries of the Koshi basin include Tamor, Arun, Dudhkoshi, Likhu, Tamakoshi, Sunkoshi, and Indravati. These seven tributaries meet at Triveni from where it is called Sapta-koshi. The Koshi basin comprises of 845 glaciers and 599 glacial lakes(CBS, 2019) . This basin receives high rainfall due to which it is prone to hazards like glacial lake outburst flood (GLOF), soil erosion, floods, landslides and others.

Table 1: Major River Basins of Nepal (Source: WECS, 2002)

River Basin	**Catchment area (sq. km.) (Both India and Nepal)**	**Source of streamflow**
Koshi	60400	Monsoon and snowmelt
Karnali	43679	Monsoon and snowmelt
Gandaki	34960	Monsoon and snowmelt
Mahakali	15620	Monsoon and snowmelt

The Karnali basin is another significant river system in Nepal. It originates from glaciers and snow-fed lakes and flows through the western part of the country. The Karnali basin is divided into the

High Himalayas, Middle Mountains and Hills, Siwalik Hills (Churia Range) and Terai Region from north to south with different climates and vegetation. Karnali river which is the longest river with a length of 507 m flowing through Nepal along with some other snow-fed rivers constitutes the Karnali basin. The main tributaries of this basin are West Seti River, Bheri River, Humla Karnali, Mugu Karnali, Kawari River and Tila River. More 90% of the total area of Karnali basin lies in Nepal (Panthi et al., 2019). The Karnali basin has 1459 glaciers and 742 glacial lakes (CBS, 2019). 80% of the total precipitation of Karnali basin is received during summer monsoon however the region faces winter drought most frequently. This region receives an annual average precipitation of about 1479 mm (Khatiwada et al., 2016). Upper Karnali watershed, Mugu Karnali watershed, and Budi Ganga watershed are the most vulnerable watersheds to climate change and are at higher risks from hazards like landslides, floods, droughts, food insecurity, and others (Siddiqui et al., 2012). Therefore, the Karnali river basin is the most vulnerable basin to climate change in Nepal.

The Mahakali River Basin, also known as the Sharda River Basin in India, is a significant trans-boundary river system shared between Nepal and India. It lies in the westernmost part of Nepal and Most of the catchment area lies in India and only 35.4% falls in Nepal side. The basin is divided into three zones High Himalayas, Siwalik and Terai Region from north to south. The Chamelia and Surnagad rivers are the main tributaries of the Mahakali basin on the Nepal side. Other than these rivers the Mahakali basin consists of 9 glacial lakes and 164 glaciers in Nepal side (CBS, 2019). The discharge of the basin highly fluctuates during monsoon and winter season due to which the basin is prone to hazards like GLOF, floods, landslides and others (Siddiqui et al., 2012).

The Gandaki River basin, also referred to as the Narayani River system, is a trans-boundary river system originating from the Tibetan Plateau flowing through central Nepal and draining into the Ganges of India. Based on the elevation and topography, the basin is divided into five zones namely Trans-Himalaya, Higher Himalaya, Lesser Himalaya, Siwaliks, and Terai from north to south with different climates and vegetation. About 69% of the total area (46,300 sq. km) of the Gandaki basin lies within Nepal (Chand et al., 2019) . This basin receives most of its precipitation (i.e. around 80%) during the monsoon between June and September (Panthi et al., 2015). Thus, during monsoon, the basin is most vulnerable to water-induced disasters like floods, debris flow, and landslides. The basin has 1340 glaciers and 116 glacial lakes in Nepal side (CBS, 2019). Gandaki basin is significant for its hydro-power potential which is estimated to be around 17800.2 MW (Jha, 1970). Kaligandaki hydropower station is the largest hydropower in the country to date which lies in this region.

Water balance in Gandaki River Basin shows that in the Tibetan Plateau the lateral flow contributes 29%, the groundwater contributes to 20% and the surface runoff contributes to 45% of the total water yield (Pant et al., 2021). On the other hand, in the High Himalayas, the contribution from the lateral flow is nearly 50%, the groundwater is only 8%. Similarly, in the high mountain the lateral flow contributes to 64%, groundwater contributes to 8% and 27% from the surface mountain. In the middle mountain, the lateral flow contributes to 51%. Groundwater 14% and 34% from the surface runoff.

The Gandaki system consists of seven major tributaries namely Daraudi, Seti Gandaki, Madi, Kaligandaki, Marsyandi, Budhi Gandaki, and Trisuli, also known as Sapta Gandaki. Among these tributaries the Kaligandaki flows through the world's deepest valley between the 8,000-meter Dhaulagiri and Annapurna ranges. Upon the convergence of these seven upper tributaries, the river is known as the Narayani within Nepal, and also called Gandak river system in India.

2.1 Water Availability and Uses Situation of Gandaki River Basin

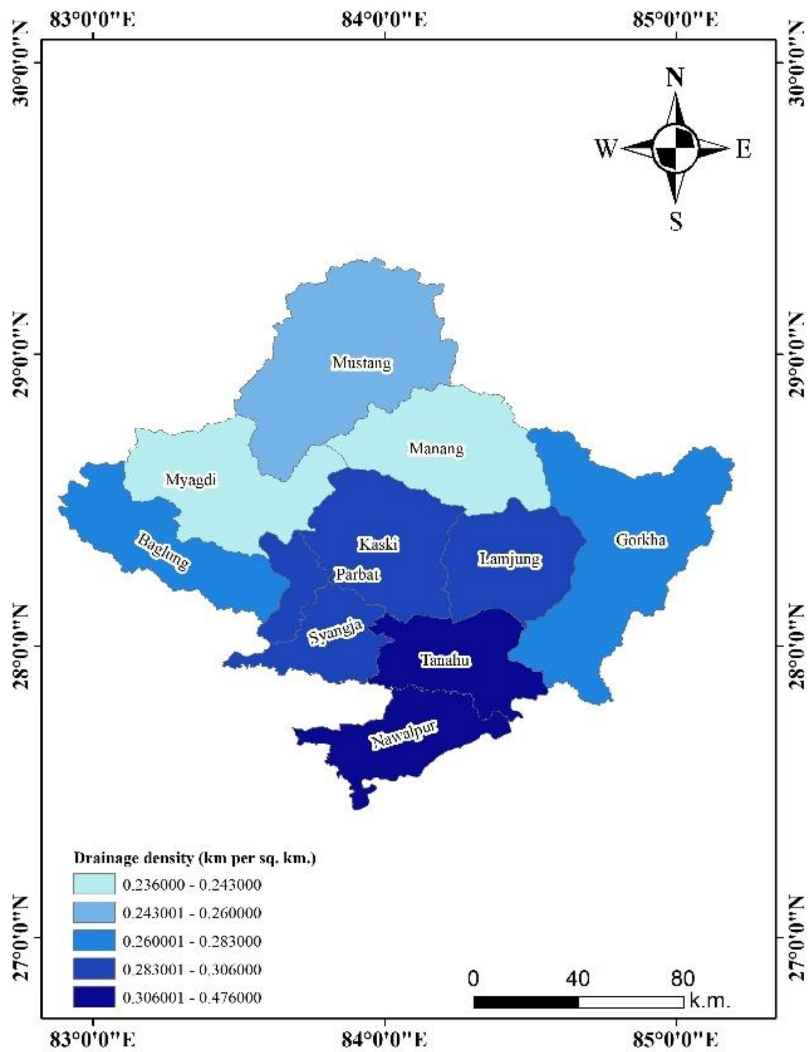
The Gandaki River Basin, spanning the Gandaki province, influences the province's name. To plan water strategies effectively, we require precise data on the extent of river channel, water availability and its usage for various purposes like irrigation, domestic needs, hydroelectric power, and industry. This chapter focuses into an analysis of the Gandaki River Basin, covering water availability, usage, and demands across districts and major rivers within the Gandaki province.

2.1.1 Drainage Density

Drainage density, a metric indicating the extent of river channels within a specified area, is calculated by dividing the total length of rivers and streams by the district's area. In Gandaki Province, this measure reveals notable variations among its districts, reflecting differences in topography, climate, and geological features. Figure 2 illustrates the district wise drainage density of the Gandaki Province. Nawalpur, with a drainage density of 0.476 km/km², has the densest river network, suggesting a highly dissected terrain and efficient drainage. Tanahu and Lamjung also exhibit high drainage densities of 0.408 km/km² and 0.306 km/km², respectively, indicating similarly dense river networks.

On the other hand, districts like Manang, with the lowest drainage density at 0.243 km/km², and Myagdi, at 0.236 km/km², have sparser river networks, likely due to more rugged terrain or less favorable climatic conditions for river formation. Mustang, with a density of 0.260 km/km², and Baglung, at 0.273 km/km², fall below the province's average density of 0.295 km/km², pointing to relatively fewer river channels per unit area. These variations provide insight into the hydrological and environmental dynamics of the province, where districts with higher drainage densities might experience more rapid surface runoff and potential for soil erosion, while those with lower densities might have less surface water flow, affecting local agriculture and water availability. The overall average drainage density of 0.295 km/km² serves as a comparative baseline, highlighting the diverse landscape and water distribution in Gandaki Province.

Additionally, the drainage density data for Gandaki Province, when analyzed by physiographic



zones, provides a deeper understanding of how topography influences river distribution. In the High Mountain zone, which spans 9579 km², the river length totals 2039 km, resulting in a drainage density of 0.213 km/km². This low value indicates a sparse river network, likely due to the rugged and steep terrain which limits the formation and extension of rivers. Moving to the Middle Mountain zone, which covers 4763 km² with a river length of 1561 km, the drainage density increases to 0.328 km/km². This higher density suggests a more developed river network compared to the High Mountains, influenced by less severe topography that allows for more extensive drainage systems. On the other hand the Hill zone, with an area of 6493 km² and a river length of 2350 km, exhibits a drainage density of 0.362 km/km². This is one of the highest densities among the zones, reflecting a very dense and intricate network of rivers, likely due to moderate slopes and more favorable conditions for river development. The Siwalik zone, despite being the smallest at 1021 km², has a river length of 506 km, resulting in the highest drainage density of 0.495 km/km². This extremely high density indicates a very well-developed and dense river network, possibly due to the softer rock formations and abundant rainfall which facilitate the creation of numerous streams and rivers.

2.1.2 Water Demand vs Supply

Figure 3 shows the total Water Demand in 11 districts of Gandaki Province. Districts such as Kaski, Nawalpur, and Tanahu has high population thus leading to high level of water demand. Baglung has an annual water demand of 15 MCM, which translates to a daily demand of 39,546 cubic meters. This moderate level of demand indicates the amount of water required to support its population and various activities. Gorkha, with an annual demand of 12 MCM and a daily average of 30,267 cubic meters. Similarly, Kaski stands out with a substantial annual water demand of 30 MCM, equating to 81,204 cubic meters per day which is the highest amongst all. This high demand reflects the large population and extensive agricultural activities in the district. In contrast, Lamjung has an annual demand of 10 MCM and a daily average of 26,032 cubic meters, indicating moderate water needs that must be met to sustain local demands.

Manang and Mustang have lower water demands compared to other districts. Manang's annual water demand is 1 MCM, with a daily requirement of 697 cubic meters, while Mustang's demand is also 1 MCM annually, with a daily requirement of 1,342 cubic meters. These figures reflect the smaller populations and potentially less intensive agricultural or industrial activities in these districts.

Myagdi has an annual water demand of 5 MCM, translating to a daily demand of 12,798 cubic meters. This indicates moderate water requirements to support its population and activities. Nawalpur, with an annual demand of 18 MCM and a daily average of 49,250 cubic meters, has significant water needs, supporting a variety of uses within the district. On the other hand, Parbat's annual water demand is 7 MCM, which translates to 16,962 cubic meters per day, indicating sufficient water requirements to meet the district's needs. Similarly, Syangja has a higher demand with 17 MCM annually and 44,469 cubic meters per day, reflecting its substantial water needs to support its population and activities. Tanahu, with an annual water demand of 18 MCM and a daily average of 48,594 cubic meters, has significant water needs. This high demand supports extensive agricultural and residential needs, ensuring that the district can sustain its economic activities effectively. This diverse demand landscape necessitates a comprehensive approach to water resource management to ensure sustainable development and adequate water supply throughout the province.

Breaking the water demand into various categories we found, insights into the specific water needs

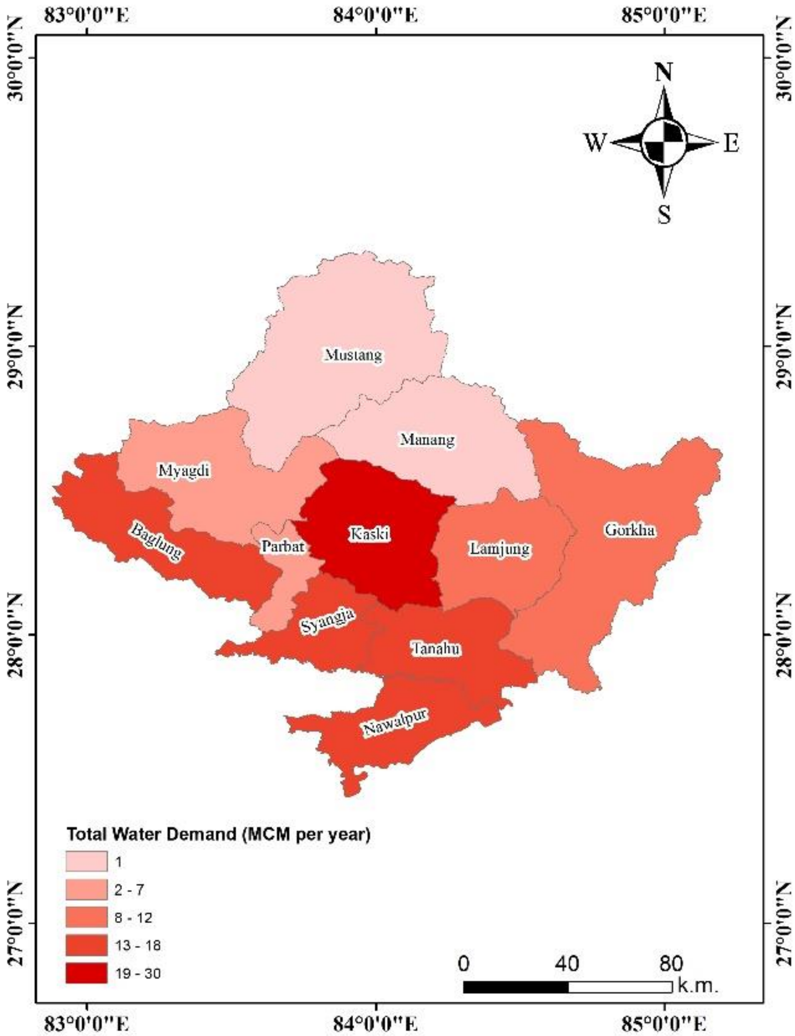


Figure 3: Total Water demand on various districts of Gandaki Province

for urban drinking, rural drinking, institutional purposes, livestock, and fire suppression within each district of the Gandaki Province as shown in Figure 4. Baglung, for instance, shows a significant urban drinking water demand of 26,106.675 cubic meters, while rural areas require 9,983.165 cubic meters. Moreover, there's a demand for institutional use (120 cubic meters), livestock (1,996.633 cubic meters), and fire suppression (1,221.397 cubic meters). Similarly, Gorkha exhibits distinct demands with urban drinking water requirements of 10,493.52 cubic meters and rural areas needing 15,427.16 cubic meters. Additionally, institutional demand is 144 cubic meters, livestock require 3,085.432 cubic meters, and fire suppression necessitates 935.126 cubic meters.

Kaski presents significant urban drinking water demand at 70,524.125 cubic meters, while rural areas need 6,626.345 cubic meters. Institutional use requires 642 cubic meters, livestock demand is 1,325.269 cubic meters, and fire suppression needs 2,007.474 cubic meters. Lamjung shows urban drinking water demand of 18,923.1 cubic meters and rural areas require 4,931.53 cubic meters. Institutional demand stands at 93 cubic meters, livestock need 986.306 cubic meters, and fire suppression requires 1,039.866 cubic meters.

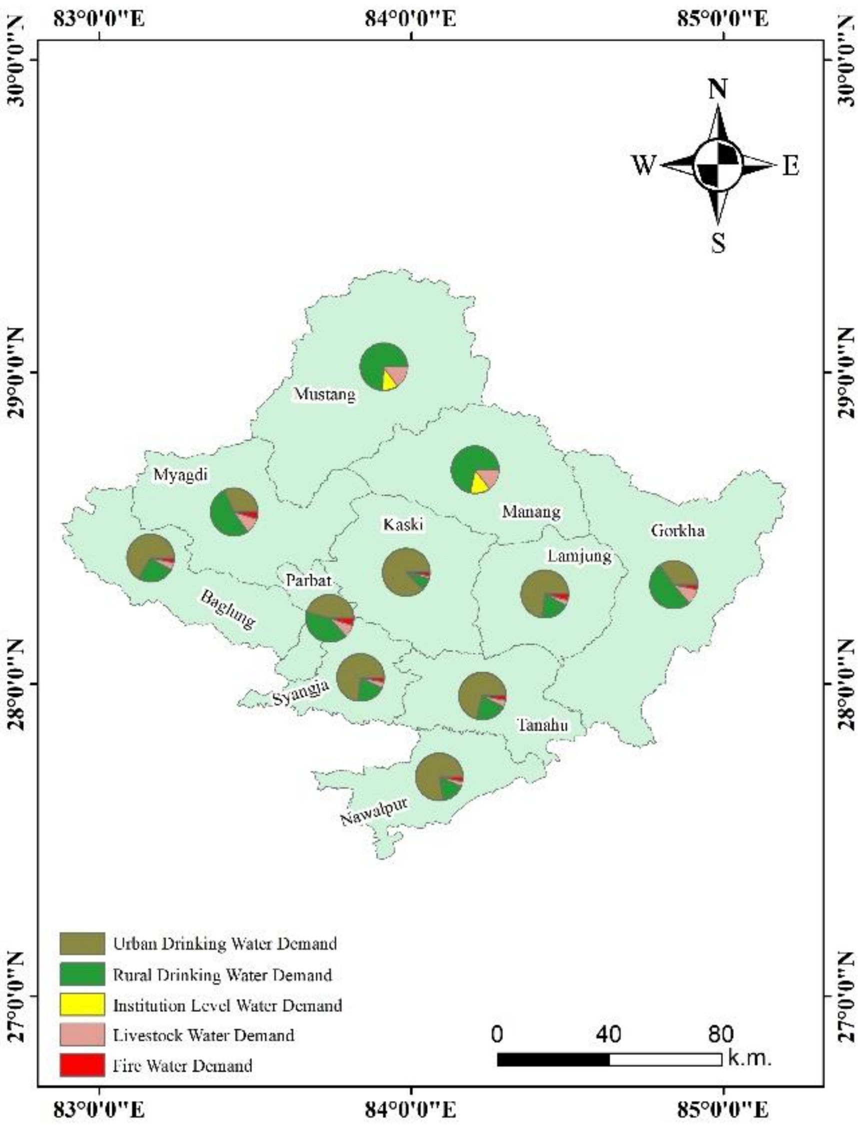


Figure 4: Distribution of water demand in various categories

Manang and Mustang have minimal or no urban drinking water demand but water needs for rural areas, institutions, livestock, and fire suppression. For example, Manang requires 495.295 cubic meters for rural drinking water, 96 cubic meters for institutional use, and 99.059 cubic meters for livestock, while Mustang requires 985.405 cubic meters for rural drinking water and 197.081 cubic meters for livestock.

Myagdi presents urban drinking water demand of 4,019.76 cubic meters and rural drinking water demand of 6,679.215 cubic meters. Institutional demand is 105 cubic meters, livestock need 1,335.843 cubic meters, and fire suppression requires 578.775 cubic meters. Other districts like Nawalpur, Parbat, Syangja, and Tanahu also exhibit varying water demands across different categories, providing valuable insights into the specific water needs and usage patterns within Gandaki Province.

Figure 5 demonstrates the water available for supply and demand in Gandaki Province. Kaski stands out with the highest water availability at 314 mm, followed closely by Lamjung with 274 mm. Conversely, Manang and Mustang demonstrate the lowest water availability, with only 41 mm and 20 mm, respectively as shown in Figure 5. When considering water demand, Kaski, Parbat, and Syangja exhibit the highest demand, each requiring 15 mm of water for supply. This demand seems notably high compared to their water availability, potentially signaling challenges in meeting the needs of these districts sustainably. In contrast, while Baglung, Gorkha, and Myagdi

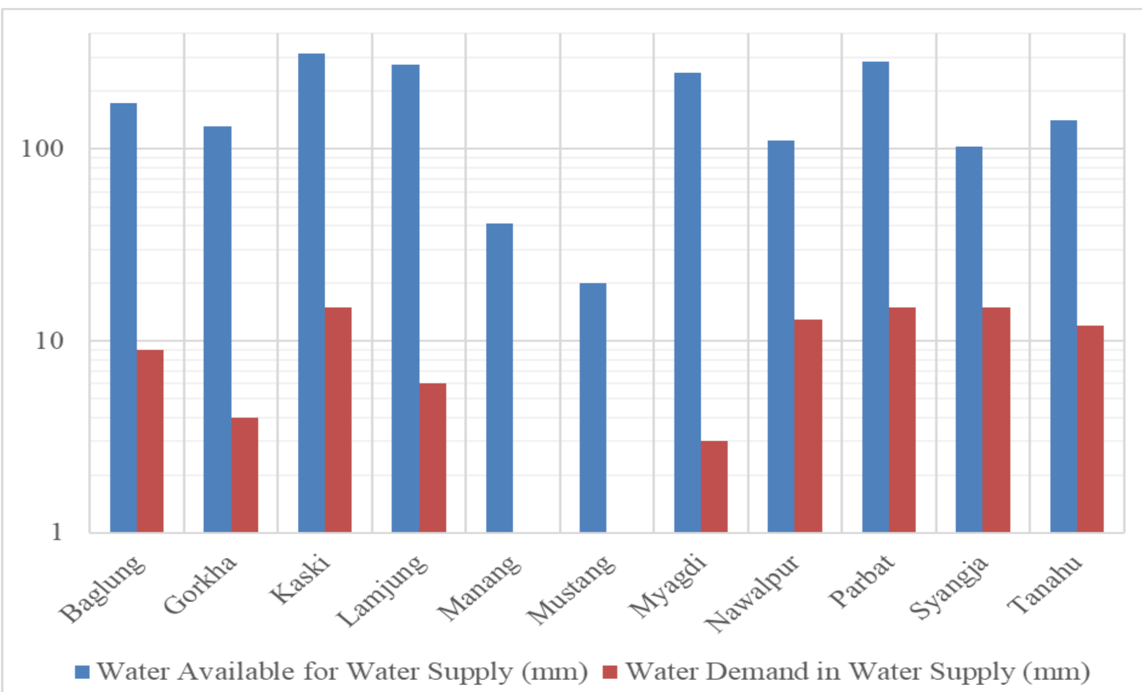


Figure 5: Water Available vs Demand in Water Supply

have comparatively lower water demand, their availability seems more balanced, suggesting a potentially more stable water supply situation. Tanahu falls in the middle, with moderate availability and demand.

Figure 6 provides key metrics regarding water availability and demand in various districts of Gandaki Province. It includes values such as water availability in streams, springs, and groundwater (mm), ecological water requirement (mm), cultural water requirement (mm), water available for water supply (mm), water demand in water supply (mm), and surplus/deficit (%). Such insights are crucial for devising targeted water management strategies to ensure sustainable water use and address the water needs of both ecosystems and human populations within Gandaki Province.

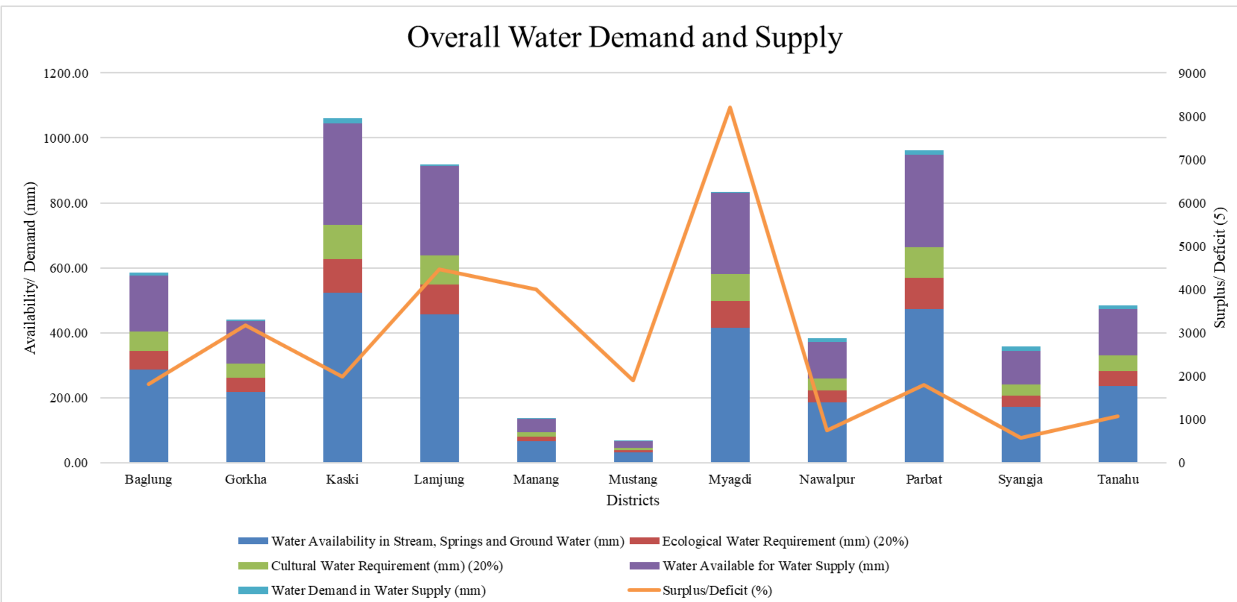


Figure 6: Overall Demand and Supply of water in Gandaki Province

2.1.3 Irrigation Water

The Figure 7 shows the total agricultural land in various districts of the Gandaki Province. Based on the data, we found Manang has the smallest total agricultural land with only 11.29 sq. km, reflecting its limited agricultural capacity, likely due to its high-altitude terrain and harsh climatic conditions. Similarly, Mustang follows with 57.84 sq. km, also indicating restricted agricultural space influenced by similar geographic factors.

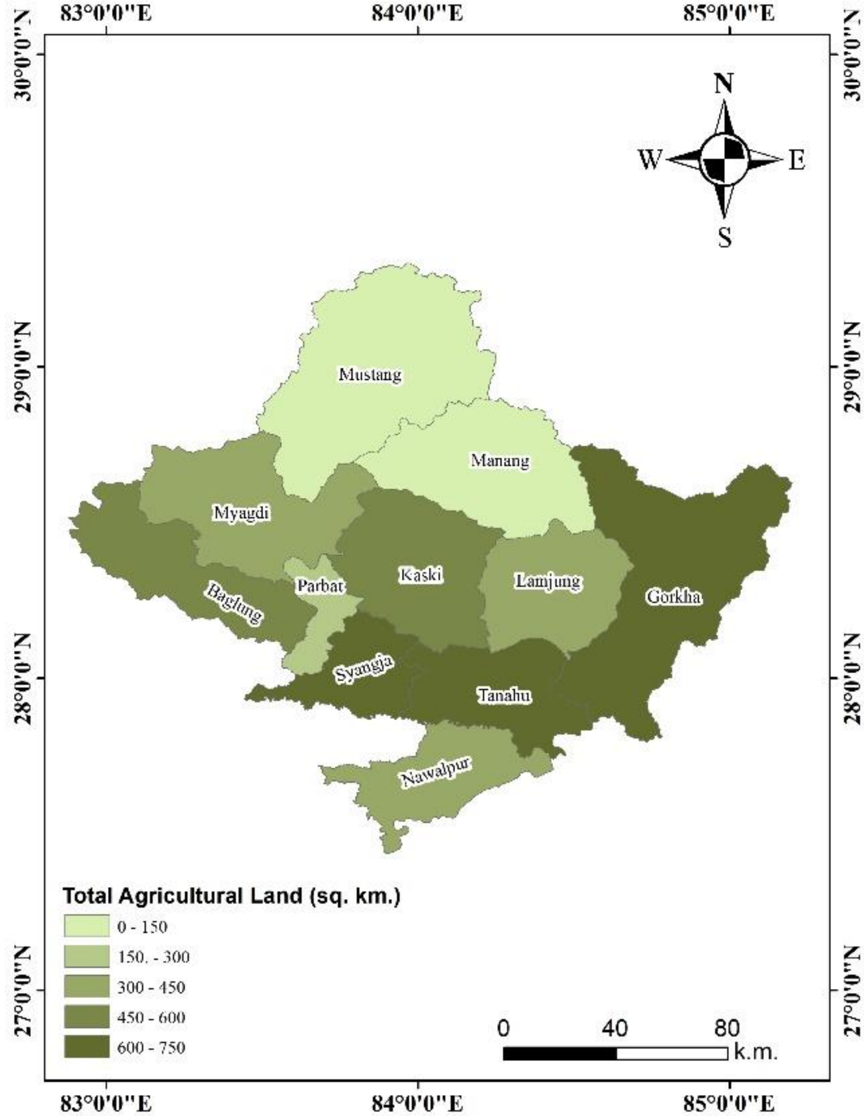


Figure 7: Coverage of agricultural land in various districts of Gandaki Province

In contrast, Gorkha and Syangja exhibit substantial agricultural land areas, with 681.19 sq. km and 681.94 sq. km respectively, highlighting significant farming activities and potential for agricultural productivity. Tanahu also has a notable amount of agricultural land, totaling 628.10 sq. km, suggesting a strong agricultural presence in the district.

Remaining districts like Baglung, Kaski, Lamjung, etc. shows high coverage of agricultural land, Baglung with 532.13 sq. km., Kaski with 519.10 sq. km and Lamjung: 447.08 sq. km. Similarly, Myagdi, with 308.80 sq. km, and Nawalpur, with 346.11 sq. km, reflect moderate agricultural land availability. Also, Parbat, with 264.75 sq. km, has relatively smaller agricultural land compared to the more prominent farming districts.

Total Annual Crop Water Requirement (MCM)

Figure 8 shows information on the total crop water requirement in million cubic meters (MCM) across various districts, indicating the volume of water necessary to meet agricultural needs. Syangja has the highest crop water requirement at 1704.84 MCM, reflecting its extensive agricultural activities and the corresponding high demand for water to sustain crop growth. Gorkha follows closely with a requirement of 1702.96 MCM, indicating similarly substantial agricultural operations and water needs. Tanahu also has a significant water requirement of 1570.24 MCM,

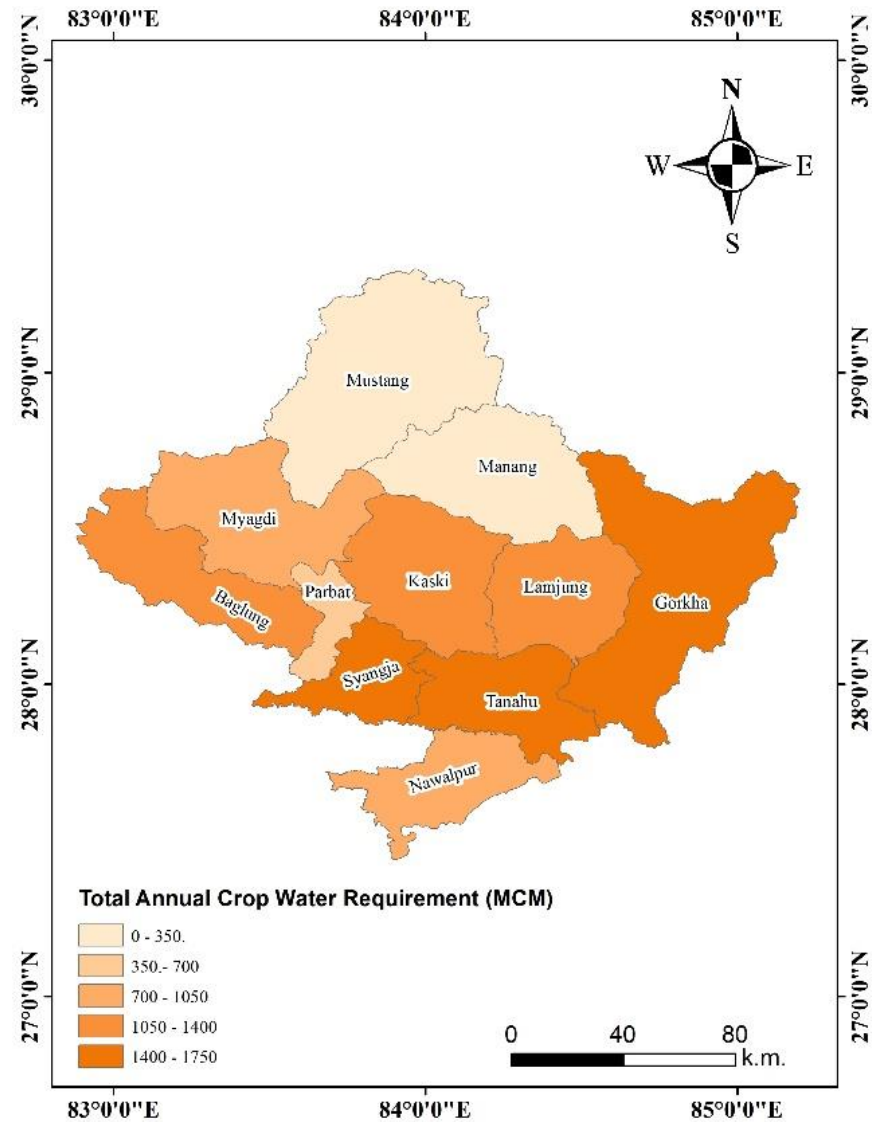


Figure 8:Map showing district wise Total Annual Crop Water Requirement (MCM) in Gandaki Province

highlighting its intensive agricultural practices. Other districts with considerable crop water requirements include Baglung (1330.33 MCM), Kaski (1297.75 MCM), and Lamjung (1117.69 MCM). These figures suggest robust agricultural activities requiring substantial water resources.

Moderate crop water requirements are observed in Nawalpur (865.27 MCM), Myagdi (772.01 MCM), and Parbat (661.88 MCM). These values indicate a significant but comparatively lower demand for agricultural water. In stark contrast, Mustang and Manang exhibit much lower crop water requirements, with 144.60 MCM and 28.23 MCM respectively. This disparity likely results from their limited agricultural land and challenging environmental conditions, which restrict the extent of farming activities.

Irrigation Projects

Figure 9 shows the number of irrigations projects in various districts of Gandaki Province of Nepal. Among the districts of Gandaki Province, Tanahu stands out with the highest number of irrigation projects at 63, reflecting a significant investment in water management infrastructure and agricultural development initiatives. Following closely behind are Gorkha and Baglung, with 39 and 34 projects respectively, indicating robust efforts to ensure water access for farming communities. Kaski and Lamjung also demonstrate substantial commitments to irrigation, boasting 30 and 32 projects respectively. Conversely,

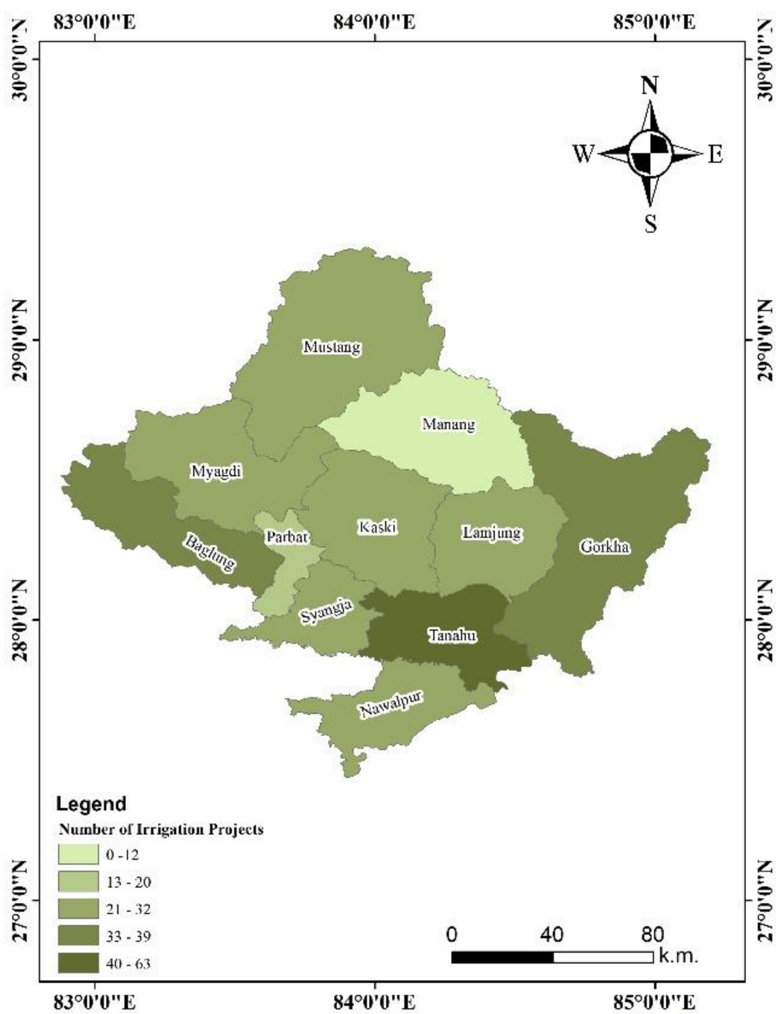


Figure 9: District wise map of Gandaki Province illustrating the number of irrigation projects

Manang exhibits a more limited scope of water management initiatives with only 12 projects, likely due to geographical constraints or lower agricultural activity. Despite variations in project count, each district's allocation of irrigation projects underscores its dedication to enhancing agricultural productivity and ensuring sustainable water resources for its population. This dataset serves as a valuable resource for understanding regional disparities in water management infrastructure and agricultural development efforts.

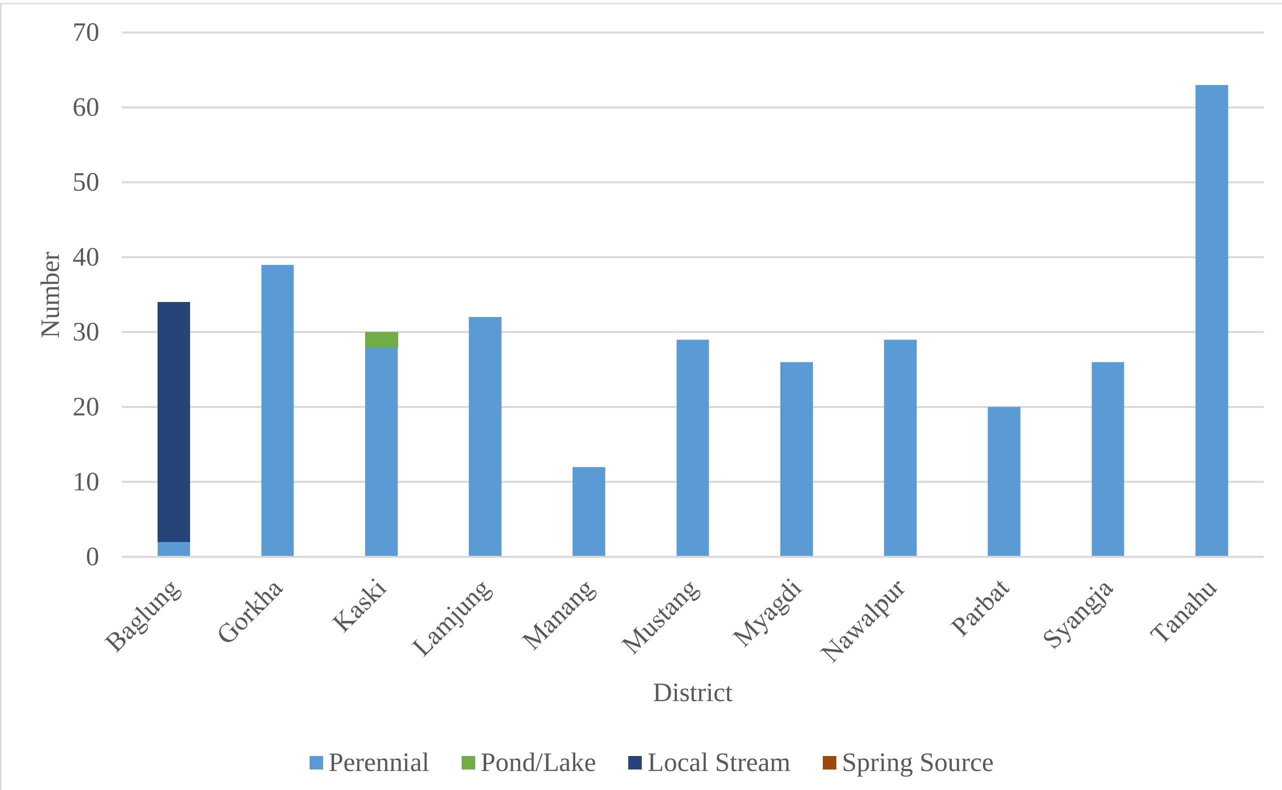


Figure 10: Different sources of Irrigation Projects in various districts of Gandaki Province

Furthermore, breaking the number of irrigation projects into different sources of the irrigation project, we found that Baglung primarily relies on local streams for irrigation, with 32 projects utilizing this source (Figure 10). It also has two projects drawing water from perennial sources, while no projects utilize ponds/lakes or spring sources. On the other hand, Gorkha shows a strong dependence on perennial water sources, with all 39 irrigation projects tapping into perennial water supply. Unlike Baglung, Gorkha doesn't utilize ponds/lakes or local streams for irrigation purposes. Similarly, in Kaski, 28 projects utilize perennial sources, while two projects rely on both perennial sources and ponds/lakes. Interestingly, Kaski doesn't utilize local streams or spring sources for irrigation. Similar to Kaski, Lamjung primarily relies on perennial sources for irrigation across all 32 projects. There are no projects utilizing ponds/lakes, local streams, or spring sources in Lamjung. With a smaller number of projects, Manang's 12 irrigation initiatives all rely on perennial sources, while there's no utilization of ponds/lakes, local streams, or spring sources. Mustang shows similar pattern as seen in Manang, with all 29 projects drawing water from perennial sources exclusively. Myagdi also follows a similar trend to Mustang and Manang, with all 26 projects utilizing perennial sources and none utilizing ponds/lakes, local streams, or spring sources. All 29 irrigation projects in Nawalpur rely on perennial sources, with no utilization of ponds/lakes, local streams, or spring sources while Parbat exhibits a similar reliance on perennial sources, with all 20 projects drawing water exclusively from this source type.

Similarly, in Syangja, all 26 projects utilize perennial sources for irrigation, while there's no utilization of ponds/lakes, local streams, or spring sources. Tanahu, like Gorkha, demonstrates a strong dependence on perennial water sources, with all 63 irrigation projects tapping into this reliable water supply. Similar to other districts, there's no utilization of ponds/lakes, local streams, or spring sources in Tanahu. Overall, in most of the districts the source of water for the irrigation project relies heavily on perennial water sources for irrigation across the districts, underscoring the importance of consistent water availability for agricultural activities.

Total Irrigation Area and all year Irrigated Area

The total area of the Gandaki Province has been estimated to be 173,773 ha. From the agricultural perspective, out of the total area 62,410 ha is irrigated area. Additionally, out of this total irrigated area 31,841 ha is irrigated all year round.

As shown in Figure 11, further breaking down the total irrigated areas into district level we have found that in Gorkha, the total area is 26,094 hectares, with 7,133 hectares designated for irrigation. Of this, 3,456 hectares receive irrigation throughout the year. This indicates a significant portion of the land is utilized for agriculture, but less than half of the irrigated land benefits from year-round irrigation, highlighting a potential need for improved irrigation infrastructure.

Manang, with a much smaller total area of 489 hectares, has only 91 hectares of irrigated land, 72 of which are irrigated year-round. This suggests that despite its small size, a substantial portion of Manang's irrigated land benefits from continuous water supply, possibly due to effective irrigation systems or favorable climatic conditions.

Similarly, another district receiving less amount of rainfall i.e. Mustang, with limited total area (1,182 hectares), has 886 hectares under irrigation, with a notable 839 hectares irrigated all year. This high percentage of year-round irrigation indicates that Mustang has well-developed irrigation systems or natural water resources that support consistent agricultural activities.

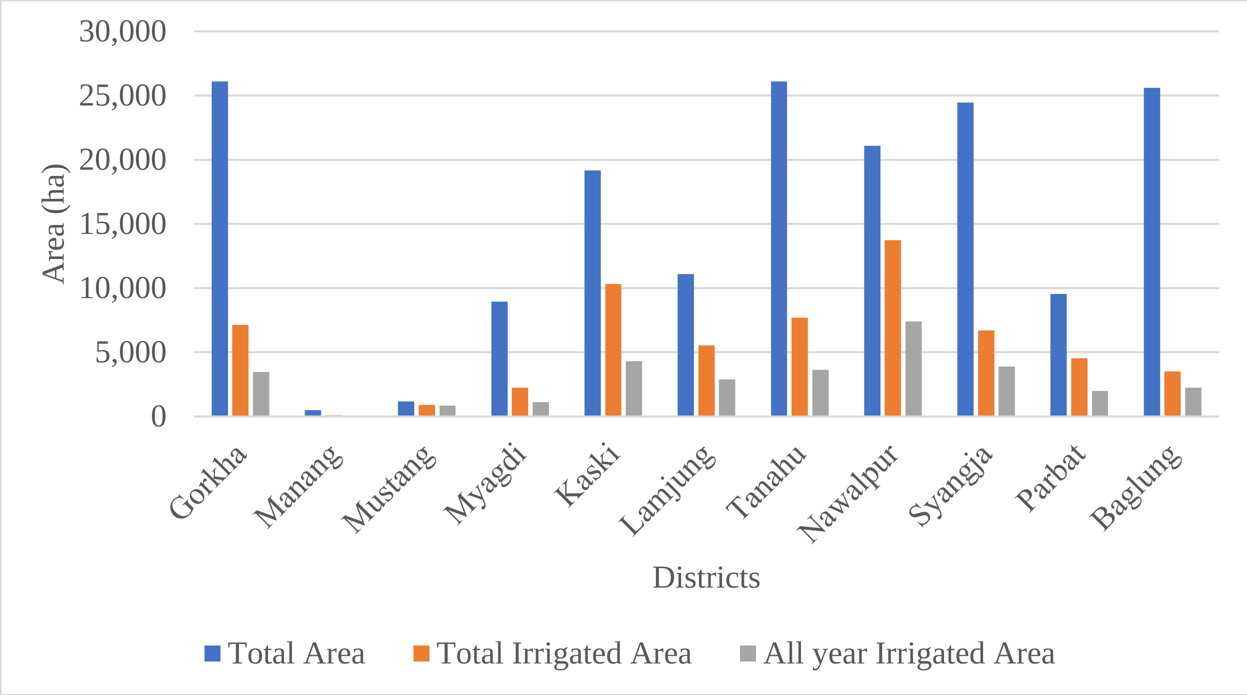


Figure 11: Districtwise distribution of Irrigated Land and all year irrigated land in Gandaki Province [Source: National Agriculture Census, 2078]

In Myagdi, out of 8,953 hectares, 2,253 hectares are irrigated which is nearly one-fourth of the total area, and nearly half of which i.e. 1,132 hectares receive year-round irrigation. While a portion of the land is well-irrigated, there is still room to enhance the irrigation infrastructure to support more consistent agricultural production.

Kaski boasts a larger total area of 19,164 hectares, with 10,316 hectares irrigated and 4,313 hectares benefiting from year-round irrigation. This indicates a relatively high level of agricultural activity, though there is potential to expand year-round irrigation to support more stable and diverse crop production.

Lamjung has 11,083 hectares in total, with 5,524 hectares under irrigation, of which 2,880 hectares are irrigated year-round. This shows that more than half of the irrigated land still relies on seasonal water supply, indicating a need for improved irrigation solutions to boost agricultural productivity.

Tanahu, with a total area of 26,100 hectares, has 7,693 hectares of irrigated land, and 3,629 hectares are irrigated all year. The district has a substantial agricultural area, but similar to other districts, there is a significant portion that could benefit from enhanced irrigation infrastructure.

Nawalpur stands out with a total area of 21,090 hectares, featuring 13,731 hectares of irrigated land, and 7,396 hectares under year-round irrigation. This district demonstrates a high level of agricultural activity with substantial year-round irrigation, suggesting effective use of water resources.

Syangja, with a total area of 24,457 hectares, has 6,717 hectares irrigated, and 3,898 hectares benefit from year-round irrigation. This district has a relatively high percentage of its irrigated land receiving continuous water supply, supporting stable agricultural practices.

Parbat, with a total area of 9,552 hectares, has 4,549 hectares under irrigation, and 1,982 hectares receive year-round irrigation. The data suggests that while irrigation is prevalent, there is significant potential to increase year-round water supply to improve agricultural outputs.

Lastly, Baglung, with 25,609 hectares in total, has 3,509 hectares of irrigated land, and 2,245 hectares irrigated year-round. Despite having a large total area, a smaller portion of land is irrigated, indicating room for development in irrigation infrastructure to maximize agricultural productivity.

Source of Irrigation

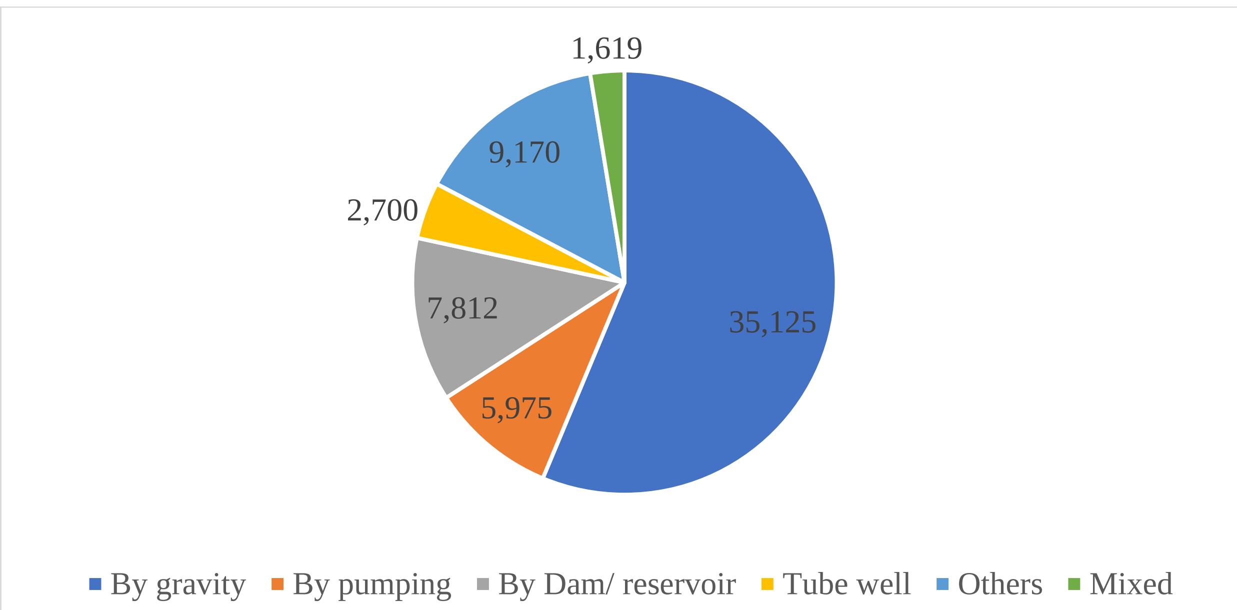


Figure 12: Distribution of irrigation source in Gandaki Province [Source: National Agriculture Census, 2078]

The major sources of irrigation in the Gandaki Province is mainly by gravity, pumping, by the Dam or reservoir, tubewell, etc. as shown in Figure 12. Overall, in the Gandaki Province most of the land is irrigated by gravity 35,125 ha, followed by Dam/ reservoir 7,812 ha and by pumping with 5,975 ha and Tubewell with 2700 ha area. 9,710 area is irrigated by other source while 1,619 ha is irrigated by mixed source.

Breaking down the irrigation sources of by the district we have found that the in Gorkha, the predominant method of irrigation is by gravity, with 3,412 hectares irrigated by this method. Other significant methods include irrigation by pumping (1,183 hectares) and using dams or reservoirs (483 hectares). Additionally, 1,836 hectares are irrigated by other methods, while a smaller portion relies on tube wells (56 hectares) and also mixed methods (164 hectares).

Similarly, another district i.e. Manang is a smaller district in terms of total area, primarily utilizes irrigation by gravity (39 hectares) and dams/reservoirs (43 hectares). There is minimal reliance on pumping (9 hectares) and no use of tube wells or mixed methods. Similar district to Manag is the Mustang district in the north. The Mustang also primarily relies on gravity based irrigation (616 hectares), with additional contributions from pumping (140 hectares) and dams/reservoirs (113 hectares). The use of tube wells is minimal (17 hectares), and there is no significant use of mixed methods. The reliance on gravity and natural water flow suggests that Mustang utilizes its mountainous terrain effectively for irrigation. Myagdi shows a significant use of gravity-fed irrigation (1,583 hectares) and some reliance on pumping (114 hectares) and dams/reservoirs (239 hectares). Tube wells and other methods account for a smaller portion of the irrigation (300 and 17 hectares, respectively). The varied methods indicate an adaptive approach to irrigation, utilizing both natural and mechanical means. Kaski also has a notable reliance on gravity-fed irrigation (5,795 hectares) and a significant use of other methods (3,110 hectares). Pumping (457 hectares), dams/reservoirs (537 hectares), and mixed methods (400 hectares) also contribute to the irrigation infrastructure, with minimal use of tube wells (17 hectares). The diverse methods suggest a well-developed and multifaceted irrigation system. Similarly, Lamjung also primarily uses gravity-fed irrigation (3,711 hectares) and has significant contributions from other methods (894 hectares). Pumping (443 hectares), dams/reservoirs (347 hectares), and mixed methods (113 hectares) are also utilized, with minimal reliance on tube wells (15 hectares). This diversity indicates an effective use of natural and mechanical irrigation sources. Tanahu relies heavily on gravity-fed irrigation (6,003 hectares), with dams/reservoirs (597 hectares), other methods (472 hectares), pumping (293 hectares), mixed methods (292 hectares), and minimal use of tube wells (36 hectares). This suggests a dependence on natural water flow and topography. Nawalpur employs a balanced mix of irrigation methods, mostly gravity (4,601 hectares), followed by pumping (1,844 hectares), dams/reservoirs (3,309 hectares), tube wells (2,424 hectares), other methods (1,088 hectares), and mixed methods (465 hectares). Syangja mainly uses gravity-fed irrigation (4,058 hectares), supplemented by dams/reservoirs (1,176 hectares) and other methods (747 hectares), with lesser reliance on pumping (594 hectares), mixed methods (73 hectares), and tube wells (69 hectares). This indicates a preference for gravity-fed systems.

Parbat's irrigation is primarily gravity-fed (2,736 hectares), with significant use of dams/reservoirs (853 hectares) and other methods (483 hectares). Pumping (326 hectares) and mixed methods (76 hectares) are also utilized, with minimal tube well use (76 hectares). Baglung similarly relies on gravity-fed irrigation (2,570 hectares), with notable use of pumping (573 hectares) and other methods (223 hectares), supplemented by dams/reservoirs (114 hectares) and mixed methods (20 hectares), with minimal tube well use (8 hectares). Both districts exhibit a flexible and adaptive irrigation strategy tailored to their respective needs and resources.

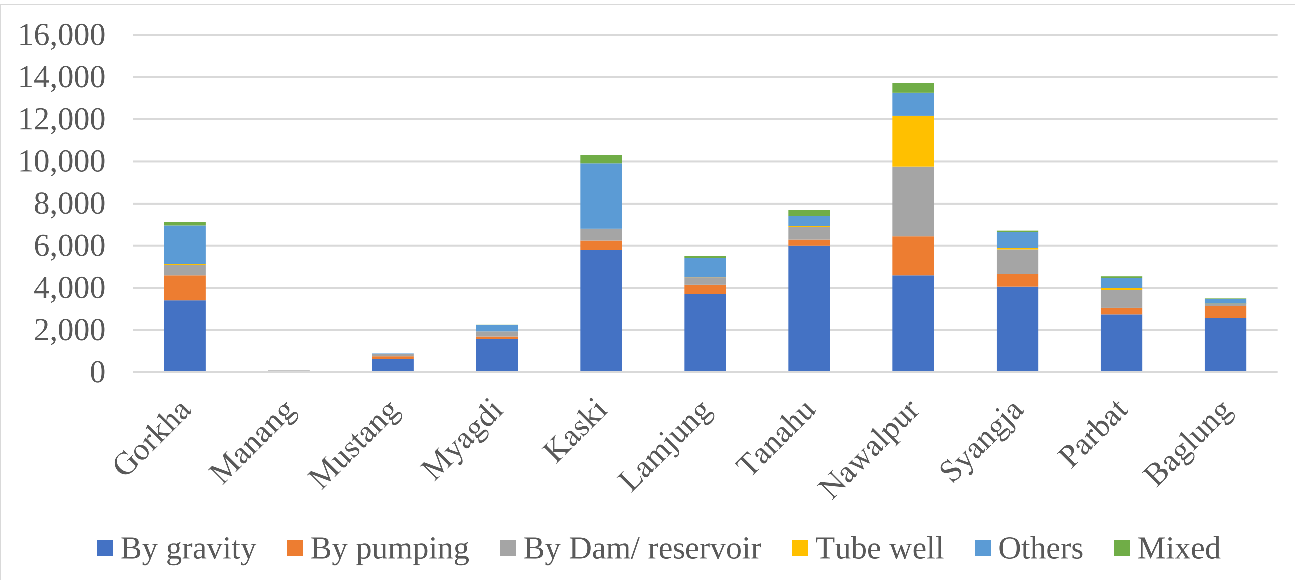


Figure 13:Disttict level distribution of irrigated land by the source in Gandaki Province [Source: National Agriculture Census, 2078]

2.1.4 Water in Hydropower

Nepal possesses significant hydropower resources, and the Gandaki Basin is a key contributor. Studies estimate the basin's theoretical hydropower potential to be around 5,270 MW (World Bank Group, 2019) . However, only a fraction of this potential has been harnessed. As of 2023, data from the International Hydropower Association (IHA)[1] indicates that operational hydropower projects within the basin generate around 523 MW. This is only about 10% of the basin's total potential. Figure 14 shows the different hydropower projects which are in different phases such as generation phase, operation phase, and survey phase.

[1] https://www.statista.com/statistics/474799/global-hydropower-generation-by-major-country/

One of the largest hydropower projects in Nepal, the 144 MW Kaligandaki A Hydroelectric Project, is located in the Gandaki Basin (Sahukhal & Bajracharya, 2015). This project, commissioned in 2002, exemplifies the challenges associated with sediment management in run-of-river projects (Nepal, 2016). Despite its contribution to national energy generation, the project has faced issues with excessive turbine abrasion and rising flood levels due to sediment load.

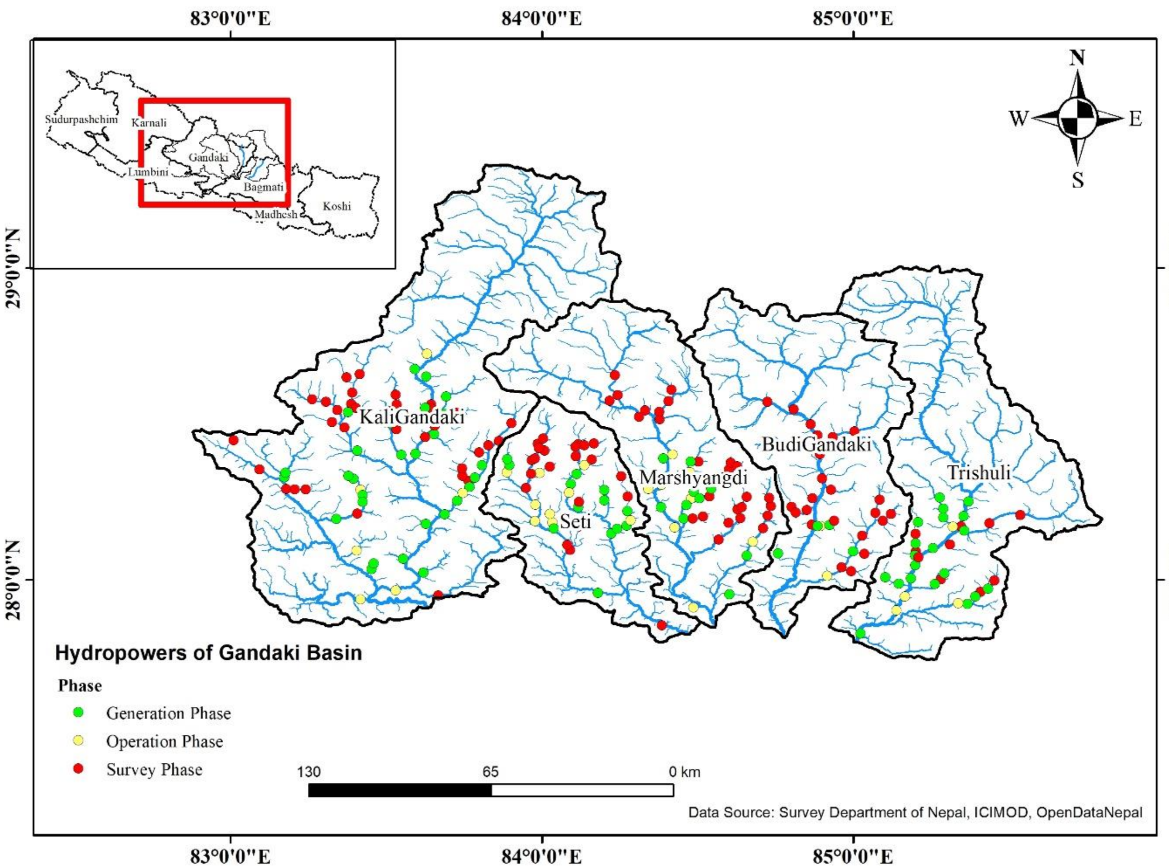


Figure 14: Hydropower stations in Gandaki Provinces.

Daraudi river basin consists of one large hydropower plant in the Daraudi River itself which is a run-of-river type hydropower project (Koirala et al., 2015). In the Madi watershed, as of 2024, 23 hydropower projects are prevalent in the region which is either in operation or generation at the survey license phase in the Madi basin. It has been estimated that the total hydropower generation potential of the Madi River Basin is 377.37 MW (Pokharel & Regmi, 2024). Modeling of the streamflow with respect to the climate change variable revealed an overall increasing trend which is marked significantly by the reduction of the discharge during the early months on the one hand with intense peaks during the monsoon season. One of the large-scale hydropower projects of the basin is the Super Madi Hydroelectric Project, in Nepal. This hydropower plant is a run-of-river hydropower plant with a capacity of 44 MW (Gautam, 2012). The location is mostly dominated by high-grade metamorphic rocks like gneiss and schists.

In the Marshyangdi watershed, as per a study done in 2004, there were two hydropower projects in operation which were the Marshyangdi Hydropower Project (69 MW) and the Marshyangdi Hydroelectric Project (Paudel et al., 2019). Furthermore, other hydropower projects were also present in different phases of development, namely Upper Marshyangdi Hydroelectric Project (600 MW), Lower Manang Marshyangdi Hydroelectric Project (100 MW), and Nyadi Hydropower Project (30 MW). One of the major hydropower projects in the Budi Gandaki River is the Budi Gandaki Hydropower project which is located around 2 km from the confluence of Trishuli River at Benighat on the Prithivi High which connects Kathmandu and Pokhara. Previously, it was estimated to be 600 MW of capacity which is further increased to 1800 MW with a total investment of $ 2.5 billion dollars. Furthermore, it is estimated that 27 local levels of two districts namely Gorkha and Dhading is expected to be affected (Khanal et al., 2021). As per the research done in 2018, there were five operational hydropower plants with a total capacity of 70.1 MW which are located in the Trishuli River Basin. Out of these five hydropower plants three of those are located from north to south on the main stem of the Trishuli River which are the Chilime (22.1 MW), Trishuli (24 MW), and Devighant (14.1 MW) (S. K. Mishra et al., 2018).

Hydropower development, while offering renewable energy generation, can have environmental and social consequences. Studies by Panthi et al. (2015) report a decrease in pre-monsoon, post-monsoon, and winter rainfall across most of the Gandaki Basin, potentially linked to the construction and operation of hydropower projects (Panthi et al., 2015). These changes in precipitation patterns can impact agricultural productivity and water availability downstream.

Climate change introduces an additional layer of complexity to hydropower development in the Gandaki Basin. Studies by Karki et al., (2017) suggest a rise in pre-monsoon precipitation for the lowlands and central Himalayas, while monsoonal precipitation might increase in specific areas (Karki et al., 2017). Conversely, post-monsoon precipitation appears to be decreasing across Nepal (Karki et al., 2017). These regional variations necessitate a nuanced approach to hydropower planning, considering potential changes in river flow patterns and water availability.

A recent data published by Department of Electricity Division (Updated on June 11, 2024) shows detail about the hydropower plants which are in different phases of hydroelectricity generation. Out of which, only in Gandaki Province, five hydropower have taken the Survey License, estimated production from these hydropower plants is nearly 125 MW (Annex I). Similarly, 38 hydropower projects have already taken the construction license with worth of 1315 MW (Annex II).

Similarly, many hydropowers are in the process of applying for survey and construction. Among them twelve have submitted the application for survey license the sum total of the electricity generation from them is 1430 MW (Annex III). On the other hand, 26 hydropower have submitted application for construction license, the sum total of their generation is 2347 MW (Annex IV). Similarly, the currently operating hydropower plants are listed in Annex V.

Apart from the hydropower plants, there are operation solar plants as well which supports the electricity generation. Particularly there are two solar power plants, one in Tanahu and another in Kaski with total capacity of 5MW and 4.4 MW (Annex VI).

In conclusion, The Gandaki Basin holds immense potential for hydropower generation, but careful consideration of environmental and social impacts is crucial. Climate change adds another layer of complexity, requiring flexible adaptation strategies and robust infrastructure design. Further research investigating the basin's specific climate vulnerabilities and exploring alternative renewable energy sources will be crucial for ensuring sustainable energy development in the region.

2.2 Description of Major River Basins within Gandaki

2.2.1 Kaligandaki

Kaligandaki is a significant sub-basin of the Gandaki basin with various uses and characteristics discussed below.

Physiographic And Climatic Characteristics

The Kaligandaki basin lies between 27.8° N, 29.3° N, 82.86° E, and 83.6° E, with a catchment area of roughly 11851 Km^2. As shown in Figure 15, the Kaligandaki River system flows through the Manang, Mustang, Myagdi, and Syangja districts of Gandaki Province with an elevation ranging from 190 m to 8168 m above mean sea level (Yuqin et al., 2019). The mean annual precipitation of this basin is around 1396 mm most of which occurs between June to August. A significant topographic variation is seen in this region. The chilly temperature in the high heights and some glacier coverage in the upper portion of the subtropical climate with high precipitation in the South of Kaligandaki Basin plains is seen. Whereas, the center section of the basin is largely hilly with high-altitude topography. This climatic information is based on the data (temperature and precipitation) gathered from the Department of Hydrology and Meteorology (DHM) by Dahal et al., (2022).

Water Balance

The water balance and hydrological regime of the Kaligandaki basin are highly seasonal and could be influenced by climate change (Mishra et al., 2014). Previous studies have shown that the water balance components like evapotranspiration, snow melt, and water yield of the Kaligandaki basin are affected by increasing temperature and increasing precipitation. It has been observed that there are increasing trends in temperature, approximately by 0.03 to 0.08 °C per year, and mixed trends in seasonal precipitation (Mishra et al., 2014). Climate change is causing a rise in the river's annual average discharge (Dahal et al., 2022). In a study done by A. R. Bajracharya et al. (2018), modeling results predicted a potential 50% increase in discharge at the outlet of the basin. Snowmelt's contribution is largely affected and is projected to increase by 90% by 2090. This shows a need for effective planning and management of water supply and demand in the Kaligandaki basin to reduce the possible risks associated with an increase or decrease in hydrological flow. The increase in reliable water availability from the catchment could be beneficial, but its negative effects such as floods and GLOF will be hard to ignore.

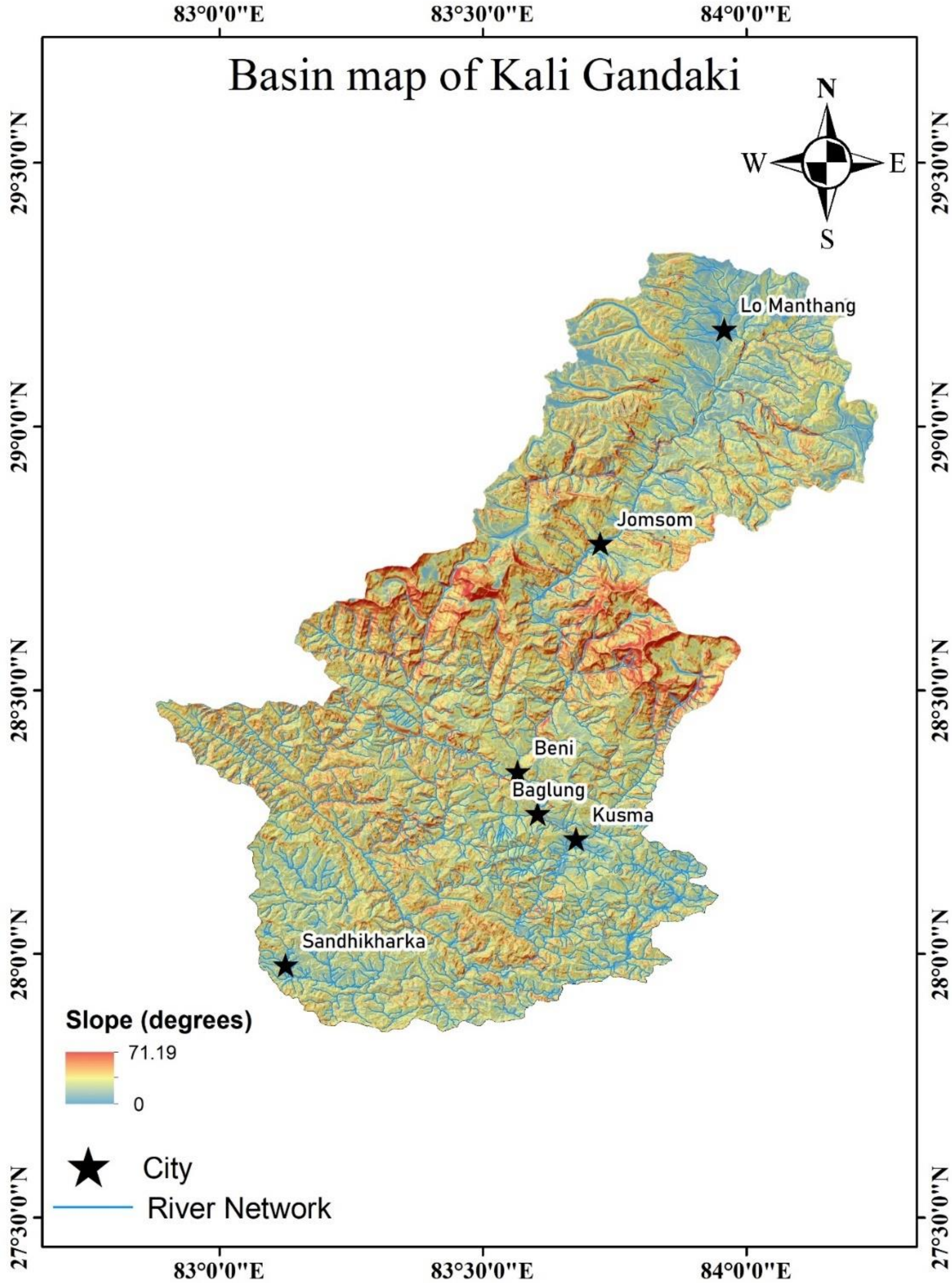


Figure 15: Kaligandaki River Basin.

Domestic Water Use

The Kaligandaki River is a crucial source of water for domestic use in the surrounding communities. However, the available information and investigations related to domestic water use in the Kaligandaki basin are limited. A study done by Manandhar et al., (2011), showed that the Water Poverty Index (WPI) of Kaligandaki basin is from 37.1 to 56.5 indicating some level of water stress in the basin. WPI is a tool that assesses water stress by linking physical estimates of water availability with socio-economic drivers of poverty. The study showed relatively higher water sufficiency in terms of domestic water use for drinking compared to agricultural use in the basin. Studies also suggested that the people from the Mustang region of the Kaligandaki Basin have perceived the impact of climate change on the water resources of the region (Manandhar et al., 2013). Additionally, the result of the study showed that the increase in temperature and average annual discharge in the Kaligandaki River as well as poor water use, is a major problem at all levels in the basin. Therefore, climate change has a significant effect on the hydrological regime of the basin and social settings like population growth can have increased water demand which defines the requirement of policy interventions and management plans to improve the overall water poverty situation in the basin and maintain a consistent access to useable water.

Irrigation Potentials and Development

Gandaki River basin has been identified as a water surplus basin with the potential to irrigate the adjacent Terai area (WECS, 2002). The Kaligandaki is the longest river in the Gandaki basin and has a considerable flow of water that can be used for both power generation and irrigation. The water from the Kaligandaki River can be through irrigation schemes like canal systems and reservoirs to enhance agricultural productivity along its basin. However, climate change has a prominent effect on the temporal and spatial variation of water balance components in the Kaligandaki basin. Studies showed that there will be a rise in the river's annual average discharge and average annual volume with time (Bajracharya et al., 2018; Dahal et al., 2022). Therefore, careful management and sustainable practices are necessary to ensure that the available water resources are used effectively and continue to support the communities that depend on them. An effective management of water supply and demand in the basin considering the effect of climate change during monsoon and dry seasons is required.

Two major irrigation projects in Kaligandaki River contribute to increasing the water availability in the dry season for irrigated agricultural areas in the region. The Kaligandaki Tinau Diversion Multipurpose Project and Kaligandaki Nawalparasi Diversion Project. The Kaligandaki Tinau Diversion Multipurpose Project is an inter-basin Water Diversion Project where the conventional practice of water management is used. The water from surplus basins is transferred to deficit basins. The length of the transfer tunnel of the project is 25 km with a design discharge of 66 m^3/s

(Irrigation Master Plan, 2019). This tunnel transfers water from the Kaligandaki River to Rupandehi District. The project aims to provide irrigation to 98,601 ha of land in the dry season in the districts of Rupendehi and Kapilvastu. The irrigation command area is divided into two parts, eastern and western. The net command area is 24,191 ha and 13,534 ha in the dry season and wet season for the Eastern Command Area. Similarly, the net command area is 74,410 ha and 61,834 ha in the dry season and wet season for the Western Command Area respectively (*DWRI*, 2024). The project also has a secondary product of hydropower and includes a hydropower development component along the diversion route

Kaligandaki Nawaparasi Diversion Project also diverts the water from the Kaligandaki River by a tunnel of length 6 km with a design discharge of 17 m^3/s. The project provides irrigation to almost 11,500 ha of agricultural land and also includes a small hydropower station of 4 MW. The project has been a subject of discussion due to its potential impact on the local ecosystem and population. However, the project has been considered uneconomical by the Irrigation Master Plan (2019).

Hydropower Potential and Development

With its steep gradients and high flow, the river has substantial hydropower potential. As discussed above, precipitation and temperature changes play a crucial role in altering the hydrology of the Kaligandaki River. The Kaligandaki 'A' Hydroelectric Project is the biggest hydropower project in the country till date contributing to Nepal's energy supply. The project with an installed capacity of 144 MW, generating an annual output of 860 GWh. The project is a run-of-the-river type project whose construction started in 1997 and was completed in April 2002.

Studies have shown that there does not seem to be a problem with water availability in the Kaligandaki basin as the river's average annual discharge seems to increase in the future. Thus, an increase in hydropower production with adaptation strategies can be future benefits associated with an increase in the river's average annual discharge which can also lower risks associated with an increase in the river's hydrological flow. The Kaligandaki River is becoming a hub for hydropower projects, with new hydropower projects either proposed or underway along the Kaligandaki River.

- The Tiplyang Kaligandaki hydropower project with a capacity of 58 MW.
- The Middle Kaligandaki hydropower project with a planned capacity of 150 MW.
- The Kaligandaki Gorge hydropower project with a proposed capacity of 164 MW.
- The Upper Kaligandaki hydropower project with a planned capacity of 65 MW.

Industrial Use

Kaligandaki River is utilized for industrial purposes primarily for hydroelectric power generation. As discussed, earlier Kaligandaki's swift flow and significant water volume make it an attractive resource for hydroelectricity projects. Along with operational hydropower projects, there are several projects planned or under construction. The hydroelectric projects contribute to meeting the energy needs of the country as well as have the potential to export surplus electricity to the nearest region. This shows the significance of the Kaligandaki river in the industrial development and economic growth of the country. Additionally, the water from the Kaligandaki river is also used for irrigation benefiting farms along its bank and contributing to the agricultural economy. Effective irrigation can lead to the development of agro-based industries, thereby boosting the local economy. It also provides employment opportunities in both the agricultural and industrial sectors. However, it is important to manage these industrial activities carefully to minimize environmental impacts and ensure the river's sustainability.

Environmental Use

It is well known that development projects in the sector of irrigation especially in hydropower is largely seen in the Kaligandaki river. But it is essential to balance development with environmental sustainability and the needs of local communities. The water of Kaligandaki river support diverse ecosystem, including, vegetation along river bank, habitat for fish species and other wildlife. The river also plays a crucial role in influencing local climate. To maintain the ecological health of the river assessing environmental flow in the Kaligandaki river is important to ensure that enough water is available to sustain its ecosystem. A comprehensive study has been conducted to determine the most suitable methods for allocating e-flows in the Kaligandaki River, which is crucial for sustaining the riverine ecosystem's annual dynamic demand (Suwal et al., 2020). Since Kaligandaki river is considered for multiple hydropower and irrigation projects, it is important to balance these developmental activities with environmental sustainability in the region. Thus, proper planning and sustainable management practices along the basin is essential.

Tourism

Kaligandaki river offers a blend of natural beauty and adventure tourism. This is one of the famous rafting rivers in Nepal with an exhilarating experience as the river flows through one of the deepest gorges in the world. With the majestic view of Mt. Dhaulagiri and Mt. Annapurna, the journey through Kaligandaki is full of beautiful waterfalls and endless suspension bridges, adding to the adventure and charm of the area. The region is not only rich in natural beauty but also in cultural heritage. Various temples along the riverbanks, and the jungle is full with wildlife, offering a serene and spiritual experience. Kaligandaki region is a perfect tourism spot for both adventure seekers or someone who appreciates the tranquility of nature.

2.2.2 Marshyangdi

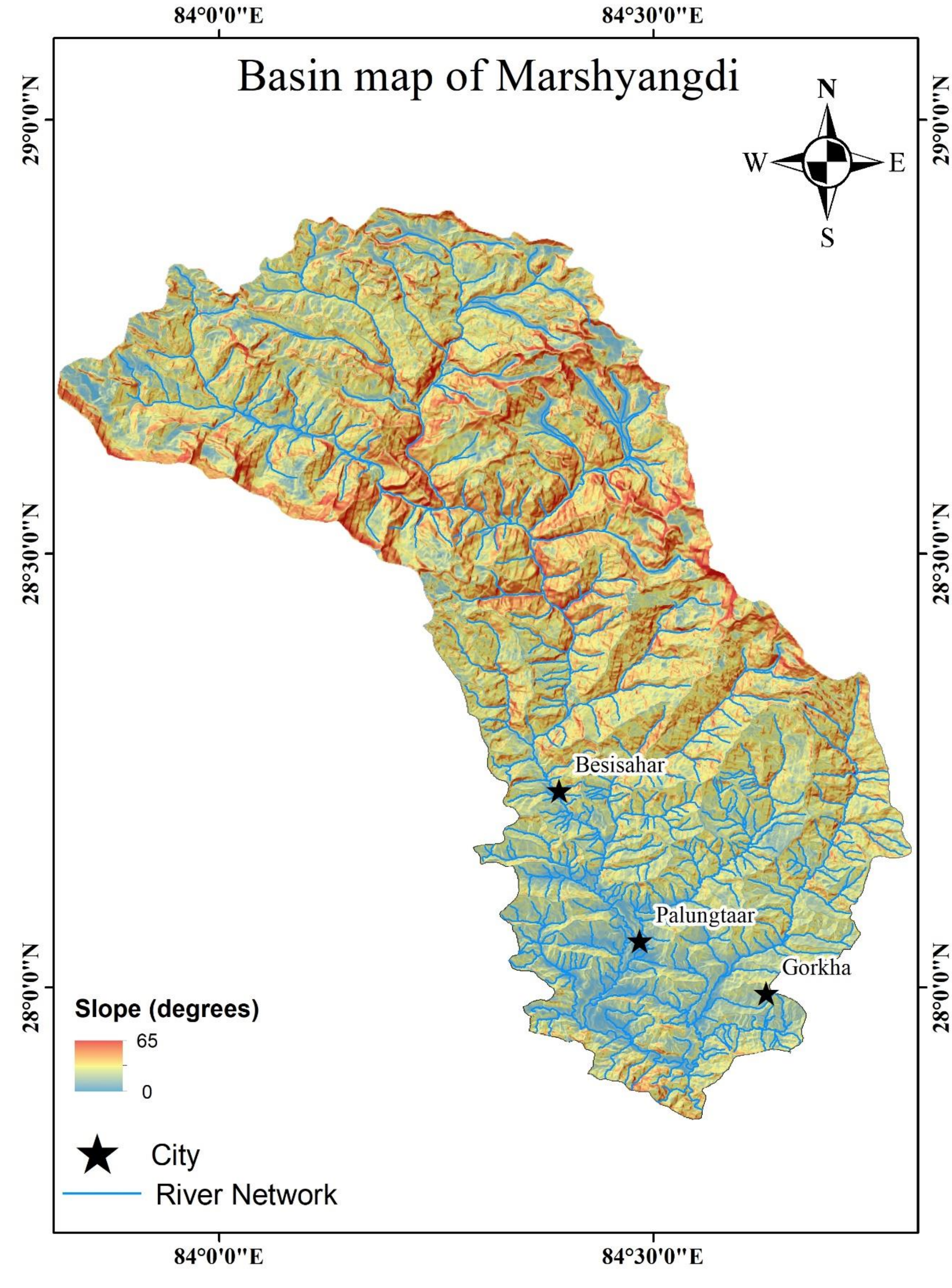


Figure 16: Marshyangdi river basin.

Physiographic And Climatic Characteristics

The Marsyangdi basin is located between 27°56’13” N to 28°54’03” N latitudes and 83°47’23” E to 84°41’51” E longitudes. It has a total area of 4,058.59 km^2 with a length of 150 km. As shown in Figure 16, Marsyangdi river originates from the northern slopes of the Annapurna massif in the Himalayas. The Marsyangdi river flows through four districts namely, Manang, Lamjung, Gorkha, and Tanahu with an elevation ranging from 357 m. to 8,055 m. above sea level and ultimately confluence with the Ganges River. The basin extends from the high Himalayan in the north to the lesser Himalayan region in the south and is a mountainous basin with complex topography and diverse hydro-climatic conditions (Basnet et al., 2019). Nar Khola, Dudh Khola, Dordi Khola, and Chepe Khola are the major tributaries of the Marshyangdi river.

The Marsyangdi River exhibits diverse hydro-climatic conditions starting from the cold, arid climate of the high Himalayas to the subtropical climate of the lower plains. The average annual precipitation received in the Marsyangdi basin is 2157.5 mm with the maximum flow occurring in August, while the minimum flow is in March, indicating high precipitation in the summer monsoon (Adhikari et al., 2022).

Water Balance

The water balance of the Marsyangdi River basin is highly influenced by its climatic conditions and mountainous geography. The hydrology of the basin is impacted by the monsoonal rains and the melting of snow and glaciers. Studies have shown that the basin’s average annual evapotranspiration constitutes about 27% of the precipitation, which is a significant component of the water balance in the region (Adhikari et al., 2022). A previous study on the climate change projection for the Marsyangdi River basin suggests that both precipitation and temperature will increase by 2090s (Khadka & Pathak, 2016). Thus, climate change is evident in this region which should be considered for water resource management and planning in the Marsyangdi River Basin.

Domestic Water Use

Marsyangdi River is a crucial source of water for domestic use and supports local agriculture and domestic water supply in the adjacent villages. The water from the river and its tributaries can be used by the communities living on the banks for domestic purposes like drinking, cooking, sanitation, and irrigation. Hand pumps and tube wells are common in the lower region (Terai), while in hilly and mountain regions, surface water from the river and its tributaries is often used (Bhusal et al., 2023). However, the available information and investigations on the extent of these uses are limited. The climate change impact and social settings like population growth can affect future conflicts in water demand and supply. Therefore, proper water resources management and planning are essential in the Marsyangdi basin to ensure continued access to clean water for domestic purposes without distressing the ecosystem of the river.

Irrigation Potentials and Development

While the primary focus in the Marsyangdi River Basin has been on hydropower, there is potential for irrigation development, especially considering the hydrological characteristics and groundwater availability in the region. Marsyangdi River receives water from snowmelt, glaciers, and rainfall ensuring a relatively reliable water supply throughout the year. The availability of water for irrigation in many areas along the Marsyangdi river where agriculture is the main economic activity can provide enhanced agricultural production and food security. Therefore, proper planning for the sustainable development of the basin's water resources, balancing the needs of hydropower along with irrigation and other uses is required.

Hydropower Potential and Development

The Marsyangdi river basin in Nepal is known for its significant hydropower potential due to its fast-flowing water and steep gradients. At present, two hydropower projects; the Marsyangdi Hydropower Project with a capacity of 69 MW, and Middle Marsyangdi Hydroelectric Project with a capacity of 70 MW are operating in the basin. Additionally, the Upper Marsyangdi Hydroelectric Project with a planned capacity of 600 MW, Lower Manang Marsyangdi Hydroelectric Project with a planned capacity of 100 MW, and Nyadi Hydropower Project with a planned capacity of 30 MW are under different stages of development. Sustainable practices should be adopted to maintain a balance between hydropower development and environmental conservation. Studies have shown that equitable benefit sharing among stakeholders and water use conflicts exist among different industries and communities (Vikas Sanstha & Nepal, 2019). Thus, effective water resource management and planning is crucial for hydropower development to maintain a consistent water flow in the river, adapt to the potential impacts of climate change on the Marsyangdi River basin, and resolve possible water conflicts.

Industrial Use

The water of Marsyangdi river is significantly used for hydropower generation, which is a major industrial use. Several hydropower projects are operational, and many are under different stages of development. These projects help meet the country's growing demand for electricity, both for domestic consumption and export.

Other than hydropower, the Marsyangdi river basin can also serve other industrial sectors like agriculture and tourism. The water from the Marsyangdi river can be used for irrigation in the adjacent agricultural farms. Farmers managed irrigation schemes and canals can be built to divert water from rivers to the farmlands. The Marsyangdi River is also a famous destination for adventure tourism like river rafting and kayaking. The scenic beauty and cultural aspect of the villages along the river make it a famous tourist spot for adventure, nature, and culture. However, sustainable management practices are required to balance these industrial uses with environmental conservation and maintain the river’s ecosystem.

Environmental Use

Marsyangdi River has significant environmental importance due to its role in the region's ecosystem. It supports diverse aquatic and terrestrial ecosystems. A study assessing the water quality of the Marsyangdi River found that the river has excellent water quality suitable for sustaining the aquatic ecosystem (Singh et al., 2021). Since the Marsyangdi river is primarily used for hydropower generation, it is necessary that environmentally sustainable hydropower plants should be built to provide clean energy for local communities without significantly harming the river's ecosystem. The scenic beauty and biodiversity along the Marsyangdi River make it an attractive destination for ecotourism. However, proper planning and management of the available water resources are essential to mitigate any adverse environmental impacts and balance human needs with environmental conservation.

Tourism

Marsyangdi River is one of the tourist attractions as it is famous for adventure sports like river rafting and kayaking. The fast-flowing water and its scenic beauty along the river fascinate tourists from all around the world. There are many resorts, tourist lodges, and adventure sports companies along the river. The Marsyangdi River is a mountainous river with a steep topography which makes it a destination for trekking and hiking for both local and international tourists. The famous Annapurna circuit passes through the Marsyandi region. Tourists can also enjoy the local culture of the traditional villages along the river. Overall, tourism in the Marsyangdi River region offers an exclusive blend of adventure, culture, and nature.

2.2.3 Madi

Physiographic And Climatic Characteristics

The Madi River is located in the central part of Nepal covering a north-south distance of about 68 km (Figure 17). The basin occupies an area of 1123 km^2 within an altitude ranging from 307m to 7937m above mean sea level positioned at 27°58′12.72″N latitude and 84°15′59.40″E longitude (Khanal & Watanabe, 2017). The Madi River has a total of 14 tributaries, the largest is the Midim, and the others include Rudi, Madkyu, Kyaduso, Nyache, Idi, Madame, Paste, Birdi, Khalte, Pisti, Risti, Sange, and Kalesti. The river originates from the Annapurna II glacier and is supplemented by other features like the Kahphuche Lake (Pokharel & Regmi, 2024).

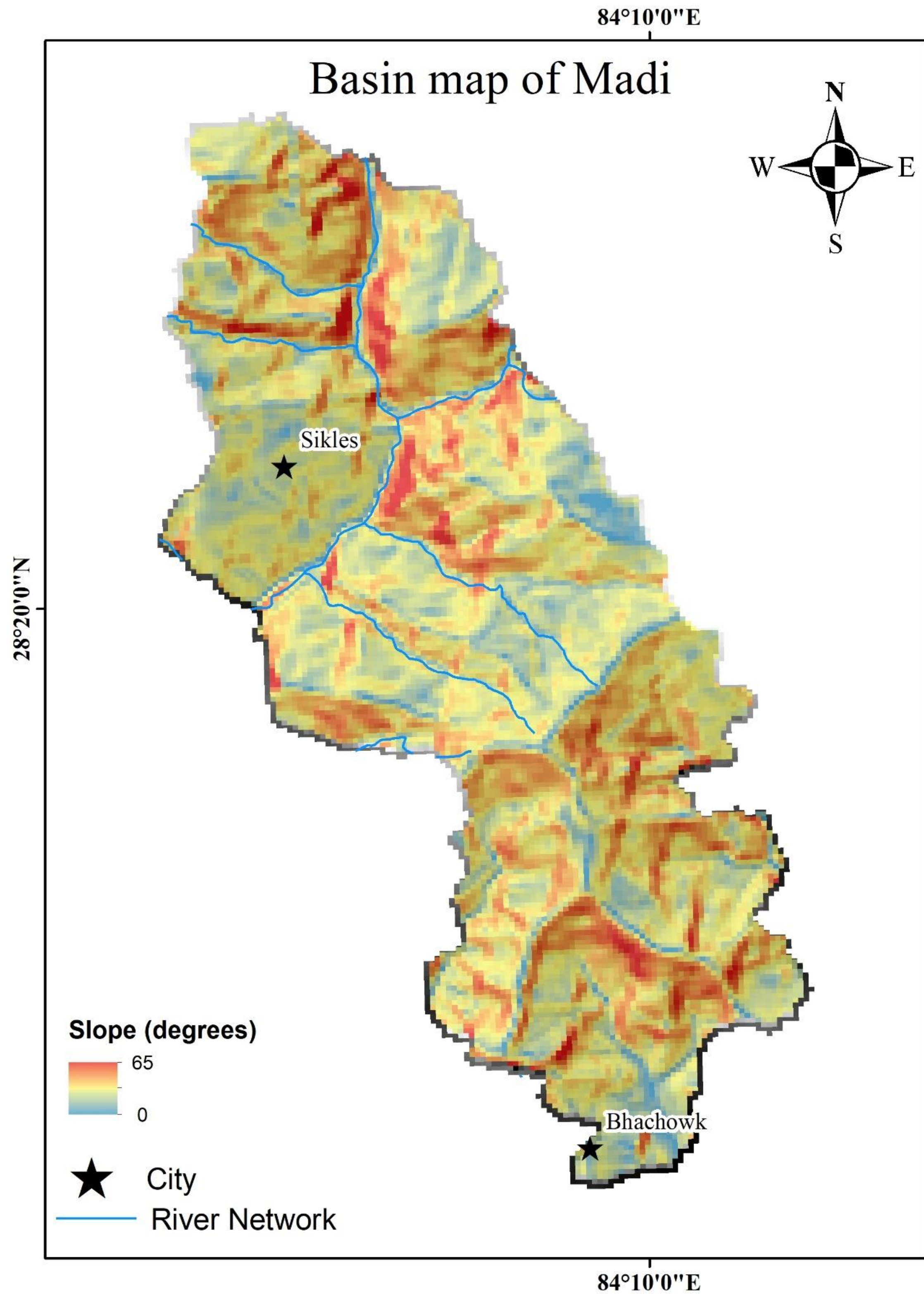


Figure 17: Madi river basin.

The Madi River basin has a diverse climatic condition with differences in the altitude, gradient, and orientation of slopes. The basin comprises almost all the ecological regions of the mountain areas, the higher Himalayan region, the middle Himalayan region, and the lesser Himalayan region. Almost 80% of the total precipitation of the basin is received in summer monsoon from June to September with a varied mean annual precipitation ranging from 1,795 mm at Damauli in the south to 3,743 mm at Sikles in the north. The Madi watershed can be classified into five major temperature zones which include the i) sub-tropical zone with a mean annual temperature between 20 and 35ºC; ii) warm temperate zone with a mean annual temperature between 15 and 20ºC; iii) cool temperate zone with a mean annual temperature between 10 and 15ºC; iv) sub-alpine and alpine zone with a mean annual temperature below 3 and 10ºC; and v) arctic line zone with a mean annual temperature below 3ºC (Khanal & Watanabe, 2017).

Water Balance

Water balance explains how much water is retained in a basin, how much is lost through evaporation and plant use, and how much exits the system as runoff. It helps in managing water resources, predicting water shortages, and understanding the effects of climate variability and human activities on water systems. The Madi River Basin receives most of its annual precipitation (almost 80%) during the monsoon season. Since the Madi River is mainly used for hydropower production, the water balance of the Madi River is highly influenced by the use of water in hydropower other than precipitation and evaporation. However, the seasonal flow variations and the impact of climate change also affect the water balance of a basin.

A recent study found that topographically influenced climatic conditions are significant in controlling low flow at larger scales and human-induced changes in land use and land cover are crucial at smaller scales (Khanal & Watanabe, 2017). A study by Pokharel & Regmi, (2024) used an integrated modeling approach to analyze historical and future hydroclimatic trends. The future projections indicated an increase in annual precipitation and temperature in the Madi basin which can affect the streamflow and cause an overall increasing trend. The streamflow in the Madi River Basin is projected to increase in the future with a significant flow reduction in early months and high flow in monsoon. Water flow data recorded at Sisaghat in the Madi River between 1978 and 1995 show that the mean flow ranged from 16.8 m^3/s in February to 225.7 m^3/s in August (Khanal & Watanabe, 2017). Catchment area, precipitation, altitude, and steepness of the slope are important factors in controlling the flow in the Madi watershed during the dry season. The uppermost part of the Madi River is covered by snow and ice. The melting of snow and ice contributes to a considerable volume of water during the dry season. Thus, it is important to understand the water balance in the context of climate change and sustainable development for regions like the Madi River basins, due to its vulnerability to hydroclimatic variation.

Domestic Water Use

Madi River is an important source of water for households and communities within the basin for various domestic purposes such as drinking, cooking, bathing, cleaning, and sanitation. This usage depends on factors like the population of the region, water availability, and other climatic factors. Many households in the Madi watershed, particularly from the upper slopes in the Middle Mountains, have migrated permanently to the valleys and lower slopes because of an increasing shortage of drinking water (Khanal & Watanabe, 2017). Therefore, effective water management for domestic use is essential in the Madi River basin to ensure a sustainable and reliable water supply to fulfill the demands of the community.

Irrigation Potentials and Development

The Madi River and its flow significantly influence the irrigation supply of the surrounding agricultural land. According to a study on low-flow hydrology in the Madi Watershed, stream flow remains very low for about 9 months a year, from October to June (Khanal & Watanabe, 2017). Madi River is nearly 25% of the total Madi River Basin area under cultivation. Many households from the upper slopes in the Middle Mountains have migrated permanently to the valleys and lower slopes because of an increasing shortage of drinking water, due to which the agricultural lands in their place of origin have been abandoned and left idle. However, the lower and middle regions of the watershed have been extensively utilized for agricultural purposes, but the low-flow period poses challenges for irrigation in the Madi river basin. (Khanal & Watanabe, 2017).

Madi-Dang Diversion Project is an ambitious initiative of The Department of Water Resources and Irrigation to address issues like water scarcity. This is a multipurpose project designed to provide irrigation and generate electricity with irrigation being the major component. In this project, the water from the Madi River will be diverted to the Dang Valley via a 25 km tunnel with a design discharge of 24 m^3/s and a hydropower plant of 61 MW will be constructed. It would supply sufficient water for irrigation of about 17,000 ha of agricultural land. However, this project was found to be uneconomical for the above parameters and is under revision(Irrigation Master Plan, 2019). Some multipurpose hydropower projects like The Madi Multipurpose Hydro Power Project and Project Naumure Multipurpose Project also aim to provide irrigation for the adjacent region. These multipurpose projects, involving irrigation and hydropower enable better management of water resources and play a crucial role in sustainable development of the region offering a blend of environmental, economic, and social benefits.

Hydropower Potential and Development

Hydropower in Nepal is highly vulnerable to climate-induced variations, including alterations in precipitation patterns and glacier melt dynamics, necessitating focused research (S. R. Bajracharya

& Shrestha, 2011; Hamududu & Killingtveit, 2012; Xu et al., 2009). Madi River Basin is a significant basin due to its hydropower potential and the large number of hydropower projects constructed or to be constructed in the basin. It is one of the glacier-fed systems in Nepal as the uppermost part of the Madi River is covered by snow and ice and the melting of snow and ice contributes a considerable volume of water during the dry season.

The Madi Khola has several hydropower projects at different stages of development. At present, there are 23 hydropower projects either at the operation, generation, or survey license phase in the Madi basin with a combined potential power generation of 377.37 MW (Pokharel & Regmi, 2024). However, it is important to design resilient hydropower systems that can adapt to changing environmental conditions for long-term sustainability.

Industrial Use

The water of the Madi river is significantly used industrially in Nepal, particularly for hydropower projects. Several hydropower projects are operational, and many are under different stages of development which is a major industrial use. These projects help in contributing to the renewable energy sector.

Other than hydropower, the Madi river basin can also serve other industrial sectors like agriculture and tourism. The government of Nepal is also planning to operate a multipurpose irrigation project along the Madi River. Water adventures like rafting and kayaking in the river, nature walks and birdwatching in the lush forests along the basin provide opportunities of ecotourism in the region and support the local industry in Nepal.

Environmental Use

The Madi River supports a variety of ecosystems and species, this biodiversity and ecological balance needs to be maintained which can be done by effective watershed management of the region. The Madi River area is prone to landslide dam

outburst flood risks and managing these risks is important for protecting communities and maintaining the environmental integrity of the river (N. Khanal & Gurung, 2013). Mitigation in terms of landslide control is immediately needed considering the potential property loss that can be seen as many hydropower projects are proposed in the area and numerous settlements are present downstream.

Research indicates a significant impact of climate change and human activities on water availability, like increased flow peaks during the rainy season and decreased flows during the dry season in the Madi River basin (Khanal & Watanabe, 2017). The water availability in the basin is vital for agriculture, drinking water, and other uses. Therefore, and effective management of Madi

River affects climate change resilience, biodiversity conservation, water resource availability, and disaster risk reduction.

Tourism

Madi River is located in the beautiful Annapurna region of Nepal. It offers a variety of tourism opportunities, especially in adventure and experiencing local cultures. The scenic beauty along the river with traditional villages and local cultures fascinates tourists from all around the world. Madi Khola is also known for water adventures like white-water rafting and kayaking. The area is not only a treat for adventure seekers but also for those looking to immerse themselves in the local Nepalese culture and the stunning natural beauty of the Himalayas.

2.2.4 Seti

Physiographic And Climatic Characteristics

The Seti River Basin emerges from the glaciers and snowfields around the peaks of Api and Nampa (Figure 18). The basin is located between 27050' and 28010' N latitude to 83050' and 84050' E longitude at an altitude ranging from 540 m to 1020 m above sea level covering an area of 200 km2. The catchment area of the basin is 7,427 km2. The great topographical and geological variations are found in the basin. The Seti River is snow-fed river that originates near the base of the Mount Machhapuchhre and Mount Annapurna IV. The river flows down to the lesser Himalaya along the steep and narrow valley of Pokhara (Pokharel et al., 2018).

The Seti River Basin experiences the sub-tropical to sub-alpine types of climates with an average annual temperature of 19.30 °C and precipitation of about ~ 3710 mm/year. The region receives intense rainfall among which more than 80% of the total rainfall is received during the monsoon season from June to September. The mean rainfall in the middle of the river basin is 5700 mm per year (Lumle station-70 1740 m above sea level), which is the highest mean rainfall in the country (Pant et al., 2021).

Water Balance

The water balance of the Seti River basins can be affected by various factors, including precipitation, evapotranspiration, and changes in storage due to human activities or climate change. The catchment area of the basin is about 2966 km^2 and the major tributaries are Sardi, Mardi, Yamgdi, Kali, Bijayapur, Kotre, and Madi rivers. The basin is characterized by high seasonality in terms of discharge with a minimum during February - March and maximum during July-August (Pant et al., 2021).

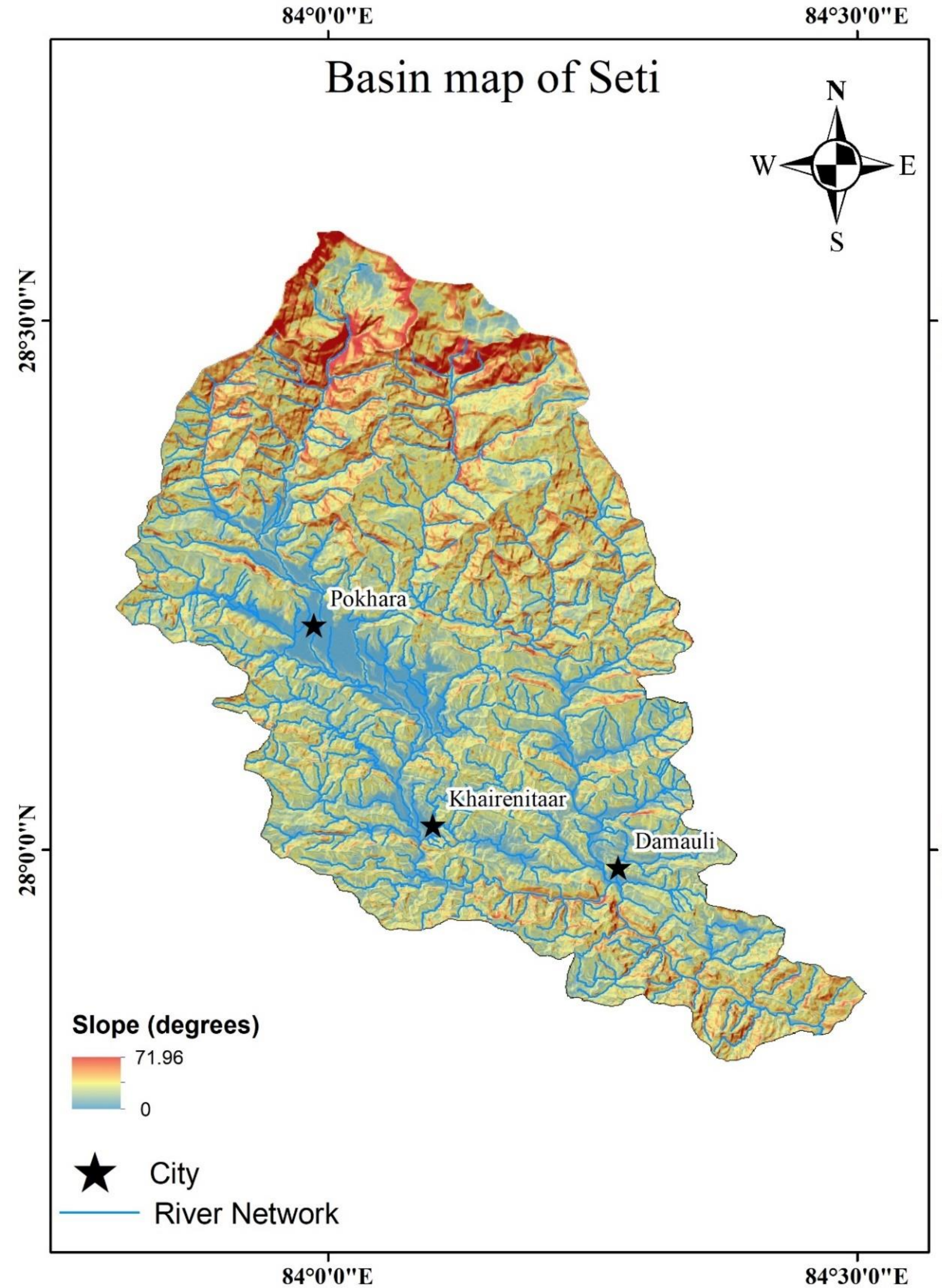


Figure 18: Seti River basin.

A study on the West Seti River Basin, which is part of the Narayani basin, has shown that climate change impacts the water balance and hydrological extremes in the regions (Budhathoki et al., 2021). The research indicates that the Middle Mountain region of the basin is expected to receive the highest increase in precipitation (11.2%) and water yield (18.2%) compared to the High Mountain and High Himalayas regions. On the other hand, the High Himalayas are expected to have the highest increase in evapotranspiration (19.9%) (Budhathoki et al., 2021). The study also projects that low flows in the basin will decrease by −15.5% and −19.3% under different climate scenarios, while high flows are expected to increase by 10.7% (Budhathoki et al., 2021). Thus, it is important to develop adaptive strategies in river basins in context of potential risks and opportunities posed by climate change on water resources.

Domestic Water Use

The Seti River is the main source of water for more than 1 million 76 people residing in core urban area and the neighborhood region (Rupakheti et al., 2017). The river provides water for supporting agriculture in the regions it flows and for daily household needs and drinking purposes in nearby settlements. It also has cultural and religious significance, several sites along its banks are used for ceremonies, cremations, and pilgrimages. The river's domestic uses are intertwined with the livelihoods and cultural practices of the local population, making it a vital resource for the region.

Irrigation Potentials and Development

The Seti River has significant potential for irrigation. The river's flow is harnessed by the Seti Hydropower Station, which uses water from the river for electricity generation. The electricity generated is used for various purposes, including irrigation. The Seti River in Nepal has been the subject of studies assessing its water quality and potential for irrigation use. A study published in 2021 examined the hydrochemistry of the Seti River Basin, particularly concerning its suitability for drinking and irrigation purposes (Pant et al., 2021). The research involved collecting water samples across different seasons and analyzing various chemical parameters. The study suggested that due to the quaternary landfills and the lacustrine deposits, the basin has fertile soil where the highly urbanized Pokhara Metropolitan city is located (Pant et al., 2021). The findings indicated that the water in the Seti River Basin is mildly alkaline, with a pH of around 8.40, and the solute acquisition processes are largely controlled by carbonate weathering, with a minor contribution from silicates. The water's chemical composition can affect its suitability for irrigation. Overall, the study suggests that the Seti River's water quality has mostly retained its natural state, which is favorable for irrigation. However, regular monitoring and assessment are required to maintain the quality.

Hydropower Potential and Development

The Seti River has been recognized for its hydropower potential. A study used SWAT modeling and spatial technology to assess the hydropower potential in the Seti Gandaki River. The study identified 171 potential hydropower locations and estimated a total potential of 529.97 MW at 40% exceedance. Currently, The Seti River Basin is home to several hydropower projects. The West Seti Hydropower Project with an aim of generating 1200 MW of electricity and The Seti Khola Hydropower Project with an installed capacity of 22 MW.

Industrial Use

The Seti River has both natural and industrial significance. The Seti Gandaki River is a major attraction for tourists, adding to the domestic economy of the region. The Seti River plays a significant role in hydropower, irrigation and tourism industry. The Seti is also one of the holiest rivers in Nepal, worshiped in Hinduism as a form of Vishnu. The Seti gorges around Pokhara and is a major attraction for tourists worldwide, thus has a huge impact in the tourism industry of Nepal. The Seti River is also a site for hydropower development with a huge potential in hydropower industry. Although the Seti River's natural beauty, cultural significance, and potential for hydropower make it a vital resource in Nepal, there are instances of contamination. The Seti River receives the untreated domestic and industrial wastes and agricultural runoff from the vicinity of urban and semi-urban areas which has increased the concentrations of the variables such as the turbidity, conductivity, free carbon dioxide, alkalinity, etc. (Pokharel et al., 2018). Therefore, regular monitoring of the basin is essential to maintain the water quality and ecological integrity. A proper water management policy and planning is required to ensure sustainable and efficient use of water resources while supporting economic development.

Environmental Use

The Seti River plays a vital role in shaping the various ecological and economical activities, and biodiversity conservation. It provides fresh water that is essential for drinking, agriculture, and sustaining local ecosystems. The riverbanks and the surrounding areas are home to various species of plants and animals. However, the highly urbanized Pokhara Metropolitan city is located in this basin. The river faces ecological challenges, such as pollution within the metropolitan area, which affects downstream ecosystems, wildlife habitats, and agricultural practices. Owing to the high population density, the basin is also influenced by the high anthropic interferences.

The Seti River receives untreated domestic and industrial wastes and agricultural runoff from urban and semi-urban areas in and around the basin, which could be potential threats to the sustainability of the riverine environment of the SRB. A study on the large mammals on the Seti River Basin has found that the wildlife habitats in the Seti River Basin is more vulnerable due to high anthropogenic disturbance and habitat fragmentation (Adhikari et al., 2021). The Seti River's natural beauty, cultural significance, and environmental challenges make it a fascinating water course in Nepal. However, a sustainable water management policy and planning is required to preserve the natural beauty and ecological balance of the river system.

Tourism

Tourism around the Seti River in Nepal is quite vibrant and offers a range of activities for visitors as the Seti gorges around Pokhara and is a major attraction for tourists worldwide. The Seti River is famous for its dazzlingly white water, which appears milky due to the limestone it carries from the Annapurna region. White-water Rafting, kayaking and canyoning are some of the water adventure sports tourists can experience in this river. Fishing and bird watching along the river can also be done as it is the habitat for many fish for bird species.

The river's banks are also important sites for religious rituals among the local population. The Seti River and its surroundings are also renowned for their natural beauty, offering a serene landscape that captivates tourists. The Seti River also carves spectacular natural sight. The Seti River basin provides a variety of experiences to tourists in the form of adventure, culture and nature.

2.2.5. Daraudi

Physiographic And Climatic Characteristics

The Daraudi River Basin constitutes a significant component of the Gandaki River Basin system (Figure 19). It serves as a left tributary of the Marshyangdi River, which eventually joins the Trishuli River. The basin lies between 27°59'11.68" N and 84°33'55.32" E to 28°2'8.96" N and 84°36'10.50" E. The upper part of the Daraudi river basin lies in Manaslu Conservation Area and it flows in the Mahabharat region. The main source of river is Glacier Lake which originated from Naradhpokhari River (Banstola & Sapkota, 2019). Total area of Daraudi watershed is estimated to be 60,610 ha and the length of the Daraudi river from the Baluwa in the north to Ramsahaghat in the south is estimated at 117.91km (Pokhrel, 2022).

The climate in the Daraudi Basin varies significantly with elevation. This basin encompasses a diverse array of landscapes, including mountainous terrains and valleys. Majorly the Daraudi River basin consists of Lesser Himalayan and Higher Himalayan Rocks (Pathak, 2019). The upstream areas experience a cold climate due to the high altitude, while the downstream areas have a warmer climate.

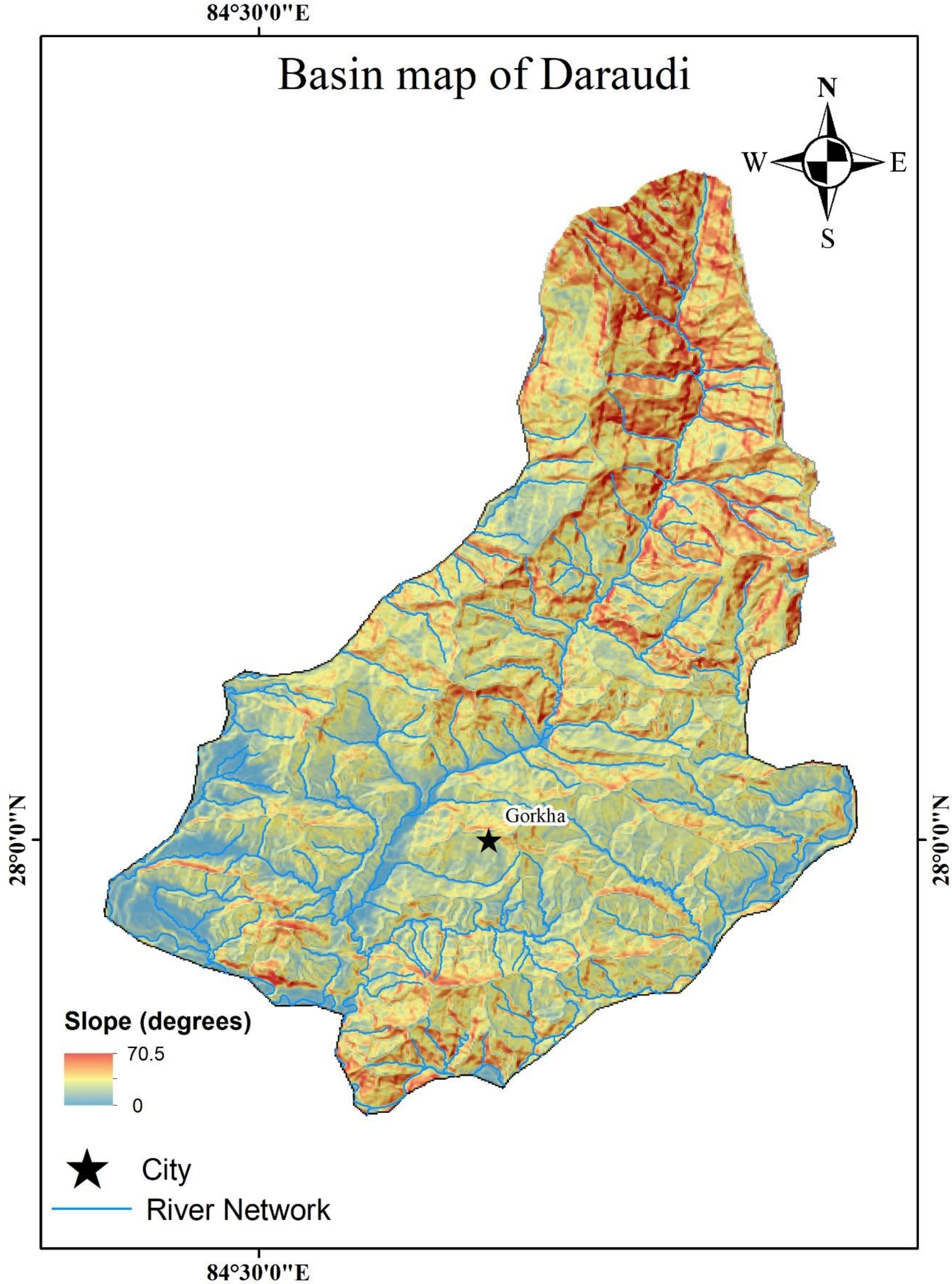


Figure 19: Daraudi river basin.

Water Balance

There are a number of tributaries (total 37, major 16) that fed Daraudi within this length. The total length of these tributaries is estimated at 260.46 km. Thus, a total of 378.37 km long basin and the sub-basin have consisted along the length of Daraudi River and its tributaries (Pokhrel, 2022). To maintain a balanced water system, it's essential to consider all aspects of the hydrological cycle, including precipitation, evaporation, infiltration, and human extractions for agriculture or other uses. The water used by the Daraudi River's hydroelectric plant for electricity generation is the major outgoing flow of the river. However, a trend analysis of rainfall from the last 30 years (1988 to 2017 AD) recorded from the Jagati station by Department of hydrology and Meteorology (Banstola & Sapkota, 2019). It was found that the total annual rainfall is increasing at the rate of 42.28 mm per year. Similarly, the 24-hour period maximum rainfall was found to be increased at the rate of 10.98 mm per year.

Domestic Water Use

The domestic water use potential of the Daraudi River in Nepal is significant, especially considering the dependance of local communities on natural water sources for their daily needs. Previous study suggests that the people in the region heavily rely on natural springs to meet their domestic water demand, which includes drinking, agriculture, and other household purposes (Pathak, 2019). Therefore, a careful planning and sustainable water resources management is required in the Dauradi river basin. Cooperation among local communities, government agencies, and other stakeholders should be maintained to ensure that the domestic water needs are met without compromising the ecological balance of the river system.

Irrigation Potentials and Development

The Daraudi River, which flows through the Gorkha district in Nepal, has been a vital source of water for irrigation. Daraudi basin is one of the fertile areas supplying rice to the major settlements in Gorkha. Agriculture is the major occupation in the Daraudi watershed. Nearly 90% of the rural population in the Darudi basin depends on agriculture. The cultivated land in the Daraudi watershed is estimated to be 20,656 ha out of which only 40% is irrigated and 60% is under rain-fed agriculture (Pokhrel, 2022). The study suggests the need for additional irrigation systems, lift & solar irrigation, and micro irrigation along with the improvement of farmers' managed irrigation systems in the basin.

Hydropower Potential and Development

The Daraudi River has a significant potential for hydropower generation. The river's flow has been utilized to operate a large hydropower plant, which is a 6 MW run-of-river hydroelectric plant located in the Gorkha District (Koirala et al., 2015). The Daraudi A Hydropower Plant, located in the former Muchok, Takumajh Lakuribot, and Saurpani VDCs of Gorkha District has a catchment area upstream from the intake covers 224 km^2.

Industrial Use

The Daraudi River in Nepal is primarily utilized for hydroelectric power generation. The hydropower generated from the Daraudi River contributes to the local and national grid, supporting both residential and industrial electricity needs. Apart from hydropower, the Daraudi River basin also has a huge potential in the agro-industry as almost 90% of the rural population in this basin depends on agriculture. However, the access of farmers to important agricultural and market infrastructures is very low. The basin also has the scope of a tourism industry considering its scenic beauty, diverse culture, and opportunities for adventures like hiking and trekking. Therefore, development in the sectors of irrigation and tourism can be beneficial in ensuring the economic growth of the people in the region.

Environmental Use

The ecosystem of the Daraudi river provides a habitat for various species of fish, birds, and other wildlife. The quality of water in the Daraudi River is crucial for maintaining the health of the ecosystem. However human activities like hydropower generation and illegal extraction of riverbed materials, have significant impacts on the river's ecology. Concerns have been raised that the Daraudi hydropower project and dam could obstruct the migration of fish up the river, potentially reducing their population. Daraudi basin is also facing serious climate-induced disasters. Flooding, sand inundation, and land-cutting are very common(Pokhrel, 2022). Therefore, implementing the environmental risk reduction programs, regulating human activities, monitoring water quality, and ensuring the sustainable use of the river's resources are necessary to protect the river's ecology from further degradation. Sustainable management practices are essential to preserve the river's ecosystem for future generations.

Tourism

The Daraudi River and its surroundings offer a blend of natural beauty and cultural experiences. The Rupina La Pass trek which lies in this basin is both geographically spectacular and culturally fascinating. The tall waterfalls, typical houses, insights into local lifestyles, and diverse ecosystem along the trail is captivating for tourists and can provide a variety of experiences in nature, adventure, and culture.

2.2.6 Budi Gandaki

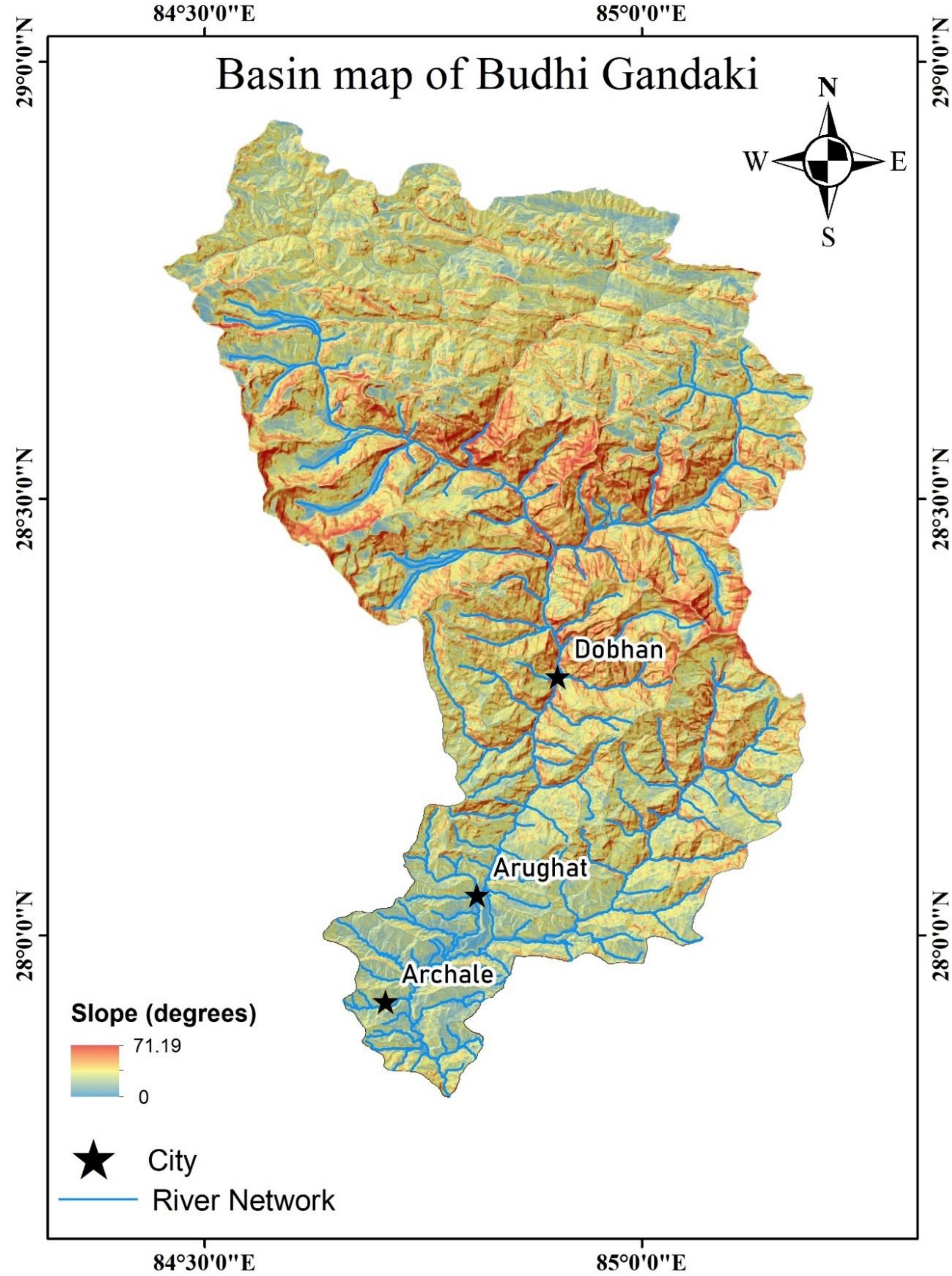


Figure 20: Budhigandaki river basin.

Physiographic and climatic characteristics

The Budhi Gandaki River Basin is the part of Narayani River Basin with origin in Tibet (Figure 20). This river basin covers parts of the Gorkha and Dhading districts of Nepal. The basin extends from the snow-covered Himalayan Mountains in the north to green hills in the south with the elevation ranging from 8092 m to 322 m above sea level.

The climatic characteristics of Budi Gandaki are controlled by the larger elevation range from subtropical to alpine seen in the region. Seasonal variation is strongly influenced by the monsoon rain. The mean annual precipitation has been recorded as 1495 mm with variation in terms of spatial and temporal pattern. Most amount of rainfall occurs during the monsoon season. The temperature varies between 60 Celsius during the winter and 350 Celsius during the summer (Devkota et al., 2017).

Water Balance

The water balance of the Budi Gandaki Basin is influenced by various factors such as precipitation, glacier melt, evapotranspiration, and river flow. A hydrological analysis of the river system revealed that the river discharge reaches 377 m^3/s at the peak of monsoon season (August) and goes down to 22.5 m^3/s in the driest month (i.e. February) (MoEWRI, 2023). Study have found that the discharge of the Budi Gandaki has increased by 0.5076 m^3/s, but the dry season flow (November to April) shows that the flow has decreased by 0.1627 (Bajracharya et al., 2021).

Domestic Water Use

The water from the Budi Gandaki River Basin is the major source of water used for household activities like drinking, cleaning, and sanitation. However, there are plans to build a dam on the Budi Gandaki River, which could significantly alter the river’s discharge. Most of the discharge from the river will be diverted to the powerhouse, affecting the domestic and agricultural use of the basin’s water resources.

The basin also faces challenges due to climate change, which has led to an increase in extreme events like floods and droughts, affecting the domestic use of water resources (Devkota et al., 2017). It is also seen that taps and water from streams are the major sources of water in the area. Thus, the construction of a hydropower project may also affect the community and household taps in this region (MoEWRI, 2023). Therefore, it is essential to develop sustainable management practices that can support the livelihoods of local communities while also addressing the challenges posed by climate change and developmental activities.

Irrigation Potentials and Development

The Budi Gandaki Basin in the Gandaki region of Nepal holds significant potential for irrigation due to its extensive river system. The population density of the Dhading and Gorkha districts are 174 persons per sq. km. and 75 persons per sq. km. respectively which is much lower than the national average of 180 persons per sq. km. The inhabitants of the region are mainly dependent on the agriculture for their source of livelihood in the region (Devkota et al., 2017). Agriculture is the major activity sustaining the livelihood of the people of this region (CBS, 2019) and the water used for agriculture is mainly obtained from this river. Furthermore, the Budi Gandaki watershed needs sustainable management of its water resources to ensure long-term irrigation potential considering the river's vulnerability to climate change.

Hydropower Potential and Development

One of the major hydropower projects in the Budi Gandaki River is the Budi Gandaki Hydropower project which is being developed to boost Nepal's energy development and economic growth. The project is located around 2 km from the confluence of the Trishuli River at Benighat on the Prithivi High which connects Kathmandu and Pokhara. Previously, it was estimated to be 600 MW of capacity which is further increased to 1800 MW which could greatly expand Nepal's power generation capabilities. with a total investment of 2.5 billion dollars. Furthermore, it is estimated that 27 local levels of two districts namely Gorkha and Dhading are expected to be affected (Khanal et al., 2021). This shows that the Budi Gandaki Basin in the Gandaki region of Nepal has a significant hydropower potential.

Industrial Use

The Budi Gandaki Basin in the Gandaki region of Nepal is primarily known for its agricultural and hydroelectric potential. The development of the Budi Gandaki hydropower project is a significant step towards ensuring energy security for Nepal. By ensuring steady and affordable energy access, the project can encourage industrial growth within Nepal. The water from the basin also supports irrigation, which is essential for agro-based industries in the region. The hydropower development in the Budi Gandaki Basin promises significant economic and energy benefits for Nepal, but it needs to be carefully managed to minimize the socio-economic and environmental impacts in the basin.

Environmental Use

The ecosystem of the Budhi Gandaki River is characterized by a rich diversity of flora and fauna, supported by the basin's heterogeneous land cover types. However, the basin is facing the effects of climate change, such as increased temperature and erratic rainfall patterns, which have led to more frequent extreme events like floods and droughts. These changes are impacting the ecology of the basin, including the timing of seasonal flows and the availability of water resources (Devkota et al., 2017). The environmental health of the Budi Gandaki River basin is vital for the sustainability of the region’s natural resources and the well-being of its communities. Therefore, it requires a careful management to balance development needs with conservation efforts.

Tourism

The Budi Gandaki River basin provides a wide range of experiences and exciting activities for the tourists. Adventure sports like rafting, bungee jumping, skiing, and canyoning available in the region can provide thrilling experiences to the tourists. The Tsum Valley Trek, which is a 14-day journey that traverses the Budi Gandaki River valley features hot springs, waterfalls, and spectacular mountain views. Overall, the Budi Gandaki River Basin can provide a blend of nature and adventure for the tourists.

2.2.7 Trishuli

Physiographic and climatic characteristics

Trishuli river is one of the seven major tributaries of the Gandaki River (Figure 21). The name of Trishuli River comes from mythology in which *Trishula* means trident. The basin lies within the longitude 84º57'34" E to 85º05'30" E and latitude 27º47'25" N to 27º51'52" N (Ghosh et al., 2020). The Trishuli River basin originates from Kirong Tsangpo in Tibet Autonomous Region of China. The Trishuli River carries a high discharge of water and its climate is strongly influenced by its topography. Physiographically, the Trishuli River basin can be divided into three zones based on gradient and temperature; (i) A steep (3 percent slope) cold water zone (upstream), (ii) A less steep (1 percent slope) cold-to-cool zone (midstream), and (iii)A milder (<1 percent slope) cool-to-warm zone (downstream) (IFC, 2020). The upstream consists of some of the highest alpine mountain ranges in the country, the midstream consists of hills and highlands and the downstream consists of plains with a mild river gradient.

The Trishuli River flows into the Narayani river and flows across the Chitwan National Pak and further into the Gandaki River in India. The upstream of the basin falls in Rasuwa District with an altitude ranging from 1,000 m to 7,250 m above sea level. The middle part of the basin falls in the Nuwakot District of central Nepal with a subtropical to temperate climatic regime with an elevation ranging from 457 m to 5,144 m above sea level. The lower part of the basin falls in Dhading, Gorkha, and Chitwan Districts with a subtropical to temperate climatic regime, and an extreme range of elevation from 430 m to 7,409 m above sea level (IFC, 2020).

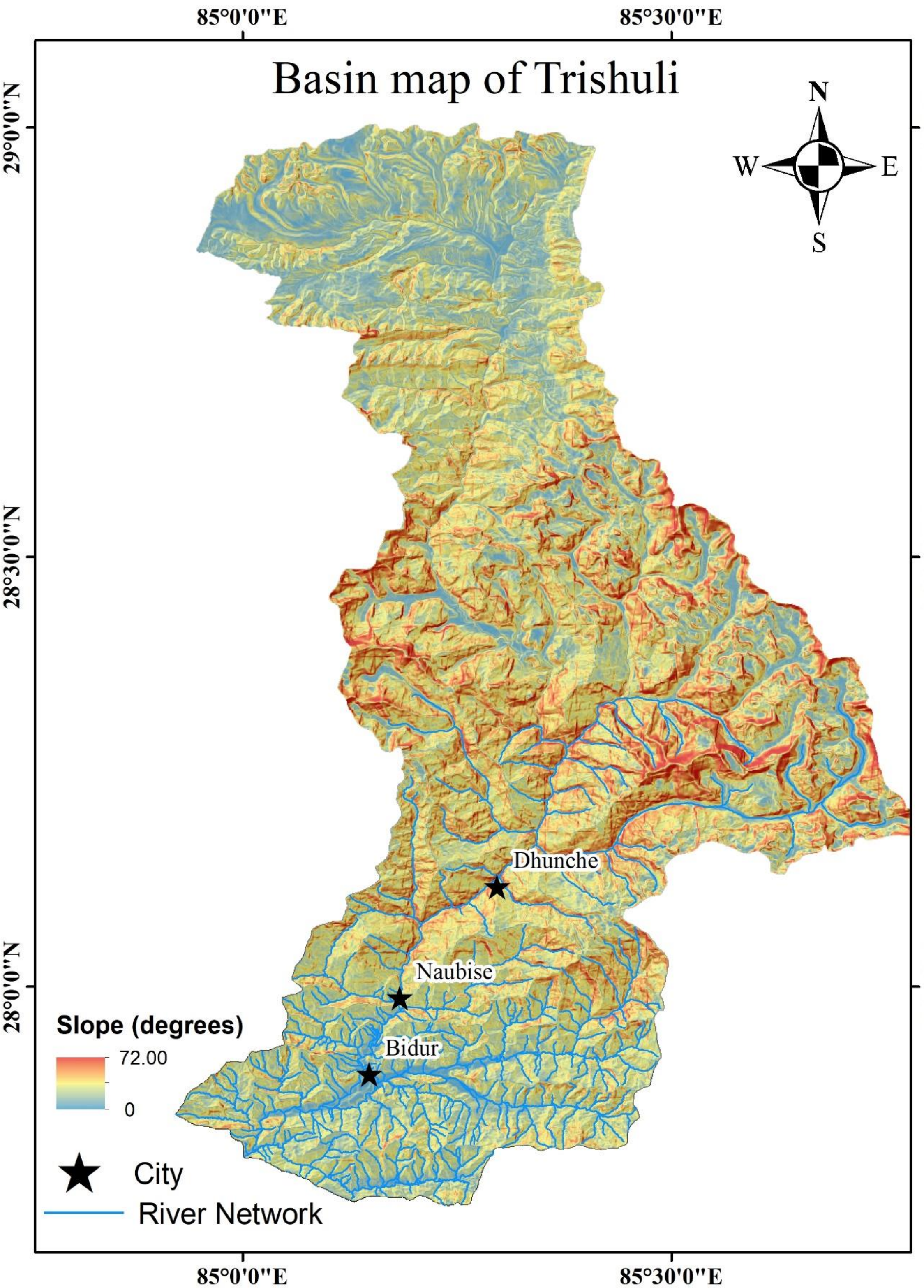


Figure 21: Trisuli river basin.

Water Balance

The water balance of the Trishuli Basin is affected by various factors, including precipitation, evaporation, transpiration, and the flow of water through the river system. The flow of water in the Trishuli River Basin depends on annual rainfall and glacier melt (upstream in the Tibet Autonomous Region) and is affected by extreme events and interventions such as river diversion schemes.

Changes in snowfall and rainfall patterns are a major water-related concern in the basin (IFC, 2020). Records taken from 1977 to 2007, it was found that the minimum discharge of the Trishuli River was 36.6 m^3/s in March 2001 while the maximum flow was recorded to be 904 m^3/sec in July 1990 (Bajracharya et al., 1970). Similarly, the monthly mean flow revealed that 2003 had the minimum with only 273.5 m^3/s and the minimum was in 1985 with 151.43 m^3/s. Overall, the annual average discharge of the Trishuli River was found to be increasing by 2.733 m^3/s per year on the other hand the flow is decreasing during the dry season by 0.22 m^3/sec per year.

Domestic Water Use

Domestic water use in the Trishuli River Basin (TRB) is primarily sourced from springs and piped water systems provided by municipalities. Stakeholder consultations showed that the surface water from the Trishuli River itself is not used for drinking purposes. Most of the communities consulted indicated that they use untreated water from springs and piped water systems provided by municipalities (IFC, 2020). The water resources in the basin are affected by various factors, including annual rainfall, and glacier melt, and human interventions such as river diversion schemes have increased challenges for water supply systems. These challenges have intensified water shortages and damaged water infrastructure, especially after the 2015 earthquake. Therefore, to address these challenges, a holistic and basin-wide approach to water resources management is essential in the basin.

Irrigation Potentials and Development

The irrigation potential of the Trishuli Basin depends on its physiographic and climatic characteristics, as well as the availability of water resources. Communities in the upstream section do not use water from the basin for irrigation as the area under cultivation in this section is low because of the steep hills and mountains. Whereas, the communities in the midstream and downstream sections of the river practice riverine agriculture and also use the river for irrigation (IFC, 2020). The basin’s potential for irrigation is also influenced by the presence of hydropower projects. While these projects are primarily focused on electricity generation, they can also have the potential to provide regulated water flow, which can be beneficial for irrigation during dry periods.

Hydropower Potential and Development

The Trishuli River Basin (TRB) in Nepal has significant hydropower potential, with many hydropower projects in various stages of development or planning. As per the research done on 2018, there were five operational hydropower plants with a total capacity of 70.1 MW which are located in the Trishuli River Basin. Out of these five hydropower plants three of those are located from north to south on the main stem of the Trishuli River which are the Chilime (22.1 MW), Trishuli (24 MW), and Devighant (14.1 MW) (Mishra et al., 2018). However, a year-long study was conducted by The International Finance Corporation (IFC) with a comprehensive approach to understanding and managing the environmental and social impacts of hydropower development in the basin. The stakeholder consultations, qualitative and quantitative data analysis, and strategic workshops were conducted throughout the study period. The study emphasizes the need for a holistic and basin-wide approach to address the challenges associated with infrastructure development in the Trishuli River Basin (IFC, 2020).

Industrial Use

The industrial use of the Trishuli River Basin is primarily focused on hydropower development with multiple projects at various stages of development. In the Trishuli River basin, fishing is one of the major sources of livelihood and food security in the Tamang, Gurung, and Sherpa communities of the Mid-hills. Based on the ichthyofaunal study, it was found that the main species found in the Trishuli River was the *Schizothorax richardsoni Gray* a.k.a Asala in the local language which was found in more than 80% of the catch (Gurung, 2013). Some communities and families in the midstream and downstream sections of the study area rely on the river for some ecosystem services-based livelihoods, such as for irrigation, river-based sand mining, and whitewater rafting (IFC, 2020).

Environmental Use

The ecosystem of the Trishuli River Basin is diverse and influenced by its varied physiography and climate. However, the ecosystem is under pressure because of various factors, including climate change, slope instability, sand mining, and urbanization. Adding to these factors, the 2015 earthquake had a huge alteration in environmental and social conditions. The hydropower projects in the basin also have significant impacts, including aquatic habitat fragmentation, overall degradation of the catchment area, reduced water availability, and an increased risk of landslides. Water quality is already poor here, specifically in the midstream and downstream sections. Addition of future hydropower projects are likely to further degrade the habitats in the midstream sections which is already highly degraded (IFC, 2020).

Tourism

The Trishuli River is one of the most popular destinations for tourism in water-based tourism called the white-water rafting. The river's scenic beauty, its proximity to Kathmandu, and its suitability for a range of outdoor activities make it a key tourist attraction. Tourists can also enjoy a cable car ride up to the famous Manakamana temple from the Trishuli area, combining adventure with cultural exploration.

IMPACT OF CLIMATE CHANGE AND FUTURE SCENARIOS

The Himalayan region is vital for sustaining communities reliant on its snow-fed river system. Nepal boasts ample water resources, offering potential for hydroelectric power, irrigation, and domestic and industrial use. However, climate variability and extreme events have inflicted significant economic costs in Nepal. Its diverse topography, fragile geology, and sensitive ecosystems render it highly vulnerable to climate change. Limited capacity for adaptation further exacerbates this vulnerability. Studies indicate that global warming, particularly changes in precipitation patterns, will severely impact the water sector. While temperature increases are evident from observed data, rainfall trends present a more complex picture.

Studies investigating historical precipitation data in Nepal reveal a lack of a clear, nationwide trend. Some analyses, like one examining the Nepal Himalayas between 1959 and 1994 (Shrestha et al., 2017) , found no distinct changes. However, others, using data from later periods (Baidya et al., 2008), suggest increasing trends in total and heavy precipitation events. This regional and temporal variability makes it difficult to predict future precipitation patterns with absolute certainty.

Delving deeper into specific regions, we see even more diverse trends. The Gandaki river basin, for example, reports a decrease in pre-monsoon, post-monsoon, and winter rainfall across most of the basin (Panthi et al., 2015). However, there was found to be increasing monsoon rainfall throughout the area (Panthi et al., 2015)

The Koshi river basin, which lies in the eastern part of the country, presents a similar story. Here, some stations show increasing annual precipitation, while others show a decrease (Nepal, 2016). The results are only statistically significant at a handful of stations, highlighting the localized nature of precipitation change. Adding another layer of complexity, studies suggest an increase in the frequency and intensity of extreme weather events within the Koshi basin (Shrestha et al., 2017). Moving west to the Karnali river basin, the trend leans towards a decrease in average precipitation. Studies by Khatiwada et al., (2016) show a decline of around 10% on average, indicating a potential challenge for water resources in the region.

Recent research offers a more nuanced perspective on these regional variations. It suggests a rise in pre-monsoon precipitation for the lowlands and central Himalayas, while monsoonal precipitation increases in the middle mountains of the western region and central high mountains (Karki et al., 2017). Conversely, post-monsoon precipitation appears to be decreasing across the country, with winter precipitation declines limited to the western middle mountain region. This spatial complexity highlights the need for region-specific adaptation strategies to address the potential for floods, landslides, and droughts.

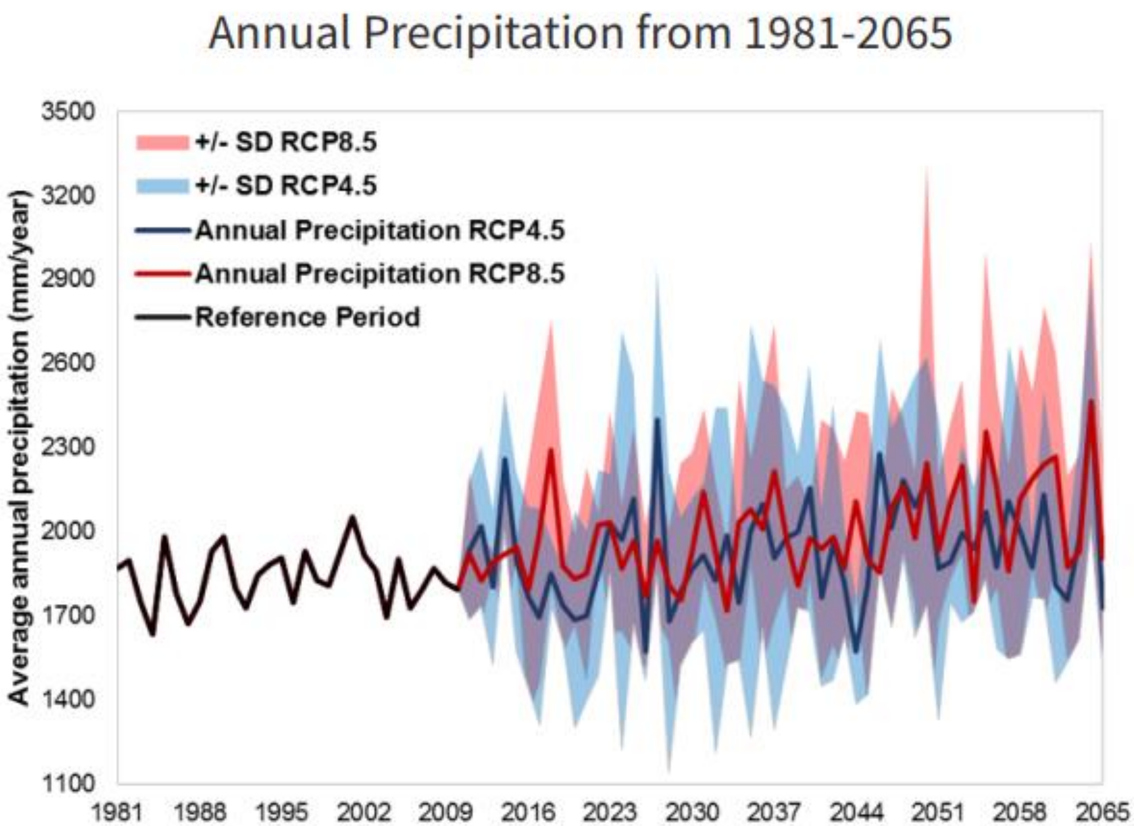


Figure 22: Historical and projected precipitation in Nepal from 1981 to 2065 (Source: ICIMOD, 2020).

Looking to the future, projections suggest an average annual increase in precipitation for both the medium and long term. Estimates range from a 2-6% increase in the medium term to an 8-12% increase in the long term. These projections, however, are not uniform across seasons (Figure 22). The pre-monsoon season might see a decrease of 4-5%, while the post-monsoon season is projected to experience the most significant rise, potentially reaching 19-20% in the long term.

Another concerning trend is the projected increase in the frequency of intense precipitation events. While the total number of rainy days might decrease, these days are likely to pack a heavier punch, potentially leading to more flash floods and landslides.

The changing precipitation patterns pose a significant challenge for Nepal. The potential for increased floods, landslides, and droughts demands proactive adaptation strategies. Investing in early warning systems, improving water management infrastructure, and promoting drought-resistant crops are crucial steps to navigate this uncertain future. Understanding the regional variations in these changes is also essential for developing targeted solutions that address the specific vulnerabilities of each area.

By acknowledging the complexity of climate change's impact on precipitation, Nepal can move towards a more resilient future. Through careful planning and targeted adaptation measures, the country can ensure its water resources remain a source of life. The impact of climate change in different scenarios has been discussed and presented in the subsequent subsection.

3.1 Change in Groundwater flow

Figure 23 shows the projected changes in groundwater flow as a percentage across various districts under different climate change scenarios which are the RCP4.5 for the 2030s and 2050s, and RCP8.5 for the 2030s and 2050s.

In the RCP4.5 scenario for the 2030s, districts show varied increases in groundwater flow. Gorkha stands out with a substantial 52.86% rise, indicating significant improvements. Conversely, Kaski experiences an extraordinary surge of 634.54%, reflecting a considerable enhancement. Other districts like Baglung, Lamjung, and Myagdi also show notable increases, ranging from 10.61% to 28.98%, signaling positive shifts. However, Manang and Mustang exhibit smaller increases, suggesting more modest changes.

In the RCP4.5 scenario for the 2050s, trends continue with further increases. Gorkha and Kaski maintain their upward trajectories, with rises of 56.46% and 637.86%, respectively, indicating sustained improvements. Lamjung and Myagdi see continued rises, reaching percentages of 31.48% and 13.91%, reflecting ongoing positive changes. Despite smaller increases, districts like Baglung, Manang, and Mustang experience upward trends, albeit at varying rates.

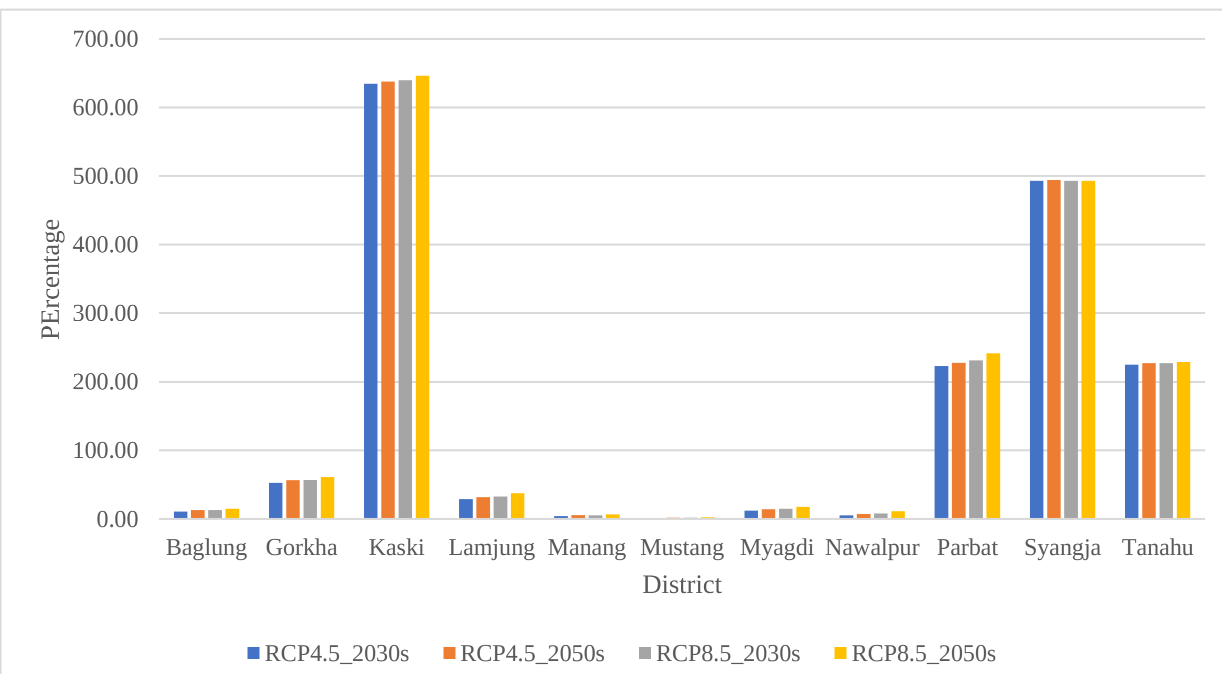


Figure 23: Projected ground water flow in Gandaki Province's districts.

Under the RCP8.5 scenario for the 2030s, characterized by higher emissions, changes become more pronounced. Kaski sees an astonishing increase of 639.90%, reflecting the significant impact of high emissions on groundwater. Gorkha also experiences a substantial rise of 56.70%, highlighting the pronounced effect of elevated emissions. Other districts witness notable increases, indicating significant alterations in groundwater dynamics.

In the RCP8.5 scenario for the 2050s, increases in groundwater flow reach their peak levels. Kaski continues its remarkable trend with a rise of 646.53%, underlining the profound impact of high emissions. Gorkha sees a further increase to 61.29%, suggesting continued enhancement. Other districts also experience significant rises, indicating substantial changes in groundwater dynamics under the most extreme emission scenario.

3.2 Change in Annual Water Availability

Figure 24 presents the annual water availability as a percentage for various districts under different climate change scenarios: RCP4.5 for the 2030s and 2050s, and RCP8.5 for the 2030s and 2050s. These changes highlight the varying impacts of climate change on water resources across different regions.

Under the RCP4.5 scenario for the 2030s, several districts exhibit increases in water availability. Nawalpur shows the most significant rise at 9.784%, indicating a substantial improvement in water resources. Lamjung and Tanahu also experience notable increases of 5.798% and 6.099%, respectively. Kaski, Parbat, and Gorkha show moderate rises ranging from 2.958% to 4.712%, reflecting positive trends in water availability. Conversely, Manang and Mustang experience decreases of -5.486% and -1.782%, respectively, signaling potential challenges in water resource management. Syangja also shows a slight decline of -1.263%.

In the RCP4.5 scenario for the 2050s, the positive trends generally continue with more pronounced increases. Nawalpur leads with a 10.399% rise, while Lamjung and Tanahu see further increases to 7.886% and 8.076%, respectively. Kaski and Parbat experience significant improvements, with increases of 6.082% and 7.200%, respectively. Gorkha and Baglung also show substantial rises, indicating improved water availability. However, Manang remains negative at -2.939%, and Mustang continues to face a slight decrease at -1.414%, highlighting ongoing challenges.

Under the RCP8.5 scenario for the 2030s, characterized by higher emissions, the changes in water availability become more varied. Nawalpur experiences the most considerable increase at 14.192%, reflecting significant improvements. Lamjung and Tanahu also show substantial rises of 9.272% and 9.643%, respectively. Kaski and Gorkha see notable increases of 5.768% and 4.175%, respectively. However, Manang and Syangja experienced declines of -4.648% and 0.559%, respectively. Mustang shows a significant rise of 7.669%, contrasting with the declines under RCP4.5.

In the RCP8.5 scenario for the 2050s, water availability continues to change significantly.

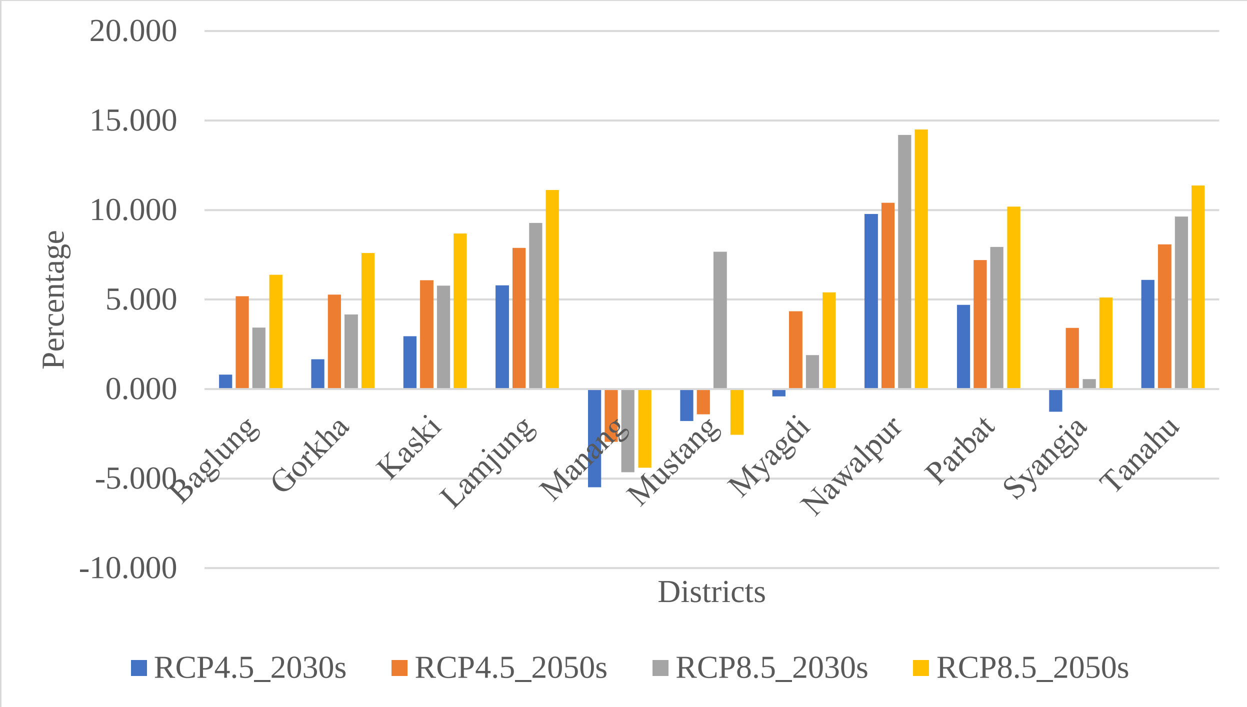


Figure 24 : Change in annual water availability (%).

Nawalpur leads with a 14.493% increase, indicating sustained improvements. Lamjung and Tanahu also see further rises to 11.117% and 11.372%, respectively. Kaski and Parbat experience substantial increases of 8.690% and 10.194%, respectively, suggesting improved water resources. Gorkha and Baglung show notable rises, while Myagdi and Syangja also see positive changes. However, Manang remains negative at -4.390%, and Mustang experiences a decline at -2.557%, highlighting the potential adverse effects of high emissions on water resources in these areas.

Figure 25 presents the annual total water availability by volume (in MCM) for various districts of Gandaki Province under different climate change scenarios, including the present baseline, RCP4.5 for the 2030s and 2050s, and RCP8.5 for the 2030s and 2050s. The changes projected under these scenarios reflect the varying impacts of climate change on water resources across different regions.

In the RCP4.5 scenario for the 2030s, most districts show an increase in water availability compared to the present baseline. Gorkha sees a moderate rise from 32,656.10 MCM to 33,200.57 MCM, indicating a positive shift in water resources. Similarly, Kaski's water availability increases from 6,174.50 MCM to 6,357.14 MCM, and Lamjung from 5,798 to 7,886 MCM. Nawalpur experiences a significant rise from 151,668.86 MCM to 166,508.67 MCM, suggesting substantial improvements in water availability. However, some districts, such as Manang, show a decrease from 1,813.53 MCM to 1,714.04 MCM, and Mustang also sees a slight decline from 1,090.97 MCM to 1,071.53 MCM.

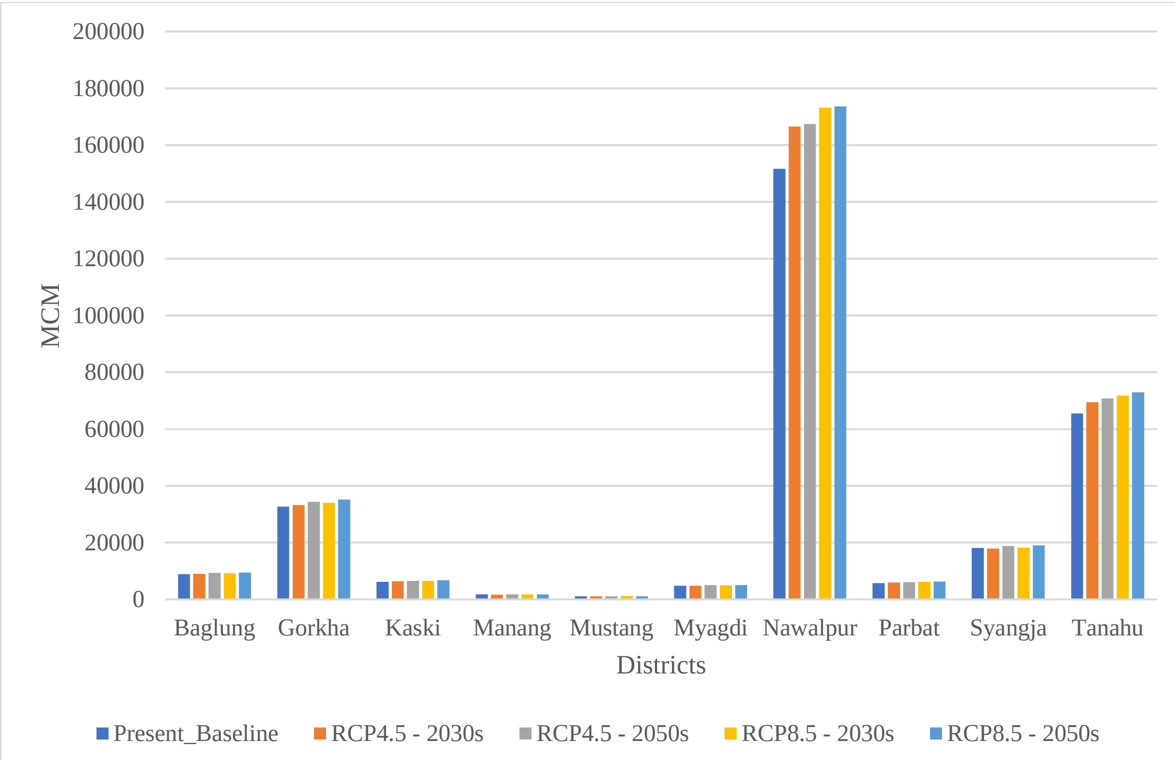


Figure 25: Annual Total Water Available by Volume (MCM) in various districts of Gandaki Basin

Under the RCP4.5 scenario for the 2050s, the positive trends generally continue with further increases in water availability. Gorkha's water availability increases to 34,378.82 MCM, while Kaski and Lamjung see their water volumes rise to 6,550.04 MCM and 7,886 MCM, respectively. Nawalpur's water availability grew significantly to 167,441.52 MCM, reflecting ongoing improvements. Parbat also experiences a notable rise from 5,692.07 MCM to 6,101.88 MCM. Although Manang and Mustang still show decreases, the declines are less pronounced, indicating a potential stabilization in these regions.

In the RCP8.5 scenario for the 2030s, characterized by higher emissions, the changes in water availability become more pronounced. Nawalpur continues to lead with a substantial increase from 151,668.86 MCM to 173,193.43 MCM, highlighting the significant impact of high-emission scenarios. Kaski's water availability rises to 6,530.62 MCM, and Gorkha to 34,019.43 MCM, indicating enhanced water resources. However, Manang and Mustang see mixed results; while

Manang's water availability decreases to 1,729.243448 MCM, Mustang experiences an increase to 1,174.640228 MCM, showing variability in response to higher emissions.

Under the RCP8.5 scenario for the 2050s, the increases in water availability reach their peak levels. Nawalpur's water volume grows to 173,650.7667 MCM, reflecting sustained improvements under the most extreme emission scenario. Gorkha and Kaski continue their upward trends, with water availability increasing to 35,140.66 MCM and 6,711.08 MCM, respectively. Tanahu also sees significant rises, with water availability reaching 72,908.9859 MCM. In contrast, Manang's water availability slightly decreases to 1,733.91 MCM, and Mustang sees a decline to 1,063.08 MCM, highlighting the potential adverse effects of high emissions on water resources in these specific areas.

3.3 Annual Water Requirement and Available for Irrigation (MCM)

Figure 26 outlines the annual usable water volume in million cubic meters (MCM) across various districts of Gandaki Province under different climate change scenarios: Present Baseline, RCP4.5 for the 2030s and 2050s, and RCP8.5 for the 2030s and 2050s. This data provides insights into how water availability might change under these scenarios.

Under the Present Baseline, districts exhibit varying levels of annual usable water volume. For instance, Nawalpur has the highest water availability at 60,668 MCM, reflecting its substantial water resources. Gorkha also shows a significant volume of 13,062 MCM, followed by Tanahu with 26,186 MCM. In contrast, districts like Mustang and Manang exhibit much lower volumes, with 436 MCM and 725 MCM, respectively, indicating more limited water resources.

In the RCP4.5 scenario for the 2030s, most districts see an increase in usable water volume. Nawalpur, for example, increases to 66,603 MCM, while Gorkha and Tanahu rise to 13,280 MCM and 27,783 MCM, respectively. These increases suggest a positive impact of moderate climate change mitigation efforts on water availability. However, some districts like Manang and Mustang show slight decreases to 686 MCM and 429 MCM, respectively, indicating potential vulnerability to changing climate conditions.

Moving to the RCP4.5 scenario for the 2050s, the trend of increasing water availability continues for most districts. Nawalpur reaches 66,977 MCM, and Gorkha and Tanahu see further increases to 13,752 MCM and 28,300 MCM, respectively. This continued rise suggests sustained benefits from climate mitigation measures. However, the water volume for Manang remains relatively stable at 704 MCM, and Mustang sees only a minimal increase to 430 MCM, highlighting persistent challenges in these regions.

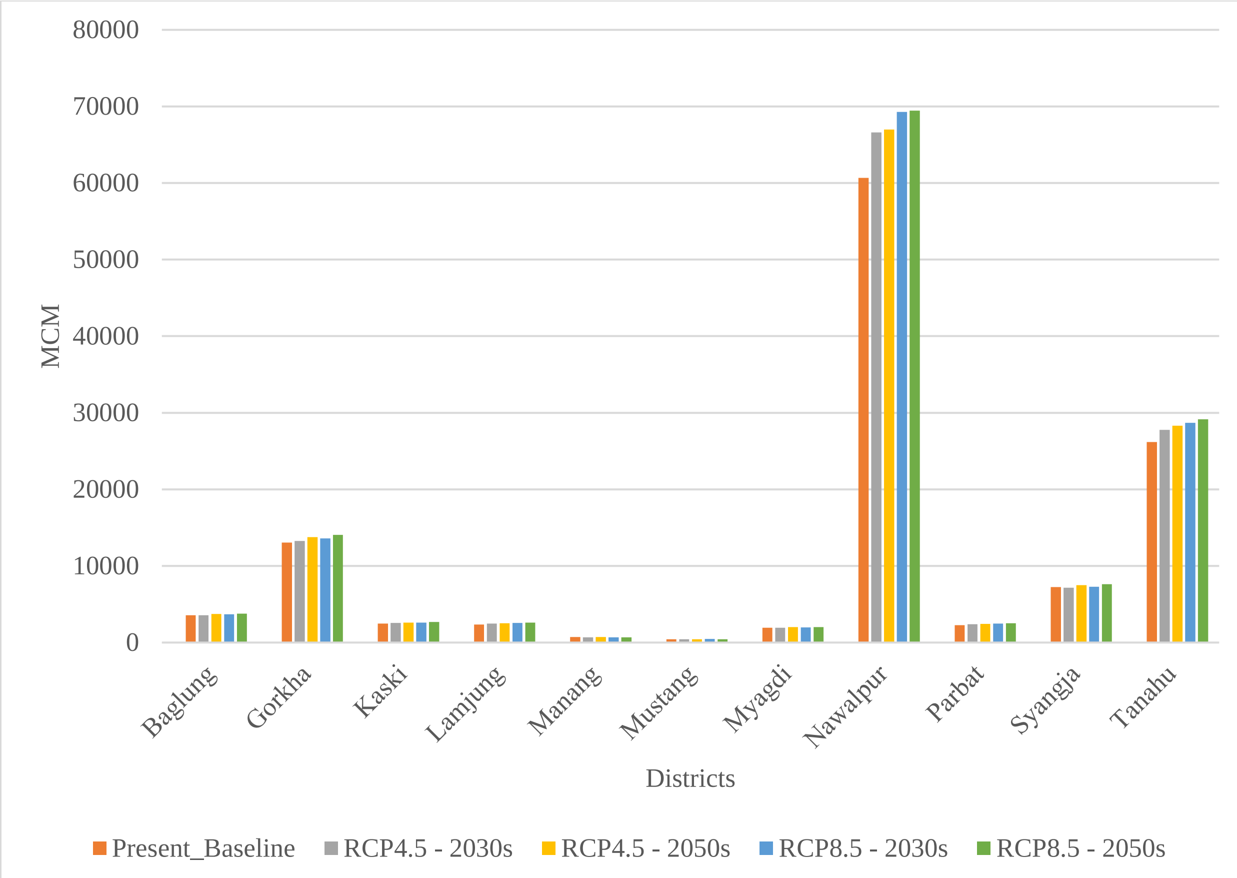


Figure 26: Annual crop water requirement in Gandaki Province under different climate change scenarios.

Under the RCP8.5 scenario for the 2030s, a scenario with higher greenhouse gas emissions, water volumes generally increase. Nawalpur sees a significant rise to 69,277 MCM, and Gorkha and Tanahu increase to 13,608 MCM and 28,711 MCM, respectively. These increases suggest that even under higher emissions, some regions might experience greater water availability, though this could come with increased variability and potential adverse effects.

Finally, in the RCP8.5 scenario for the 2050s, Nawalpur's water volume peaks at 69,460 MCM, and Gorkha and Tanahu also see their highest volumes at 14,056 MCM and 29,164 MCM, respectively. Despite these increases, the scenario underscores potential risks associated with high emissions, such as increased precipitation variability and extreme weather events. Manang and Mustang show stable yet low volumes at 694 MCM and 425 MCM, respectively, indicating ongoing water resource challenges.

Overall, this data highlights the importance of climate change scenarios in understanding future water availability. It underscores the need for region-specific water management strategies to adapt to potential changes and ensure sustainable water resources for all districts.

Figure 27 shows the surplus irrigation water for total agricultural land across various districts as a percentage under different climate change scenarios which are present baseline conditions, RCP4.5 for the 2030s and 2050s, and RCP8.5 for the 2030s and 2050s. Under the Present Baseline, Nawalpur exhibits the highest surplus of irrigation water 99%, indicating a substantial availability of excess water to meet agricultural needs. Manang follows closely with a 96% surplus, reflecting its significant water resources relative to its agricultural demands. Other districts such as Tanahu (94%) and Mustang (67%) also show high levels of surplus water, suggesting favorable conditions for agriculture. Conversely, Kaski and Myagdi have lower surplus percentages at 47% and 60% respectively, indicating more constrained water availability.

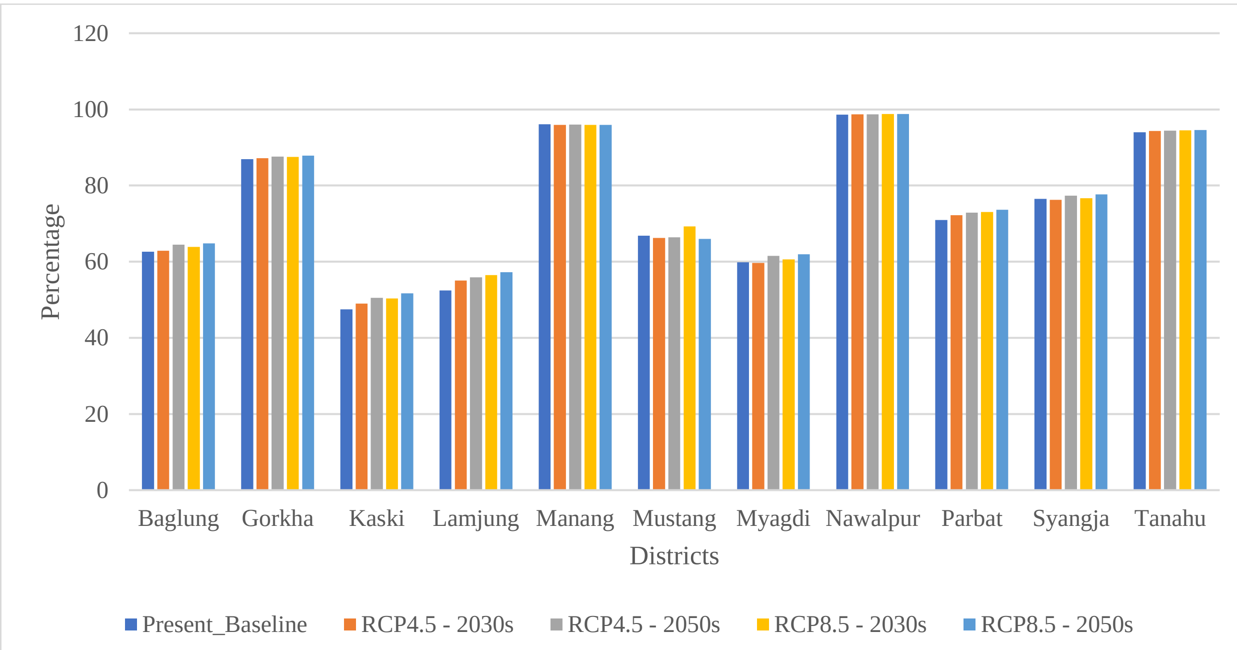


Figure 27: Surplus water in the districts of Gandaki Provinces in different climatic change scenarios.

In the RCP4.5 scenario for the 2030s, most districts maintain similar surplus water levels as the baseline. Baglung and Gorkha remain at 63% and 87%, respectively, while Lamjung sees a slight increase to 55%. Kaski's surplus rises to 49%, and Myagdi stays constant at 60%. These changes suggest moderate climate mitigation efforts help maintain or slightly improve water availability. Manang and Nawalpur retain their high surplus levels of 96% and 99%, respectively, indicating stable water resources under this scenario.

Looking ahead to the RCP4.5 scenario for the 2050s, there are minor increases in surplus water percentages for several districts. Baglung and Gorkha both increase slightly to 64% and 88%, respectively. Kaski and Lamjung continue their upward trends to 50% and 56%, respectively, while Parbat sees a modest rise to 73%. Myagdi's surplus increases to 62%, reflecting slightly better water conditions. However, Manang and Nawalpur remain unchanged at 96% and 99%, respectively, maintaining their high surplus water levels.

Under the RCP8.5 scenario for the 2030s, characterized by higher emissions, the surplus irrigation water levels show minor variations. Baglung and Lamjung increase to 64% and 56%, respectively. Kaski also rises to 50%, while Gorkha and Tanahu remain stable at 87% and 94%, respectively. Mustang sees a slight increase to 69%, indicating an improved water surplus despite the higher emissions scenario. Manang and Nawalpur continue to show high surpluses at 96% and 99%, respectively.

Finally, in the RCP8.5 scenario for the 2050s, Baglung and Kaski see further increases to 65% and 52%, respectively. Lamjung also rises to 57%, while Parbat and Syangja increase to 74% and 78%, respectively. Myagdi maintains its surplus at 62%, and Tanahu shows a slight increase to 95%. However, Mustang sees a decrease to 66%, suggesting potential challenges under high-emission conditions. Manang and Nawalpur remain at their high surplus levels of 96% and 99%, respectively.

3.4 Ecological Water Requirement

Figure 28 shows the annual ecological water requirement by volume (in MCM) for various districts under different climate change scenarios including the present scenario. At present, the ecological water requirement varies significantly across the districts. Nawalpur has the highest requirement at 45,500.66 MCM, reflecting its extensive ecological needs. Gorkha follows with 9,796.83 MCM, and Tanahu requires 19,639.28 MCM. Other districts like Baglung, Kaski, Myagdi, Parbat, and Syangja have lower requirements, ranging from 1,442.19 MCM in Myagdi to 5,445.33 MCM in Syangja. Manang and Mustang have the smallest ecological water needs, at 544.06 MCM and 327.29 MCM, respectively.

Under the RCP4.5 scenario for the 2030s, there is a moderate increase in the ecological water requirement in most districts. Baglung's requirement rises slightly from 2,667.80 MCM to 2,689.41 MCM. Gorkha sees an increase to 9,960.17 MCM, indicating a positive shift in ecological water needs. Kaski's requirement also grows from 1,852.35 MCM to 1,907.14 MCM. However, Manang shows a decrease to 514.21 MCM, reflecting a reduction in ecological water needs. Mustang's requirement slightly declines to 321.46 MCM. Nawalpur experiences a significant rise to 49,952.60 MCM, suggesting substantial increases in ecological water needs.

Under the RCP4.5 scenario for the 2050s, the trends generally continue with further increases. Baglung's ecological water requirement increases to 2,806.23 MCM, while Gorkha's rises to 10,313.64 MCM. Kaski's requirement grows to 1,965.01 MCM, and Myagdi sees an increase from

1,442.19 MCM to 1,504.9523 MCM. Nawalpur's requirement continues to rise significantly to 50,232.4573 MCM. Parbat experiences a notable rise to 1,830.5652 MCM. However, Manang's requirement increases slightly to 528.0688 MCM, though still lower than the baseline.

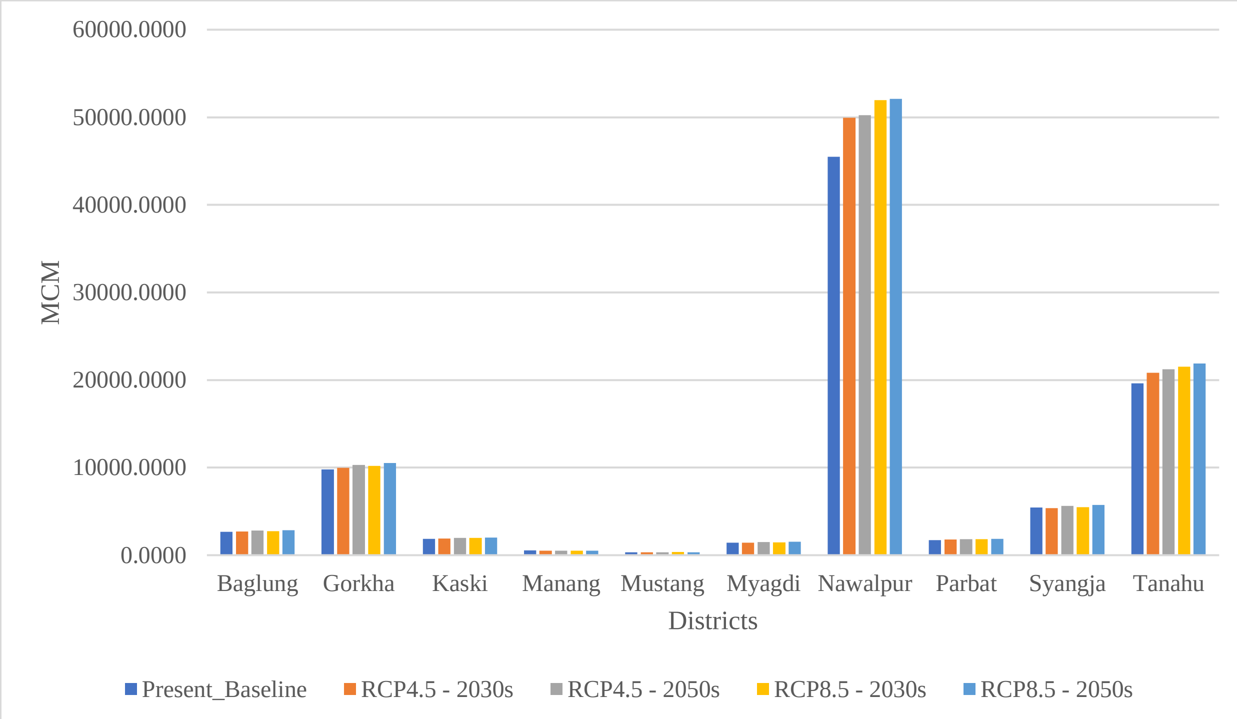


Figure 28: Ecological water requirements.

In the RCP8.5 scenario for the 2030s, characterized by higher emissions, the changes in ecological water requirements become more pronounced. Baglung's requirement increases to 2,759.5226 MCM. Gorkha sees a significant rise to 10,205.8301 MCM. Kaski's requirement increases to 1,959.1879 MCM. Manang's requirement slightly decreases to 518.7730 MCM, while Mustang experiences an increase to 352.3921 MCM, showing variability in response to higher emissions. Nawalpur continues to lead with a substantial increase to 51,958.0309 MCM.

Under the RCP8.5 scenario for the 2050s, the increases in ecological water requirements reach their peak levels. Baglung's requirement grows to 2,838.1611 MCM. Gorkha's requirement rises to 10,542.1999 MCM, and Kaski's increases to 2,013.3248 MCM, reflecting sustained improvements. Manang's requirement stabilizes slightly at 520.1749 MCM. Mustang sees a decrease to 318.9258 MCM, highlighting the potential adverse effects of high emissions. Myagdi's requirement rises to 1,520.0677 MCM. Nawalpur continues its remarkable trend with an increase to 52,095.2300 MCM. Tanahu sees significant rises, with its requirement reaching 21,872.6958 MCM.

3.5 Water Availability per Capita

Figure 29 shows the annual usable water by volume (in MCM) for different districts under different climate change scenarios, including the present baseline, RCP4.5 for the 2030s and 2050s, and RCP8.5 for the 2030s and 2050s. Currently, the annual usable water volume varies significantly across the districts. Nawalpur has the highest volume at 60,667.55 MCM, indicating substantial water resources. Tanahu follows with 26,185.71 MCM, and Gorkha requires 13,062.44 MCM. Other districts like Kaski, Myagdi, Parbat, and Syangja have lower volumes, ranging from 1,922.92 MCM in Myagdi to 7,260.45 MCM in Syangja. Manang and Mustang have the smallest volumes, at 725.41 MCM and 436.39 MCM, respectively.

Under the RCP4.5 scenario for the 2030s, there is a slight increase in the annual usable water volume in most districts. Baglung's volume rises marginally from 3,557.07 MCM to 3,585.88 MCM. Gorkha sees an increase to 13,280.23 MCM, indicating a positive shift in water availability. Kaski's volume grows from 2,469.80 MCM to 2,542.86 MCM. However, Manang shows a decrease to 685.62 MCM, reflecting a reduction in water resources. Mustang's volume slightly declines to 428.62 MCM. Nawalpur experiences a significant rise to 66,603.47 MCM, suggesting substantial increases in usable water.

Under the RCP4.5 scenario for the 2050s, the trends generally continue with further increases. Baglung's annual usable water volume increases to 3,741.65 MCM, while Gorkha's rises to 13,751.53 MCM. Kaski's volume grows to 2,620.02 MCM, and Myagdi sees an increase from 1,922.92 MCM to 2,006.60 MCM. Nawalpur's volume continues to rise significantly to 66,976.61 MCM. Parbat experiences a notable rise to 2,440.75 MCM. However, Manang's volume increases slightly to 704.09 MCM, though still lower than the baseline.

In the RCP8.5 scenario for the 2030s, characterized by higher emissions, the changes in annual usable water volume become more pronounced. Baglung's volume increases to 3,679.36 MCM. Gorkha sees a significant rise to 13,607.77 MCM. Kaski's volume increases to 2,612.25 MCM. Manang's volume slightly decreases to 691.70 MCM, while Mustang experiences an increase to 469.86 MCM, showing variability in response to higher emissions. Nawalpur continues to lead with a substantial increase to 69,277.37 MCM.

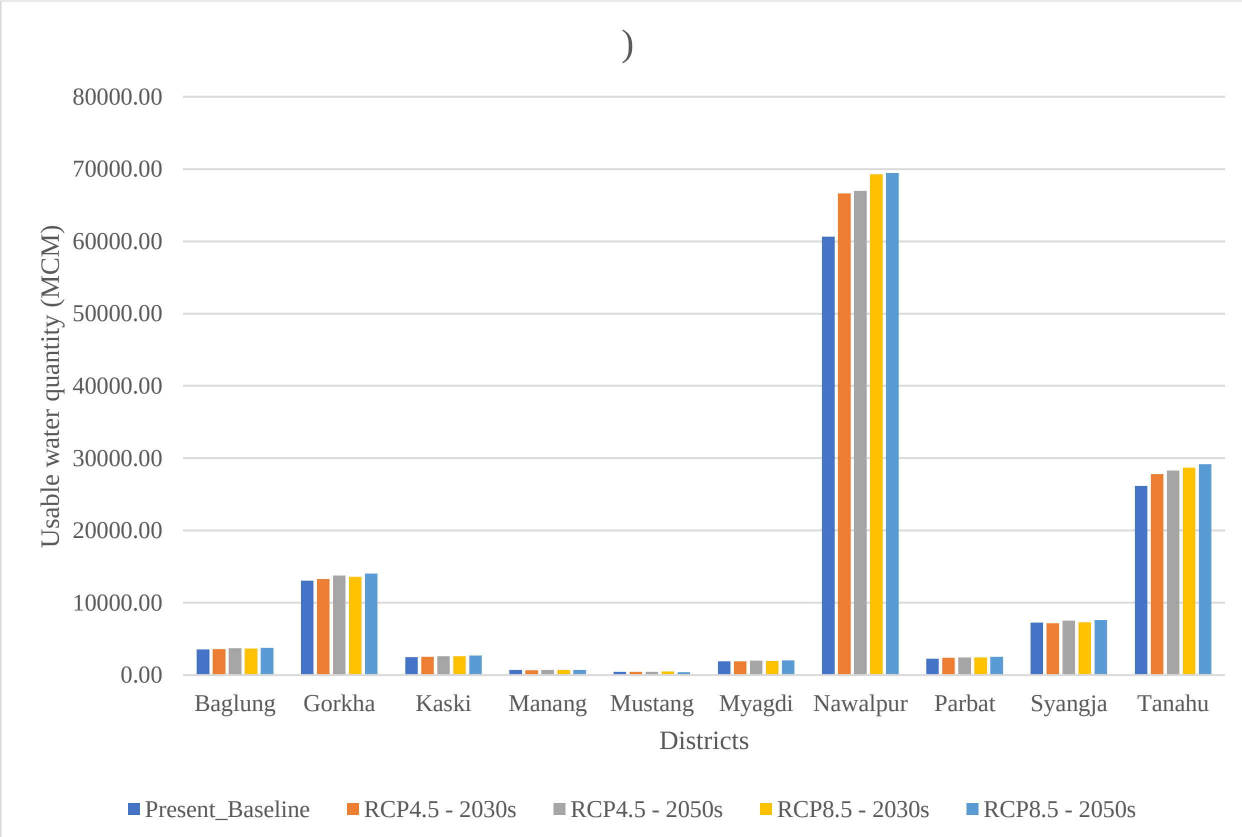


Figure 29: Usable water quantity in Gandaki Province.

Under the RCP8.5 scenario for the 2050s, the increases in annual usable water volumes reach their peak levels. Baglung's volume grows to 3,784.21 MCM. Gorkha's volume rises to 14,056.27 MCM, and Kaski's increases to 2,684.43 MCM, reflecting sustained improvements. Manang's volume stabilizes slightly at 693.57 MCM. Mustang sees a decrease to 425.23 MCM, highlighting the potential adverse effects of high emissions. Myagdi's volume rises to 2,026.76 MCM. Nawalpur continues its remarkable trend with an increase to 69,460.31 MCM. Tanahu sees significant rises, with its volume reaching 29,163.59 MCM.

Water Availability (Usable) per Capita

Figure 30 shows the population of 2011 and projected populations for the years 2030 and 2050 across various districts. This data offers insights into demographic trends and potential shifts in population distribution over the coming decades which is crucial for the calculation of the water availability per head across different climate change scenario projections for the year 2030 and 2050. As per the data in 2011, Kaski stands out as the most populous district with 492,098 residents, indicating a significant population center. Tanahu follows with 323,288 people, reflecting its status as another densely populated area. Nawalpur, Syangja, and Gorkha also have substantial populations, with 311,604, 289,148, and 271,061 residents respectively. Smaller districts such as Manang and Mustang have significantly lower populations, with only 6,538 and 13,452 residents respectively, highlighting their more rural and less populated nature.

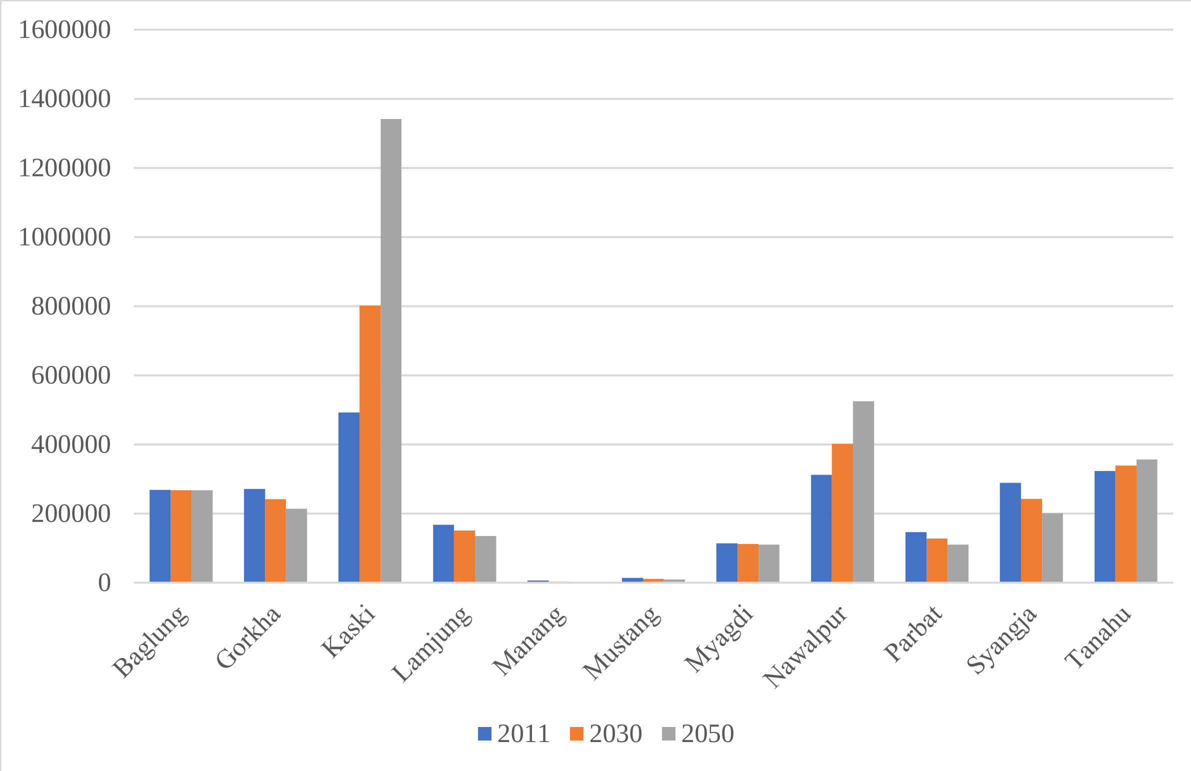


Figure 30: Projected population in Gandaki Province.

By 2030 Kaski is projected to see a dramatic increase to 802,079 people, underscoring its growing importance and potential urbanization. Conversely, Gorkha is expected to experience a significant decline to 241,360 residents, indicating a demographic shift possibly due to migration or other socioeconomic factors. Lamjung and Parbat also show decreases, with projected populations of 151,176 and 127,398 respectively. Manang and Mustang continue their trends of low population, projected to decrease further to 3,159 and 10,964 respectively. Nawalpur, on the other hand, is expected to grow to 401,865, indicating positive growth trends. Tanahu is projected to have a modest increase to 339,156, reflecting steady growth.

By 2050, Kaski's population is expected to surge to 1,341,373, as it as a major population hub. Nawalpur also shows significant growth, reaching 525,256 people, suggesting strong development and urbanization. In contrast, Gorkha's population is projected to decline sharply to 213,604, continuing its downward trend. Similar declines are seen in Lamjung, Parbat, and Syangja, with projected populations of 135,518, 109,904, and 201,210 respectively. Manang and Mustang are projected to see further reductions, with populations decreasing to 1,469 and 8,840 respectively, highlighting ongoing rural depopulation. Tanahu, however, is expected to grow steadily to 356,701, indicating consistent population growth.

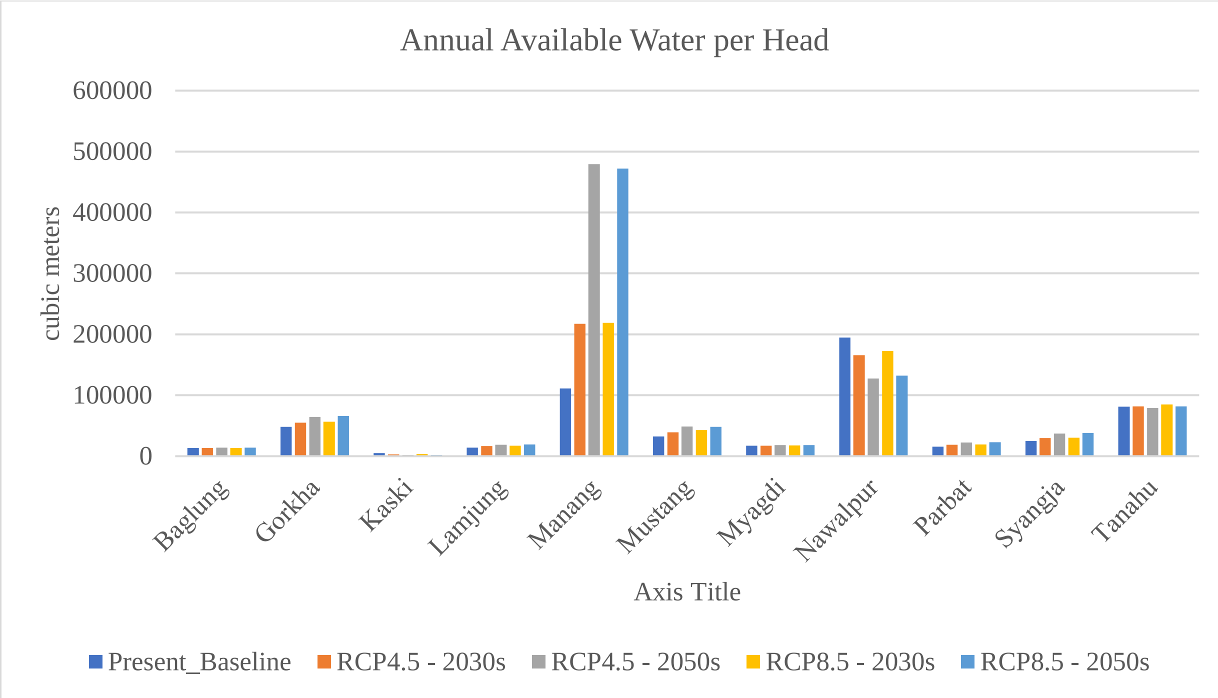


Figure 31: Per capita water availability in Gandaki Province.

The dataset provides insights into the annual water availability (usable) per capita in cubic meters across various districts, considering the present baseline and future projections under different climate change scenarios (RCP4.5 and RCP8.5) for the 2030s and 2050s (Figure 31). This data allows for an understanding of how water availability may shift in relation to both population changes and climate change impacts.

In 2011, water availability per capita varies widely across districts. Manang and Mustang exhibit the highest values with 110,954 and 32,441 cubic meters per capita respectively, likely due to their low population densities. On the other hand, Kaski has the lowest water availability per capita at 5,019 cubic meters, which may be attributed to its relatively high population density.

By the 2030s, under the RCP4.5 scenario, most districts show slight changes in water availability per capita. Baglung and Gorkha, for instance, see increases to 13,380 and 55,022 cubic meters respectively. Notably, Manang's per capita water availability surges dramatically to 217,037 cubic meters, reflecting significant increases despite population projections. Mustangs also see an increase to 39,093 cubic meters. However, Kaski experiences a substantial decrease to 3,170 cubic meters, indicating potential stress on water resources due to population growth.

Under the more severe RCP8.5 scenario for the 2030s, the trends continue but with more pronounced changes. Baglung’s water availability rises to 13,729 cubic meters, while Gorkha sees an increase to 56,380 cubic meters. Manang’s per capita water availability continues to increase significantly, reaching 218,961 cubic meters. Mustang sees a further increase to 42,854 cubic meters. Meanwhile, Kaski experiences a minor decrease to 3,257 cubic meters, still reflecting strain on water resources.

By the 2050s, under the RCP4.5 scenario, Baglung’s water availability per capita increases to 13,995 cubic meters, and Gorkha’s rises to 64,379 cubic meters. Manang sees a substantial jump to 479,300 cubic meters per capita, indicating vast water availability despite a projected decrease in population. Mustang also experiences an increase to 48,667 cubic meters. Conversely, Kaski continues to show a decrease to 1,953 cubic meters, highlighting potential challenges in water resource management.

Under the RCP8.5 scenario for the 2050s, the trends follow similar patterns but with heightened impacts. Baglung’s per capita water availability reaches 14,154 cubic meters, and Gorkha’s increases to 65,805 cubic meters. Manang’s water availability remains extremely high at 472,135 cubic meters per capita. Mustang also sees a significant increase to 48,103 cubic meters. Kaski’s per capita water availability decreases slightly to 2,001 cubic meters, indicating persistent challenges.

NATIONAL POLICY AND LEGAL CONTEXT

For formulating an effective water strategy for the province, it is imperative to thoroughly analyze the existing policy and legal framework governing water management in the country. Therefore, this chapter is dedicated to examining the current policies and legal regulations pertinent to water resources within the province. By comprehensively understanding the legal landscape and policy directives, we can identify areas of strength, weakness, and opportunities for improvement. This in-depth analysis will serve as the foundation upon which we can develop a robust and sustainable water strategy that addresses the evolving needs and challenges of the province.

4.1 Water Sector Policy and Legal Framework

4.1.1 Constitution of Nepal 2015

The Constitution of Nepal 2015 has established a framework for managing water resources across all three levels of government: federal, provincial, and local. The constitution is the foremost binding document that guides the use of water resources. The constitution recognizes the right to water and sanitation for every citizen. Article 30(1) states every citizen has the right to a clean and healthy environment and Article 35(4) states the right of access to clean drinking water and sanitation (Nepal Law Commission, 2015). The Constitutional policy, among other matters, states the following related to water (ADPC, 2021).

- To achieve multi-purpose development of water resources having accorded priority to national investment based on public participation
- To develop sustainable and reliable irrigation by controlling water-induced disasters and implement river management.

Constitution of Nepal has set the policy of early warning, disaster preparedness, rescue, relief and rehabilitation for preventing water-induced disasters, developing sustainable and reliable irrigation through river management and minimizing the risks from disasters caused by natural hazards. The Constitution has given the responsibility of managing water resources to all three levels of government – federal, provincial and local.

- The federal level is responsible for formulating national policies, plans, and standards for water resources management. It also oversees the management of trans-boundary waters and large-scale water infrastructure projects.
- The Provincial level is tasked with implementing federal policies at a regional level, adapting them to local conditions, and managing water resources within their jurisdiction. They also play a role in medium-scale water infrastructure and inter-provincial water issues.

- Local governments are responsible for managing and maintaining small-scale water infrastructure. They are closest to the communities and ensure the provision of water for local needs and handle local water resources, including local water supply and sanitation.

4.1.2 Water Resources Strategy 2002

The Water Resources Strategy (WRS) 2002 for Nepal, formulated by His Majesty's Government through the Water and Energy Commission Secretariat (WECS), aims to manage water resources sustainably and ensure that every Nepali citizen has access to water sufficient to meet basic needs, including drinking, cooking, and sanitation. It also aims to benefit citizens from Nepal's abundant water resources through the production of food and energy at reasonable costs.

The specific objectives of the strategy were defined as follows (WECS, 2002):

- Help in reducing poverty, unemployment, and under-employment by effectively utilizing water resources.
- Provide access to safe and adequate drinking water and sanitation, ensuring health security for all citizens.
- The strategy aims to increase agricultural production, thereby contributing to the nation's food security.
- The strategy focuses on generating hydropower to satisfy national energy requirements and allow for the export of surplus energy.
- It aims to supply water to the industrial sector and other segments of the economy.
- The strategy seeks to facilitate water transport, particularly connecting to a seaport.
- It aims to protect the environment and sustain the biodiversity of natural habitats.
- The strategy focuses on measures to prevent and mitigate water-induced disasters.

The WRS outputs aims to contribute to Nepal's national goal defined as "living conditions of Nepali people are significantly improved in a sustainable manner" through the achievement of short-term (5 years), medium-term (15 years) and long-term (25 years) purposes (ADPC, 2021). This was done through a number of widescale stakeholder consultations.

- The short-term purpose of the strategy is to provide tangible benefits to all Nepalese by improving their access to water sufficient to meet basic needs.
- The medium-term purpose of the WRS is to provide substantial benefits to people for basic needs fulfillment as well as other increased benefits related to sustainable water use.
- The long-term purpose of the WRS is to maximize benefits from water resources in Nepal in a sustainable manner, significantly improving Nepalese living conditions.

- The main outputs of the WRS of Nepal aim at achieving sustainable management and development of water resources. These outputs are categorized based on security, usage, and mechanisms (ADPC, 2021):

Security

- Effective measures to manage and mitigate water-induced disasters.
- Sustainable management of watersheds and aquatic ecosystems.

Usage

- Adequate supply of and access to potable water, sanitation, and hygiene awareness.
- Appropriate and efficient irrigation to support optimal, sustainable use of irrigable land.
- Cost-effective hydropower developed in a sustainable manner.
- Economic uses of water by industries and water bodies by tourism, fisheries, and navigation optimized.

Mechanism

- Regional cooperation for substantial mutual benefits achieved.
- Enhanced water-related information systems functional.
- Appropriate legal frameworks are functional.
- Appropriate institutional mechanisms for water sector management functional.

The WRS provides the main strategic framework for the sustainable development and management of water resources. In order to implement the activities identified by the WRS, a National Water Plan (NWP) was prepared and approved by the government in 2005.

4.1.3 National Water Plan 2005

The National Water Plan (NWP) aims to contribute to the country's overall national goals of economic development, poverty alleviation, food security, public health and safety, decent standards of living for the people, and protection of the natural environment enhancing water resources management in a balanced manner (ADPC, 2021). The plan recognizes the broad objectives of the WRS and outlines short-, medium-, and long-term action plans for the water resources sector, including investments and human resource development.

NWP has adopted Integrated water resources management as the main theme and it seeks to ensure improvement in the living standard of Nepalese people in a sustainable manner by addressing issues such as water-induced disasters, watershed management, domestic water supply, irrigation, hydropower, and regional cooperation. It also aims to contribute to economic development, poverty alleviation, food security, public health and safety, and protection of the natural environment. The plan addresses the environmental concerns and incorporate an Environmental Management Plan to maximize positive impacts and minimize adverse impacts (WECS, 2005). The National Water Plan sets a long-term goal for 2027. Some of the key activities and programs planned in the NWP for 2027

- The plan aims to increase the extent of irrigable land provided with irrigation facilities from 65% to 97%, increase the year-round irrigation coverage from 38% of irrigated area to 67%, and increase the average cropping intensity within year-round irrigated areas from 140% to 193%.
- Investment in projects and programs for managing water-induced disasters is a significant part of the plan.
- The NWP includes an Environmental Action Plan for the sustainable management of watersheds and aquatic ecosystems.
- There are specific investment costs allocated for drinking water and sanitation programs to improve public health and safety.
- The plan also covers investment costs for the hydropower sector and rural electrification, aiming to harness Nepal’s potential for renewable energy.
- Programs to develop the fisheries sector are included, with investment costs outlined for the enhancement of this sub-sector.
- The NWP proposes programs for river basin planning to ensure equitable distribution and sustainable development of water resources.
- There is a focus on institutional development to support the implementation of the NWP, with proposed organizational structures and investment costs.

However, the NWP’s target of 2027 is just 3 years to go. However, the planned activities and programs have not fully begun, so the plan's objective is still far from being accomplished (ADPC, 2021). The goal set for the percentage of the potential irrigable area was 85% for 2017 but the estimate (Irrigation Master Plan, 2019) is roughly 48%, a lower achievement. Additional targets using other indicators in the irrigation sector such as cropping intensity, crop yield, irrigation efficiency, etc., have also fallen short.

Similar goals were established for the hydropower sector, with output capacities of 700 MW in 2007, 2100 MW in 2017, and 4000 MW in 2027 to meet domestic demand and sell to neighboring countries, if there was a surplus. This goal has also not been obtained. Moreover, the water plan indicated areas for development that could be enabled, such as institutional and legal frameworks, but they could not be put into place, leaving the national plan lacking.

However, the Plan did set off a number of initiatives to update the institutional and legislative framework surrounding water and to bring water resources to the public's attention, which is a significant good development. It did, however, pave the way for the government to rethink its strategy and update the outdated Water Resources Act of 1992 by establishing a new Water Resources Policy and Bill and acknowledging integrated approaches as the cornerstone of water resources management (ADPC, 2021).

4.1.4 Water Resources Act 1992

The Water Resources Act, 2049 (1992), as amended by the Water Resources Rules, 2050 (1993), still provides the current legal basis for the management of water resources in Nepal. Attempts to replace the Act with a more recent version that would comply with the National Water Plan of 2005 and the subsequent new Constitution of Nepal have not been successful to date (ADPC, 2021). The Water Resources Act has several primary features that aim to manage and regulate water resources in the country effectively. The primary features of the act are:

- The Act promotes the conservation and sustainable use of water resources.
- It declares that all water resources within Nepal are the property of the State.
- To utilize water resources for purposes other than personal and domestic use, one must obtain a license as per the Act's provisions.
- Provides that projects may be transferred to water user associations in ownership and that the government may develop or use water resources without a license.
- The Act encourages the formation of Water Users Associations as a legal entity. These associations play a crucial role in managing water resources at the community level.
- Establishes a hierarchy for the utilization of water resources, independent of loss and benefit evaluations or economics.
- The Act provides a legal framework for the regulation and management of water resources, including the allocation of water rights and the resolution of water-related disputes.
- It outlines penalties for those who violate the provisions of the Act, such as unauthorized use of water resources or failure to comply with the terms of the license.
- The Act includes provisions that facilitate foreign investment in the development of water resources, subject to the laws of Nepal.

The Water Resources Rules, which cover about 40 rules on topics including water user associations, district water resources committees, licensing and licensing procedures, dispute resolution, water resources use fees (for commercial purposes), land acquisition, and other miscellaneous matters, further develop the provisions of the Water Resources Act (ADPC, 2021).

The Act outlines a priority order for the utilization of water resources to ensure their rational and equitable distribution. The priority uses are listed below in terms of priority;

- Drinking water and domestic uses;
- Irrigation;
- Agricultural uses such as animal husbandry and fisheries;
- Hydroelectricity;
- Cottage industry, industrial enterprises, and mining uses,
- Navigation;
- Recreational uses and
- Other uses

Although a significant step in water resource management, The Water Resources Act has faced specific criticisms and identified areas that could be improved. It hasn't been updated in a timely manner to reflect the recent administrative, sociological, and ecological changes that Nepal has gone through. The Act disregards women's contributions to the sustainable use of water resources (Joshi & Ghimire, 2024). The Water Resources Act needs to be significantly changed because it was passed before the new constitution and does not take it into consideration.

4.1.5 Irrigation Policy 2013

The Irrigation Policy of Nepal was approved 2013. The first irrigation policy was drafted in 1992 and was amended in 1997, 2003, and 2013. The policy was formulated to address several key areas in water management. It focuses on improving Agricultural and Farmer Managed Irrigation Systems (AMIS and FMIS) to increase water efficiency and achieve year-round irrigation. Developing large and modern irrigation systems, including inter-basin water transfer and reservoir-type systems. Promoting the conjunctive use of surface and groundwater to extend irrigation services even to marginal farms (Irrigation Policy, 2013).

This policy was part of a broader effort to increase agricultural production, reduce poverty through rural employment opportunities, and ensure food security by extending irrigation facilities to suitable lands throughout the year. The policy also suggests that the Irrigation Water User's Association have at least 33% female representation thus, includes provisions for irrigation service subsidies to underprivileged and disadvantaged groups, with a focus on gender equality and inclusive growth.

4.1.6 National Irrigation Master Plan 2019

The Irrigation Master Plan (IMP) 2019 is a comprehensive 25-year long-term plan for the development and management of the irrigation sector in Nepal. It builds upon the foundations set by the Irrigation Policy of 2013 and aims to address the challenges and opportunities in the sector. IMP provides a roadmap for sustainable irrigation development in Nepal, aiming to enhance food security and improve water resource management.

The main features of IMP are listed below:

- The IMP reviews the irrigation sector's development, achievements under the previous plan, and aligns with national policies. It highlights various irrigation systems in the country and food security scenarios.
- It also performs a detailed analysis of irrigable land, soil survey, land use, and water resources mapping for both surface and groundwater.
- Finally, defines goals and targets for improving existing and developing new irrigated areas, proposing multipurpose and large-scale surface water projects, small-scale groundwater projects, and improved irrigation management. The plan also emphasizes capacity development at all levels and the need for sub-national plans and conflict resolution between provinces.
- The financial requirements for various projects and activities is envisaged in the plan.
- It also includes a Monitoring and Evaluation Plan to track the implementation progress.

4.1.7 Water Supply and Sanitation (WASH) Act 2022

The Water Supply and Sanitation Act aims to provide clean and quality water supply and sanitation services while respecting, protecting, and fulfilling the fundamental rights of citizens. The defines terms such as "License," "Licensed Institution," "Commission," "Project," "Users," "Users Organization," "Water Supply Service," "Public Use of Water Supply", "Institutional Use of Water Supply", "Domestic," "Sewerage" and more, to standardize the understanding of water supply and sanitation services. This act plays a crucial role in advancing water supply and sanitation services, contributing to the well-being of citizens and environmental sustainability. The main objectives of this act are listed below (Ministry of Water Supply, 2022):

- To ensure accessible, affordable, and sustainable water supply and sanitation services.
- To protect public health by providing clean water and effective sanitation.
- To promote efficient management of water resources and wastewater.

4.2 Environment Sector

4.2.1 Nepal Environmental Policy and Action Plan, 2050

The Nepal Environmental Policy and Action Plan, 2050 is a comprehensive document prepared under the guidance of National Planning Commission. It aims to integrate environmental concerns into a country's development process and builds upon previous analyses of environmental issues.

The plan reviews current government policies, formulates new ones where necessary, and proposes an action agenda to address environmental problems. It responds to the global awareness of balancing economic development and environmental conservation, as highlighted during the United Nations Conference on Environment and Development in 1992 (Government of Nepal, 1993). The policy has five main objectives:

- Efficient and sustainable management of natural and physical resources.
- Balancing development efforts with environmental conservation for sustainable fulfillment of basic needs.
- Safeguarding national heritage.
- Mitigating adverse environmental impacts of development projects and human actions.
- Integrating environment and development through appropriate institutions, legislation, economic incentives, and public resources

The Policy is structured around these objectives and includes specific strategies for sustainable management of natural resources, safeguarding heritage, and mitigating environmental impacts. The Nepal Environmental Policy and Action Plan provides practical policy guidelines and actions to tackle Nepal's environmental problems. It emphasizes the need for a balance between development and conservation, ensuring a sustainable future for the country.

4.2.2 Ministry of Forest and Environment Policies and Strategies

The Ministry of Forest and Environment has a list of policies and strategies that address various environmental concerns, including climate change adaptation, forest and rangeland management, and pollution control. These policies and strategies play a crucial role in safeguarding Nepal's natural resources, promoting sustainable development, and addressing environmental challenges. The Policies and strategies developed by The Ministry of Forest and Environment are listed below (Ministry of Forest and Environment, 2024).

- Nepal's Long-Term Strategy for Net-Zero Emission: Approved by the Cabinet on 2078-07-09, this strategy aims to achieve net-zero emissions.
- National Climate Change Policy, 2076 (2019): Enacted on June 30, 2021, this policy outlines Nepal's approach to climate change mitigation and adaptation
- Gender and Social Inclusion Policy and Action Plan on Climate Change, 2077-2087: This policy addresses climate change-related issues with a focus on gender and social inclusion. It was published on July 9, 2021.
- Chronology of National Agroforestry Policy Development (2071-2076): This document traces the development of agroforestry policies in Nepal from 2071 to 2076 (2020-2025).

- National Agroforestry Policy, 2019: Published on October 1, 2020, this policy focuses on sustainable agroforestry practices.
- National Environmental Policy, 2076: Enacted on July 17, 2019, this policy addresses environmental conservation and protection.
- National Forest Policy, 2075: Published on April 10, 2019, this policy outlines strategies for forest management and conservation.
- National Ramsar Strategy and Action Plan, Nepal (2018-2024): Developed in 2018, this plan focuses on the conservation of wetlands designated as Ramsar sites.
- Forestry Sector Strategy (2016-25): Enacted on May 16, 2018, this strategy aims to enhance sustainable forest management and conservation.
- Simsar Policy, 2069: Published on May 16, 2018, this policy addresses the management of non-timber forest products.

4.2.3 The Environmental Protection Act, 2076 (2019)

The Environmental Protection Act, 2076 (2019) is a significant piece of legislation authenticated in 2019 that aims to protect the environment and address various environmental issues. it is intended to amend and consolidate laws related to environmental protection and ensure every citizen's fundamental right to live in a clean and healthy environment. The Act provides for compensation by the polluter to the victim for any damage resulting from environmental pollution or degradation. It aims to prevent harmful environmental effects on the environment and biodiversity and keep a healthy balance between the environment and development. The Act addresses the problems caused by climate change and includes mitigation and adaptation measures. The Act defines critical environmental terms such as “emission,” “climate change,” “hazardous substance,” “biological diversity,” and “pollution” to ensure clarity in its application (Government of Nepal, 2019). This Act provides a legal foundation to environmental pollution, natural resource management, and climate change-related challenges.

4.2.4 Environmental Protection Regulations, 2077 (2020)

The Environmental Protection Regulations, 2077 (2020) is a comprehensive set of rules and procedures established by the Government of Nepal for the protection and management of the environment. It was authorized by The Environmental Protection Act, 2076 (2019). These regulations aim to address various environmental issues, promote sustainable development, and ensure that environmental considerations are integrated into development projects and activities. The key aspects of the regulations are listed below (Government of Nepal, 2020). The regulations detail the requirements for conducting Environmental Impact Assessments (EIA) to evaluate the potential environmental impacts of proposed projects and activities.

- They outline the responsibilities of various stakeholders in environmental protection.
- Procedures for getting environmental clearances for projects are outlined, ensuring that environmental considerations are integrated into development initiatives.
- To ensure compliance with the established standards, there are obligations for regular monitoring and reporting on environmental quality.
- Penalties for non-compliance with environmental standards are set, aiming to make sure that the regulations are followed.
- There are provisions for public participation in environmental decision-making procedures, which encourages transparency and community involvement.

4.3 National Policies and Legal Framework on River Basin Management

4.3.1 Water Resources Strategy

The Water Resources Strategy (WRS) plays a significant role in shaping the water sector's objectives and guiding the sustainable management and development of water resources. The WRS initiated the approach of Integrated Water Resources Management (IWRM) to manage river basin system which was later adopted by NWP as the main theme. The plans and strategies of WRS and NWP has been discussed above.

4.3.2 Integrated Water Resource Management (IWRM) Action Plan

IWRM Action Plan for Nepal is developed by the Government of Nepal in the year 2022. The action plan was prepared in consultation with multiple stakeholders from government, non-governmental organizations, academia, the private sector, and development partners. The plan is aimed at guiding the country towards sustainable water resource management.

The Action Plan consists of 21 action projects in total. Among these, four priority actions are directed at the strengthening the enabling environment, which is considered the weakest in IWRM implementation in Nepal. Four at institutions and participation, one action to assure financing and the other five at strengthening the management instruments, for IWRM. The other five activities are directed towards the ongoing projects or programs where there is a chance to show how incorporating IWRM features could significantly improve their intended outcomes as well as help in the sustainable management of water resources in the corresponding areas (WECS, 2022).

4.3.3 Water Resources Policy 2020

National water resources policy in 2020 gives careful consideration to the implementation of river basin plans and IWRM. This policy integrates the use of water resources across various sectors including drinking water, irrigation, energy, and water-induced disaster management. The National Water Resources Policy 2020 of Nepal outlines seven objectives and eleven strategies to guide the country towards sustainable water resource management (ADPC, 2021; National Water Policy, 2020). The seven objectives of the policy are mentioned below:

- To use water resources wisely in order to easily meet the demands of several sectors.
- To contribute to the growth of national production through the multi-dimensional and equitable development and utilization of water resources.
- To make decisions based on science and facts.
- To plan the preservation, development and use of water resources in coordination with the federal, provincial, and local governments.
- To ensure easy access of water resources to fulfill citizen demands of water and water-related products.
- To manage and use water resources with minimal impact on the economic, social and environmental aspects.
- To manage and mitigate water-induced disasters.

The eleven strategies developed to achieve these objectives are listed below:

- Water resources will be used and managed on the basis river basin master plan.
- Priority will be given to IWRM and multipurpose uses while developing and managing water resources.
- Proper institutional arrangements will be developed for the protection, development, management and regulation of water resources.
- Participation of private sector and concerned stakeholders will be encouraged in the conservation and development of water resources.
- Along with expanding the study and research in the field of water, the available knowledge and facts will be recorded, analyzed and studied.
- Capacity building of institutions and human resources related to water resources will be developed.
- The roles and responsibilities of the federal, provincial and local level will be clarified, and the water resources will be used and managed in a coordinated manner.
- The people and the areas affected from the water resources projects shall be secured and protected.
- The basic necessities in terms of energy, drinking water and irrigation benefits should be provided to the people in the project areas with will be provided easily and fairly on the principles of equity.
- The use and management of water resources will be done by minimizing the negative impacts on social, cultural and environmental aspects.

- Water-induced disasters will be controlled and mitigated while making watershed management effective.

4.4 Constitutional, Policy and Legal Framework of Provincial Government

After the new constitution in 2015, Nepal introduced to a federal structure of government, devolving power and authority to 753 local governments and seven provinces. The Constitution of Nepal has given the responsibility of managing water resources to all three levels of government – federal, provincial and local.

- The federal level is responsible for formulating national policies, plans, and standards for water resources management. It also oversees the management of trans-boundary waters and large-scale water infrastructure projects.
- The Provincial level is tasked with implementing federal policies at a regional level, adapting them to local conditions, and managing water resources within their jurisdiction. They also play a role in medium-scale water infrastructure and inter-provincial water issues.
- Local governments are responsible for managing and maintaining small-scale water infrastructure. They are closest to the communities and ensure the provision of water for local needs and handle local water resources, including local water supply and sanitation.

Table 2: Jurisdiction of the Federal, Province and Local Levels (Source: ADPC, (2021))

Entities	Schedule	Item No. and Item of the schedule
Federal Jurisdiction only	5	7. International treaties or agreements, extradition, mutual legal assistance and international borders, international boundary rivers 11. Policies relating to conservation and multiple uses of water resources 14. Central level large electricity, irrigation and other projects 27. National and international environment management, national parks, wildlife reserves and wetlands, national forest

		policies, carbon services
Province Jurisdiction	6	7. Province level electricity, irrigation and water supply services, navigation 19. Use of forests and waters and management of environment within the province
Concurrent jurisdiction of the Federation and the Provinces	7	13. Province boundary rivers, waterways, environment protection, biological diversity 18. Tourism, water supply and sanitation 23. Utilization of forests, mountains, forest conservation areas and waters stretching in inter-State form
Local municipalities Jurisdiction	8	19. Water supply, small hydropower projects, alternative energy 21. Protection of watersheds, wildlife, mines and minerals
Concurrent jurisdiction of the Federation, Provinces and Local Level	9	5. Services such as electricity, water supply, irrigation 7. Forests, wildlife, birds, water uses, environment, ecology and bio- diversity 14. Royalty from natural resources

Table 2 shows that some issues fall under the concurrent authority of the Provinces and the Federation, while other issues are at all three levels. Although the provinces are responsible for the development of water resources, the rules and regulations necessary to support them are still being developed and inherited from federal laws and policies. The three levels of government must comprehend and be clear about how to apply the water-related legislation because although envisaged by the Constitution, province and local governments still do not have any policy that can guide their development programs in water sector. Along with the national policy, a province-level policy is also required for implementation at the local and provincial government levels. The province and local governments would be in a significant position to delegate authority and responsibility for managing water resources if the province level umbrella policy were implemented. This would enhance Nepal's federal governance structure (WECS, 2022).

Study on the policy gaps and institutional arrangements for water resources management in Nepal suggests that the issues of devolution of authority and resources and decentralization becomes critical as Nepal moves toward a federal governance structure. There is a lack of comprehensive legal and policy provisions to address issues like climate change, resulting in ineffective responses at the local level. Therefore, a more intricate integration of climate change into government operations' planning, budgeting, and governance frameworks is required for an effective climate change mainstreaming at both the local and national levels of policy (HI-AWARE, 2018).

4.5 Climate Change and Disaster Management Policy and Act

4.5.1 National Climate Change Policy 2019

The National Climate Change Policy 2019 is an update to the old Climate Change Policy from 2011. The policy has set forth several strategies and working policies aimed at building a resilient society capable of adapting to and mitigating the impacts of climate change (Government of Nepal, 2019). The Policy addresses water resources management as a critical component in the context of climate change. The key points related to water as outlined in the policy are listed below (ADPC, 2021):

1. Agriculture and Food Security:
    - The technologies that protect crops from climate-induced disasters like drought will be developed.
    - Water efficient irrigation technology will be promoted.
    - Forest, Biodiversity and Watershed Conservation:
    - Programs for adapting to climate change will be mainstreamed with the adoption of integrated watershed management.
    - The Integrated Watershed Management Program will be carried out in the areas that are susceptible to the effects of climate change.
    - Adaptive capacity of the local community will be enhanced by combining best practices of watershed and landscape management into an adaptation program.
2. Water Resources and Energy:
    - Technologies for storage, multiple-use, and efficient use of water will be developed and promoted in risk-prone areas and settlements considering the effects of climate change on the availability of, and access to, water.
    - Rainwater harvesting ponds with be built for groundwater recharge and other purposes.

- Selection of environment-friendly sites and use of climate-friendly technologies will be done during the construction of infrastructure including that of irrigation, drinking water, and hydroelectricity.
- Measures to mitigate adverse impacts on river ecosystems will be adopted while generating hydroelectricity.
- Safe outlet will be managed by decreasing the water level for reduction of glacial lake outburst risks.

3. Health, Drinking Water and Sanitation:
    - Water sources will be protected and water efficient technologies will be developed to increase access to, and easy availability of, drinking water.

4.5.2 Disaster Risk Reduction and Management Act, 2074

The Disaster Risk Reduction and Management Act, 2074 is a comprehensive legal framework developed by the Government of Nepal to guide the country's entire disaster management process. It covers a wide range of topics including natural and non-natural disasters and outlines the role of government bodies, the private sector, and local communities in the reduction and management of these disasters (Disaster Risk Reduction and Management Act, 2018). Specifically for water-related disasters, the Act likely includes provisions for the management of water resources, the protection of infrastructure against water hazards such as GLOFs, floods, and landslides, and the establishment of early warning systems and response mechanisms to mitigate the impact of such disasters.

4.5.3 National Policy for Disaster Risk Reduction, 2018

Nepal is one of the most disaster-prone countries and experiences significant loss of human lives and property damage due to these disasters every year. Nepal experiences both natural and non-natural disaster including floods, landslides, glacial lake outbursts, avalanches, fires, road accidents, epidemics, etc. Nepal is actively working toward disaster risk reduction and management activities through policy, legal frameworks, and strategic planning.

The National Policy for Disaster Risk Reduction developed in 2018 is an important framework in Nepal designed to improve sustainable development and resistance to recurring risks. The main long-term vision of this policy is to support sustainable development by making the nation safer, climate adaptive and resilient from disaster risk. It aligns with the Sendai Framework for Disaster Risk Reduction (SFDRR) priorities for action. The main objective of this policy is to significantly reduce the natural and non-natural disaster losses in lives and properties of persons, health, means of livelihood and production, physical and social infrastructures, cultural and environmental assets.

There are multiple policies followed to achieve the objectives of this policy. The key policies related to water and water induced disasters are mentioned below (Government of Nepal, 2018).

- Assessment and mapping of disaster risks will be conducted, mandatory insurance system will be promoted for the compensation of losses and damages due to disasters in the areas of education, health, agriculture, industry, tourism, energy, housing, transportation, water supply, sanitation including infrastructure.
- Participation of local users, community organizations, and community people will be ensured in the formulation, implementation, and management of plans for irrigation, river control, forest management, schools, health institutions, drinking water, and sanitation.
- A master plan will be developed and implemented for land and watershed conservation as per the principle of integrated water resource management, addressing the river management and inter-relationship of upper and lower riparian areas.
- Flood inundation, drought resistant, and climate change adaptive agriculture systems will be developed.
- Flood inundation, drought resistant, and climate change adaptive health service systems will be developed.
- Natural hazards such as floods, landslides, droughts, and glacier lake outbursts will be monitored and forecasted regularly. Forecast-based preparedness and response plans through the development of early warning systems will be developed and implemented.

4.5.4 National Strategic Action Plan for Disaster Risk Reduction

The National Strategic Action Plan for Disaster Risk Reduction outlines a comprehensive approach to disaster risk reduction. The vision of this strategic plan is to promote disaster risk reduction and management for resilient and sustainable development in Nepal. It aligns with the Sendai Framework for Disaster Risk Reduction priorities for action The expected outcome is to significantly mitigate and prevent new natural and non-natural disaster risks and losses in terms of life, property, health, livelihood, means of production, infrastructure, and cultural and environmental heritage.

Four priority areas and eighteen priority actions have been defined in this action plan. These strategic activities are proposed for three different time frames, 2018 to 2020 as short-term, 2018 to 2025 as medium-term, 2018 to 2030 as long-term, and continuous for those that are implemented regularly. Additionally, the plan recognizes the critical importance of water management and watershed protection in disaster risk reduction. The action plan which addresses these aspects is listed below:

- The plan emphasizes the need for integrated watershed management to ensure sustainable water resources and encourages the adoption of practices like reforestation, soil conservation, and sustainable land use planning that protect watersheds.
- The plan encourages community participation in decision-making, planning, and implementation of water-related projects.
- The plan promotes ecosystem-based approaches to water management and disaster risk reduction and enhance country's resilience to natural disasters by conserving and restoring ecosystems like forests, wetlands, and river basins.
- The plan recognizes the impact of climate change on water availability and quality, the plan integrates climate change adaptation strategies which includes measures to address changing precipitation patterns, glacial melt, and altered river flows.
- Proper design, maintenance, and risk assessment is done for safeguarding water-related infrastructure and ensuring these structures are resilient to disasters.

4.5.5 National Adaptation Plan (2021-2050)

The National Adaptation Plan (NAP) of Nepal was launched in 2021. This comprehensive strategy aims to strengthen the nation's resilience against climate change. The goal of this all-encompassing plan is to increase the country's ability to withstand climate change. NAP has been developed to help the nation adapt to the effects of climate change over the short-term (until 2025), medium-term (until 2030), and long-term (until 2050). NAP will provide information about the planning and coordination. and implementation of adaptation actions required at all levels of government and across society and ecosystems. It will also guide the integrating adaptation considerations into activities, programs, and policies (GoN, 2020) . The main objectives of NAP are:

- To reduce vulnerability to the effects of climate change by increasing resilience and adaptive capacity.
- To facilitate in coherently integrating climate change adaptation, into relevant new and existing policies, programs, and activities, particularly development planning processes and strategies across all relevant sectors and at various levels as needed.

NAP outlines 64 specific adaptation interventions across eight key thematic and four cross-cutting sectors. Thematic Areas:

1. Agriculture and food security
2. Forests, biodiversity and watershed conservation
3. Water resources and energy
4. Rural and urban settlements
5. Industry, transport and physical infrastructure

6. Tourism, natural and cultural heritage
7. Health, drinking water and sanitation
8. Disaster risk reduction and management

Cross-cutting sectors:

1. Gender equality and social inclusion, and livelihoods and governance
2. Awareness raising and capacity development
3. Climate change finance management
4. Research, technology development and expansion

The NAP contains 64 strategic priority adaptation programmes/interventions across various sectors. Some key adaptation interventions for water related areas including water resources management, adaptation measures to water-induced disasters and water and sanitation are listed below:

1. Increasing agricultural productivity by developing climate resilient water management systems.
2. Building resilience to climate vulnerabilities and risks of the Karnali watershed community and people. Promoting irrigation facilities in the downstream.
3. Integrated sub-watershed management for climate resilience and improved water availability and agricultural productivity.
4. Development and strengthening ponds and lakes for resilient biodiversity in community forests development.
5. Maintain healthy wetlands, develop and conserve biodiversity at the foothills of Chure. Sustain ground recharge through retaining streams, gorges, inlets, ponds, and lakes.
6. Encourage climate-informed decision-making and creating climate-smart design and infrastructure guidelines for water resources.
7. Establishing GLOF Risk Reduction and Early Warning Systems (EWS) in Glaciated River Basins (Gandaki, Koshi, Karnali)
8. Promoting water pumping technologies in places with limited water resources to address water stress for food security in hilly areas.
9. Building climate resilient check dams on Nepal's Rivers to sustain life.
10. Promotion and conservation of water sources along with watershed management for providing sustainable water supply.
11. Development of climate change resilience through innovation, capacity building, and the construction of WASH services and facilities.

12. Research, innovation, and development of climate-resilient technologies and measures for sanitation, health systems, and water supply.
13. Development of action plans and strategies at the federal and provincial levels to mitigate climate-related disasters, especially water-induced.

VISION GOAL AND OBJECTIVE OF THE SECTOR

The vision, goals, and objectives of the sector have been crafted with a foundation grounded in the national water resources strategy, relevant literature, national level water related policies, guidelines and plans review. These documents outline the long-term vision for the sustainable management, development, and utilization of the nation's water resources. To ensure the vision, goals, and objectives are robust and well-informed, several key steps have been undertaken:

National Water Resources Strategy: The primary reference for formulating the sector's vision, goals, and objectives. This strategy provides a holistic approach to managing water resources, considering factors such as water availability, demand, quality, and sustainable usage practices. It aims to balance the needs of various stakeholders, including agriculture, industry, and domestic users, while protecting and conserving water ecosystems.

Relevant Literature: An extensive review of academic and technical literature has been conducted. This includes research papers, case studies, and reports on water management practices, innovations in water technology, and comparative studies of water resource management in different contexts. By leveraging this body of knowledge, the sector's strategy is informed by the latest scientific insights and practical experiences.

National Level Water-Related Policies: A thorough examination of existing national policies related to water has been carried out. These policies encompass a range of issues from water conservation and distribution to quality control and infrastructural development. Understanding these policies ensures that the sector’s objectives are aligned with national priorities and legal frameworks.

Guidelines and Plans Reviews: Detailed reviews of various guidelines and plans at the national level have been undertaken. These documents provide operational frameworks and specific action plans for water resource management. By incorporating insights from these guidelines, the sector's vision and goals are practical, actionable, and aligned with existing implementation mechanisms.

By synthesizing information from these diverse sources, the sector’s vision, goals, and objectives are not only comprehensive and strategic but also well-aligned with national priorities and global best practices in water resource management. This integrated approach ensures that the sector is well-prepared to address current challenges and future demands in a sustainable and effective manner.

5.1 Vision of the Water Sector

To contribute to the socio-economic development of Gandaki Province by promoting sustainable development and management of available water resources in the region, ensuring environmental protection, equitable access and multifaceted utilization of water resources. The vision is aimed to be achieved with the completion of short-term, medium-term and long-term purposes which are defined as follows:

- Short-term (5 years) purpose - Improve access to water for basic needs of the people in the province including drinking, cooking, and sanitation.
- Medium-term (15 years) – Significant benefits to people for basic needs fulfillments is provided as well as other benefits related to sustainable water use.
- Long-term (25 years) purpose- Maximize the sustainable benefits of water and significantly improve the living standard of the people in the region.

5.2 Goal and Objective of the Sector

To fulfill these purposes, goals and objectives of the water sector in Gandaki province are set. The main goal is to ensure significant improvement of living conditions of the people in the region sustainably. The specific objectives to achieve this goal in Gandaki province are discussed below:

- To help in reducing poverty and improve livelihood.
- To implement the holistic approach of Integrated Water Resource Management (IWRM) for water resources management.
- To ensure environmental protection and aquatic ecosystem
- To prevent and mitigate water induced disaster
- To ensure access to safe and adequate water supply for drinking and sanitation.
- Sustainable development of hydropower projects to ensure energy security, and promoting clean energy.
- To enhance agricultural productivity through improved irrigation systems to improve food security.
- To ensure optimization of economic uses of water by industries and water bodies by tourism, fisheries and navigation.
- Strengthening institutional and legal frameworks for coordination and transparency of water sector management.
- To develop, maintain and enhance a functional water-related information system.
- To maintain inter-provincial cooperation in water resources development and management.

However, to attain these objectives in the long run, there are multiple sets of activities has been anticipated that needs to be accomplished under several related areas. These specific activities are discussed below

1. Drinking Water Supply and Sanitation
    - Improve the ability of institutions to plan, coordinate, carry out, and monitor.
    - Create and implement standards and regulatory mechanisms for effluent discharge and water quality.
    - Prepare budget plans to invest in new water supply and sanitation infrastructures and ensure proper protection and restoration of these infrastructures.
    - Develop equitable cost-sharing procedures and implement them.
    - Streamline the administration of sewage and water supply systems in the area and also monitor the functionality of the system.
    - Implement sensible conservation and safety measures.
    - Develop and implement practices that reduces water stress and ensure adequate safe water supply with respect to the demand.

2. Hydropower Development
    - Reform hydropower policies and administration to streamline regulatory processes and ensure transparency so that private sector participation and investment in hydropower projects could be encouraged.
    - Promote private funding for the distribution of electricity and the development of hydropower.
    - Create small- and medium-sized hydropower projects to meet domestic demand at an affordable price.
    - To speed the electrification of rural areas, increase government assistance in local level.
    - Include enhanced social and environmental safeguards in the development of hydropower.
    - Encourage Nepal's power-based industries and transportation system to create markets for large hydropower generation plants and fortify the organizational and material infrastructure for electricity export.
    - Encourage the study and development of hydropower.

3. Irrigation and Agriculture
   - Enhance the way the current irrigation systems are managed.
   - Explore the scope of multipurpose irrigation projects for large irrigation system.
   - Promote modern irrigation technologies such as drip irrigation, sprinklers, and efficient canal systems to optimize water use and improve crop yields.
   - Harmonize agricultural development with irrigation planning and management.
   - Create year-round irrigation to help agriculture become more intensive and diversified.
   - Adopt community-driven approaches and involve farmers, local communities, and user groups in planning, implementing, and managing irrigation systems.
   - Provide trainings and empower farmers with knowledge and skills to optimize water use.
   - Encourage climate-resilient agricultural practices.
   - Enhance the management and development of groundwater.
   - Collaborate with neighboring provinces and countries to manage shared water resources effectively

4. Watershed management and Environmental Conservation
   - Implement an integrated approach and ensure sustainable use of natural resources within the watershed.
   - Develop and improve the database system for environmental information.
   - Draw a map of aquatic ecosystems and significant, vital, and priority watersheds.
   - Create guidelines and criteria for the quality of water and wastewater.
   - Start educational program regarding water conservation.
   - In water resource management, make use of strategic environmental evaluation.
   - Implement climate-resilient practices like afforestation and reforestation, soil conservation and water harvesting.
   - Ensure that the environmental rules are being followed.
   - Encourage involvement in the community. Form water user groups to manage water resources collectively and oversee water use, water quality, and conservation activities.
   - Improve coordination and institutional capabilities.

5. Disaster Risk Reduction

- Assessment of vulnerable areas and mapping risk zones.
- Strengthen the information and networking system for disasters.
- Enhance early warning systems to provide timely alerts to communities about the possible disasters.
- Involve local communities in disaster risk reduction planning and implementation.
- Raise awareness about water-related hazards and encourage community-led initiatives.
- Create and implement plans and policies at both provincial and local government level for managing water-induced disasters.
- Conduct needs and capacity assessments at the local level to understand existing policies and capacities.
- Conduct disaster management awareness programs and education campaigns in the community. Provide directives for proactive disaster management and response.
- Set specific targets and objectives for implementation. Establish mechanisms for coordination, monitoring, and evaluation.
- Put disaster mitigation and reduction strategies into action.
- Support research on disaster risk reduction and explore innovative solutions for water-induced disaster resilience.
- Collaborate with neighboring provinces and countries to manage shared water resources effectively and address transboundary issues related to floods and landslides.

6. Optimize the economic uses of water in across various sectors like industries, tourism, fisheries and navigation
   - Promote water-based cultural, recreational, and ecotourism activities.
   - Look into possibilities for navigation along major rivers in the province.
   - Strengthen aquaculture and fisheries by educating fish farmers on modern aquaculture techniques and sustainable practices.
   - Enhance water utilization in industry and encourage to adopt water-efficient practices.
   - Ensure sustainable and environmentally friendly uses of water.

7. Inter-provincial Transboundary Cooperation

- Encourage better understanding of the constitutional provisions related to water management.
- Implement stronger inter-provincial cooperation to ensure efficient water resource development and management.
- Evaluate and comprehend inter-provincial water-related demands.
- Establish transboundary agreements among provinces and the federal government.
- Put in place development initiatives that benefit both parties.
- Proper management of database and documents regarding the signed agreement by all parties in consensus.

WATER SECTOR CHALLENGES, OPPORTUNITIES AND KEY ISSUES

The water sector in Gandaki Province is highly challenging, yet it equally presents significant opportunities for development.

6.1 Data and Information Management and Sharing

Access to accurate and up-to-date information allows policymakers, water managers, and communities to make informed decisions. When managing water resources, decisions related to infrastructure development, allocation, and conservation rely on data about water availability, quality, and demand. Access to water information ensures equitable distribution and access for all. Therefore, up-to-date data and easy access to those data is an important factor in water resources management.

The Gandaki Basin in Nepal, a crucial water source for the region, faces significant management challenges primarily due to deficiencies in information management. One of the primary issues is limited data collection. Many rivers within the basin lack sufficient gauging stations, making it difficult to accurately measure water flow and volume throughout the year (Basnet, 2019). This lack of continuous and comprehensive data hampers the understanding of water availability, which is essential for effective resource management. Additionally, the extreme variability in rainfall across the basin exacerbates these challenges. The temporal and spatial inconsistencies in rainfall and river discharge mean that while the region may appear water-rich at times, it can suffer from severe water shortages at other times. This variability complicates the task of ensuring a reliable water supply for irrigation, hydropower, and domestic use.

Another significant issue is the difficulty in obtaining quality, verified data on water resources. Much of the existing information is outdated, often based on reports prepared 25-30 years ago, and has not undergone peer review or rigorous validation (Jalsrot Vikas Sanstha; GWP Nepal, 2016). This lack of reliable data underscores the need for a better system to vet and update reports and studies regularly.

In addition to inadequate data collection, there is inconsistent data analysis. While localized studies on rainfall patterns exist, there is no cohesive approach that encompasses the entire Gandaki Province (Basnet, 2019). This disjointed nature of studies results in an unclear broader picture of water resources and precipitation trends, complicating efforts to manage the basin's water resources effectively. Furthermore, even when data is collected, it is often not readily accessible to all stakeholders, including policymakers, researchers, and local communities (Basnet, 2019). This lack of transparency and accessibility inhibits informed decision-making and community engagement, which are crucial for sustainable water management.

The repercussions of these information management issues are extensive. Predicting floods and droughts becomes a formidable task due to unpredictable rainfall patterns and the lack of comprehensive snowmelt data (Dandekhya et al., 2017). This unpredictability impedes the development of accurate forecasting models, increasing the vulnerability of the region to natural disasters. Moreover, the inefficiency in water allocation arises from an unclear understanding of water availability. Allocating water resources without accurate data can lead to conflicts among user groups and inefficient use of the available resources (Dandekhya et al., 2017). This inefficiency is particularly problematic in a region where water is a vital but limited resource.

The limitations in data management also affect disaster preparedness. Inaccurate or insufficient data on water flow can hinder the development of effective early warning systems for floods and landslides, putting downstream communities at greater risk. Without reliable data, these communities cannot adequately prepare for or respond to natural disasters, leading to potential loss of life and property.

Overall, these issues underscore the urgent need for improved information management systems in the Gandaki Basin. Enhancing data collection methods, ensuring consistent and comprehensive data analysis, and improving data accessibility are critical steps toward more effective water resource management. Addressing these gaps will not only aid in the sustainable utilization of water resources but also enhance disaster preparedness and resilience in the region.

Glacial lakes play a crucial role in water resources management in Gandaki Province. The ICIMOD maintains a large amount of data on glacial lakes in the Koshi, Gandaki, and Karnali river basins of Nepal which is very useful for the researchers (Bajracharya et al., 2020) Click or tap here to enter text.. The department of Hydrology and Meteorology (DHM) also maintains a database with a large amount of hydrological and meteorological data from all over Nepal which can also be useful for water resources management in Gandaki Province (Devkota & Gyawali, 2015). Apart from these database systems, there are multiple research and studies done in Gandaki Province which is very useful to policymakers as well as.

6.2 Climatic Variability and Water Availability

The water resource sector in Nepal, particularly hydropower production and irrigation facilities, has been significantly impacted by global warming, with temperatures rising annually by 0.04-0.06°C, especially in the Himalayan region (Bhattarai et al., 2018). Climate change is identified as the primary cause for the increased frequency and severity of extreme events such as floods and droughts worldwide. Numerous studies have examined the effects of climate change on snow water equivalent, snowmelt runoff, glacial melt runoff, and total stream flow in Himalayan rivers.

The impacts of climate change on hydrological systems are particularly severe in mountainous regions, leading to significant changes in the annual runoff cycle.

In the context of the Gandaki Basin of Nepal, a scenario analysis was conducted to evaluate the effects of climate change on the basin's hydrology, utilizing observed temperature and rainfall data (Bhattarai et al., 2018). The findings revealed significant alterations in water flow patterns within the basin. Long-term mean and maximum flows demonstrated an increase in response to elevated temperatures or higher levels of rainfall, indicative of intensified hydrological processes. Conversely, minimum flows exhibited a decrease with rising temperatures, indicating potential challenges for water availability during certain periods.

Monthly assessments of simulated flows showed a notable reduction in stream flows throughout the dry season, spanning from February to June. However, during other seasons, stream flows exhibited an increase, corresponding to the heightened temperatures. Notably, the relationship between temperature increases and changes in water deficits and surpluses was found to be non-linear, suggesting complex interactions within the hydrological system.

These findings pose significant challenges for water managers in the Gandaki Basin. Enough access to freshwater during dry seasons becomes important to focus on considering the diminishing minimum flows. Additionally, heightened flood risks during monsoon provides a need to take proactive measures to safeguard lives and properties. Effective water management strategies are imperative to mitigate the impacts of climate change on the basin's hydrology and uphold water security for communities reliant on the Gandaki Basin's resources.

Additionally, a case study done on the two villages from Mustang which lies in the Kali-Gandaki Sub-basin of Gandaki Basin showed clear evidence in the water related conflict due to the change in the climatic regime (Bhusal & Subedi, 2014) . In the research, data was collected and analyzed from two villages (Dhakarjong and Phalyak in Kagbeni) in the context of people's perceptions and traditional practices regarding water resources. Historically, there had been no conflicts over water rights between these villages for an extended period, spanning back 200 to 300 years. However, with disruptions in the natural hydrological processes, communities began to experience adverse effects such as decreased agricultural yields and pasture availability due to water scarcity. These challenges directly impacted livelihoods, leading to emerging conflicts over water resources in the area.

6.3 Cross-Cutting Issues

6.3.1 Gender and Social Inclusion

Gandaki Basin provides one of the oldest civilizations of Nepal. For hundreds of years the development of civilization occur in the flood plains of rivers. Water remains at the center of livelihood from the beginning of human civilization. Civilization enriched mostly on the fertile plains and river valleys. With time, people began migrating to highland slopes where there was easy access to water to use.

Nepali communities' living conditions are intricately tied to water, particularly due to the predominant reliance on agriculture for livelihood (Dahal, 2021). The basin's agricultural productivity directly impacts food security for a significant portion of the population. However, the inability to fully utilize water resources sustainably has worsened poverty conditions. Farmers, in particular, face challenges in accessing and controlling water resources, hindering their ability to move beyond subsistence farming.

One significant issue is the lack of control over water allocation, which prevents farmers from accessing water when they need it the most, thus perpetuating reliance on a subsistence economy. While some communities have successfully implemented collective efforts to harness and manage water resources, traditional mechanisms for water allocation are facing threats from new development pressures. These pressures often arise from competing interests, such as industrialization and urbanization, which further complicate water resource management.

Water-related problems in the Gandaki Basin give rise to serious social concerns that demand resolution either at the local level or through political intervention. Examples include frequent flooding, scarcity of drinking water, inundation of border areas, and insufficient water in irrigation canals. These challenges not only affect agricultural productivity but also exacerbate socio-economic disparities and contribute to environmental degradation.

In addition to the social significance, the Gandaki River Basin also holds an immense cultural significance, as they are intricately woven into the fabric of Nepalese society from birth to death (Dahal, 2021). Cultural issues arise due to the increasing degradation and pollution of these sacred water bodies.

One of the primary cultural issues is the deterioration of river health and water quality, resulting from pollution caused by untreated sewage, industrial effluents, and agricultural runoff. As rivers are revered as the abodes of gods and goddesses in Nepalese culture, their pollution not only poses environmental threats but also challenges deeply rooted cultural beliefs and practices.

Furthermore, the construction of hydropower dams and other infrastructural projects in the Gandaki Basin can disrupt the natural flow and ecology of rivers, impacting their sacred status and cultural significance. These projects often lead to the displacement of communities living along riverbanks, disrupting traditional cultural practices and livelihoods dependent on the rivers.

Additionally, rapid urbanization and population growth in the basin contribute to increased waste generation and encroachment along riverbanks, further degrading their cultural importance. As sacred sites and cultural centers are located along riverbanks, the degradation of these areas diminishes the cultural experiences and spiritual connections of local communities.

Moreover, the disposal of human remains in riverbanks, a traditional practice in Nepalese culture, can contribute to water pollution and raise public health concerns. While this practice holds cultural significance, its environmental impacts need to be addressed through sustainable alternatives.

6.3.2 Climate Resilience and Vulnerable Communities

The Gandaki basin faces significant challenges related to climate change, including extreme weather events like landslides and floods. Vulnerable communities living in areas prone to these events are particularly at risk. Examples of these groups are people that rely on rain for farming, reside in physically challenging environments like High Mountain, or live in areas where floods are a regular occurrence as a result of climate change. The Green Climate Fund (GCF) has approved a project specifically aimed at improving climate resilience for vulnerable communities and ecosystems in the Gandaki River Basin.

6.4 Issues in Policy Implementation

A recent study by CARE highlighted that water policies in Nepal based on the principles of integrated water resources management (IWRM) are evolving to align with the country's newly adopted federal structure, which includes federal, provincial, and local levels of governance (Climate Adaptation and Resilience (CARE) for South Asia, 2021). The Water Resources Strategy 2002, was crucial in guiding the government to develop policies focused on resource conservation, environmental protection, and the holistic management of river basins through decentralized, autonomous, and accountable agencies, emphasizing both economic efficiency and social equity. The National Water Plan 2005 outlined short-, medium-, and long-term action plans to achieve these national goals (WECS, 2011). However, the formulation of a comprehensive new Water Resources Act, as envisioned by the National Water Plan, was disrupted by the shifting political landscape in Nepal. Subsequent attempts to pass the Bill were unsuccessful.

The review also revealed a significant mismatch between policy statements and their actual implementation mechanisms in Nepal. While the policies themselves are robust, the tools necessary for their effective implementation are lacking. Issues persist regarding both the availability of information and the extent to which available resources are utilized. Additionally, there are pressing concerns related to the implementation of the provisions outlined in the constitution and the Water Resources Policy 2020.

These concerns include the need to clearly delineate the powers and responsibilities of federal, provincial, and local authorities as directed by the constitution, which necessitates national consensus and political willpower. Additionally, there is a requirement for a national agreement on the type and extent of water resource development in the Gandaki Basin. Furthermore, there is a critical need to translate these policies into actionable measures.

6.6 Service level issues

6.6.1 Environmental Issues

The Gandaki River Basin, a crucial lifeline for Nepal, faces a multitude of environmental challenges that threaten its delicate ecosystem and the well-being of its inhabitants. The various issues prevalent in the Gandaki River Basins are Climate change, degradation in the water quality, deforestation and unsustainable land use practices, habitat destruction, alteration of the water flow in the river due to the formation of hydropower dams, etc. These issues have further been discussed below.

Climate change is significantly disrupting precipitation patterns in the Gandaki River Basin. These disruptions are leading to decreased snow accumulation in the Himalayas and erratic rainfall patterns. As a result, water availability is becoming increasingly unpredictable throughout the year. Some areas within the basin experience water scarcity during dry seasons, while others face severe flooding due to heavy precipitation events (Bhattarai et al., 2018). This variability complicates water resource management, making it difficult to plan for irrigation, drinking water supplies, and hydropower generation effectively.

The pollution of the Gandaki River is a major concern, stemming from multiple sources including untreated sewage, industrial effluents, and agricultural runoff. These contaminants pose severe health risks to humans and aquatic life (Pant, Bishwakarma, et al., 2021). The excessive use of fertilizers and pesticides in agriculture exacerbates this issue, leading to the degradation of water quality. Polluted water affects not only the health of communities relying on the river for drinking water but also the aquatic ecosystems that depend on clean water for survival.

Deforestation and unsustainable land-use practices in the catchment area significantly contribute to increased soil erosion. When trees and vegetation are removed, the soil becomes more susceptible to being washed away during rainfall. This erosion results in excessive sedimentation in the riverbed, which elevates riverbeds and raises flood risks downstream (Chaubey et al., 2021). Sedimentation disrupts aquatic habitats, reducing the river's capacity to manage high water flows and increasing the likelihood of flooding.

The degradation of water quality and habitat destruction due to human activities pose significant threats to the diverse aquatic life in the Gandaki River. Endangered fish species and other aquatic creatures are particularly vulnerable to these environmental changes. The loss of habitat and polluted water sources lead to declines in fish populations and biodiversity, which can have cascading effects on the entire ecosystem (Pokharel, 2011).

Hydropower projects are vital for energy generation in Nepal, but they come with significant ecological costs. The construction and operation of these projects can disrupt the natural flow of the river, impacting fish migration and aquatic ecosystems (Suwal et al., 2020). Dams and reservoirs alter the natural hydrological regime, which can lead to reduced water flow downstream, affecting both the aquatic life and the communities that rely on the river for their livelihoods. Careful planning and implementation of mitigation measures are necessary to minimize these ecological disruptions.

6.6.2 Water Induced Disasters

The Gandaki Basin in Nepal, while a vital source of water, is also highly susceptible to water-induced disasters such as floods and landslides. These natural events pose significant challenges to the region, impacting both infrastructure and communities.

The basin experiences a monsoon season characterized by heavy rainfall, which significantly increases its vulnerability to floods and landslides (Dandekhya et al., 2017). The mountainous terrain with its steep slopes further exacerbates this risk. During the monsoon season, the heavy downpours can lead to rapid increases in river water levels, causing widespread flooding.

Flash floods are a particular concern in the Gandaki Basin. Rapid snowmelt in the higher Himalayas, combined with intense monsoon rains, can trigger sudden and severe flash floods, especially in the Kaligandaki sub-basin (Chaubey et al., 2021). These flash floods can cause immense damage to infrastructure, sweep away roads and bridges, and result in significant loss of life.

Landslides are another major issue, particularly in the mid-hills of the Gandaki Basin (Poudel et al., 2020) . Soil saturation from heavy rainfall weakens slopes, making them prone to landslides.

Districts like Dhading, Syangja, and Gorkha are particularly affected, with frequent landslide incidents during the monsoon season. These landslides can bury homes, roads, and farmlands, leading to devastating impacts on local communities.

Human activities significantly contribute to the increased risk of landslides in the Gandaki Basin. Deforestation, unplanned settlements on slopes, and improper road construction are major factors (Poudel et al., 2020). Deforestation removes the vegetation that stabilizes the soil, reducing its ability to absorb water and increasing the likelihood of landslides. Unplanned settlements, often located on or near steep slopes, place communities directly in harm's way. Improper road construction can destabilize slopes, further increasing the risk of landslides.

The impact of floods and landslides in the Gandaki Basin is profound. These disasters cause significant damage to infrastructure, including roads, bridges, and buildings. Agricultural land is often washed away or buried under debris, leading to the loss of crops and income for farmers. Property damage is widespread, and the repair and rebuilding efforts can take years.

Loss of life and injuries are common consequences of these disasters (Dandekhya et al., 2017). Flash floods and landslides can occur with little warning, making it difficult for people to evacuate in time. The resulting displacement disrupts livelihoods and displaces communities, often leaving them without shelter or access to essential services.

The economic impact is also significant. Recurrent floods and landslides hinder economic development by destroying infrastructure and disrupting trade and commerce. The cost of disaster response and recovery diverts resources from other development projects, slowing overall progress in the region.

The susceptibility of the Gandaki Basin to water-induced disasters such as floods and landslides highlights the urgent need for improved disaster management strategies. Addressing the root causes of increased risk, such as deforestation and unplanned settlements, is crucial. Additionally, enhancing early warning systems, improving infrastructure resilience, and engaging local communities in disaster preparedness and response can mitigate the impacts of these natural events. Strengthening information management systems to provide accurate and timely data will also be key in developing effective strategies to protect the lives and livelihoods of those living in the Gandaki Basin.

6.6.3 Issues in Hydropower Sector

In the Gandaki Basin of Nepal, the vast hydropower potential of 20,650 MW stands in stark contrast to the mere 523 MW that has been harnessed. However, numerous challenges hinder the full utilization of this resource.

The Gandaki Basin, like much of Nepal, is prone to landslides due to its rugged terrain and the intense monsoon rains it experiences (Jalsrot Vikas Sanstha & GWP Nepal, 2016). When roads and infrastructure are built to support hydropower projects, they can destabilize slopes and increase the risk of landslides. This poses a significant challenge to the construction and maintenance of hydropower projects in the region. For example, both the Kaligandaki 'A' (KGA) and Khimti Khola (KK) hydroelectric projects have encountered significant landslide issues, leading to delays and additional costs.

Climate change has a direct impact on hydropower potential in the Gandaki Basin (Singh et al., 2022). Changes in precipitation patterns, glacier melt, and river flow can affect the reliability and availability of water resources for hydropower generation. The Kaligandaki Gorge Hydropower Project, for instance, may experience reduced capacity for power generation due to alterations in river flow caused by climate change. This underscores the importance of considering climate change projections in the planning and management of hydropower projects in the region.

Hydropower projects, particularly run-of-river projects like the Kaligandaki run-of-river project, are susceptible to turbine abrasion. Sediment carried by rivers during periods of high flow can cause erosion and abrasion of turbine components, leading to reduced efficiency and increased maintenance costs. In addition, rising flood levels in the reservoir's upper reaches can exacerbate turbine abrasion issues. Effective sediment management strategies are essential to mitigate the impact of abrasion on hydropower infrastructure.

The construction and operation of hydropower projects in the Gandaki Basin can have significant impacts on the region's environmental resources (Kaini & Annandale, 2019). Without proper monitoring and management, these projects can lead to habitat destruction, water pollution, and disruption of aquatic ecosystems. There is a risk of overexploitation and overharvesting of environmental resources during the construction phase, particularly if adequate safeguards and regulations are not in place. Sustainable hydropower development requires careful consideration of environmental impacts and the implementation of mitigation measures to preserve biodiversity and ecosystem integrity.

6.6.4 Irrigation

The Gandaki Province has various policies and legislation related to water resources and irrigation. However, gaps may exist in the implementation and coordination of these policies, affecting irrigation service delivery (Jalsrot Vikas Sanstha, 2021). The Kaligandaki-Tinau diversion project has sparked debates between Gandaki Province and Lumbini Province for the use of water. Therefore, there is a need for inter-province cooperation and collaboration to address challenges related to water diversion and utilization which can also enhance irrigation service delivery.

The Gandaki Basin faces various climatic challenges. These include avalanches, landslides, glacial lake outburst floods (GLOFs) triggered by heavy rainfall, and droughts in the upstream area. In the midstream area, issues include landslides and drying up of springs, while the plains experience riverine floods (HI-AWARE, 2017). These climate change impacts significantly affect agricultural area and irrigation system in the province. Therefore, addressing policy gaps, promoting inter-province cooperation, and considering climate resilience are crucial steps toward improving irrigation service delivery in Gandaki Province.

6.6.5 Water-based Tourism

Gandaki Province offers a harmonious blend of natural wonders, adventure, and cultural experiences. One of the main attractions in this province is the Phewa Lake, a stunning freshwater lake located in the provincial capital which is famous for recreational activities like boating. The lake is surrounded by lush hills and the majestic Annapurna Mountain range and is an attraction to tourists from all around the world. Water quality assessments have been conducted, and during winter and summer, the lake is suitable for drinking purposes as well (Bishwakarma et al., 2019). Besides Phewa Lake, there are other major lakes in the province, such as Begnas Lake, Rupa Lake and Tilicho Lake famous for their natural beauty.

The Gandaki province is home to several important rivers, including the Kaligandaki and Seti offering thrilling rafting experiences. The province has some of the world-famous Himalayan peaks, including Annapurna, Dhaulagiri, Machapuchhre, Nilgiri, Manaslu, and Ganesh Himal which offer breathtaking views for the trekkers. The region is rich in cultural heritage, with several important Hindu and Buddhist temples, the famous Muktinath temple is one of them. Overall, Gandaki Province offers a variety of experiences including trekking through the Himalayas, rafting down rivers, or exploring ancient temples.

6.6.6 Access to Clean Water and Sanitation

Nepal has seen significant improvements in access to clean water and sanitation over the past few decades. However, there remain large gaps with approximately 3.8 million people lacking access to basic water services, and more than 10 million people not having improved sanitation facilities (Thapa, 2023).

In Gandaki Province, households primarily rely on piped water sources for daily water consumption. About 50.4 % of the total population has access to piped water but the functionality and actual access of households to quality and safe drinking water remains questionable (Project and Planning Commission, 2019). The functionality status of the water supply in Gandaki Province showed that a considerable number require rehabilitation, reconstruction, or minor repair.

Furthermore, as Gandaki Province is highly prone to climate change impacts and cannot be underestimated when considering water and sanitation challenges in the province. Infrastructures including pipelines, intake structures, reservoirs, and sanitation facilities are heavily impacted by climate-related disasters like landslides and floods (Thapa, 2023).

The sanitation situation of Gandaki Province shows a remarkable status with 100% of households having access to toilet facilities (Thapa, 2023). The comparative analysis of the provinces reveals an inherent relationship between the percentage of households with access to piped water and households using private, improved sanitation facilities. About 73.7% of households in Gandaki Province have improved sanitation services. In general, this suggests that when a home has access to piped water, they may be encouraged to build private sanitary facilities.

6.7 Inter-Provincial Water Disputes

The inter-provincial water disputes in Gandaki Province have been a topic of concern. With the implementation of Nepal’s new constitution, debates between Gandaki Province and Lumbini Province regarding the Kali-Gandaki Tinau Diversion Project have arisen. This situation highlights the need to understand constitutional provisions, review policies, and establish effective institutional mechanisms in resolving such disputes to utilize and manage water resources sustainably (Jalsrot Vikas Sanstha, 2021). The Gandak Irrigation and Power Project and the Mahakali River Development Project illustrates the intricate nature of managing water resources across borders between Nepal and India.

WATER RESOURCES STRATEGY AND ACTIVITIES

The goal of the Water Resource Strategy of Gandaki Province is to achieve optimal and sustainable benefits from the region's water resources. It aims to realize this goal through medium-term and long-term plans. Based on studies, data analysis, and national water resource planning in line with constitutional settings, we have proposed six key strategies have been proposed to guide these efforts. In addition to the strategies, we proposed include corresponding activities and institutional frameworks necessary to accomplish the proposed strategies.

7.1 Strategies and corresponding activities

1. **To develop and enforce water induced disaster mitigation plans that include early warning systems, resilient infrastructure, and community-based disaster preparedness programs.**
   Activities

   a. ***Implement land use planning regulations and zoning laws to restrict development in flood-prone areas, protect natural floodplains, and promote sustainable land use practices that reduce vulnerability to water-induced disasters.***

   Many rivers and lakes are available in the Gandaki Province. Due to step slope and fragile geology, the threat of water induced disaster is high in the province. So that implementing land use planning regulations and zoning laws is crucial for mitigating the impact of water-induced disasters, such as floods. By restricting development in flood-prone areas, these measures help prevent human and economic losses. Ensuring that natural floodplains are protected is essential, as these areas act as natural buffers, absorbing and mitigating floodwaters. By preserving these ecosystems, we maintain their natural capacity to manage and reduce the severity of floods, which is vital for the safety and sustainability of communities. Moreover, thoughtful zoning laws can guide development towards safer areas, ensuring that infrastructure and homes are built in locations less susceptible to flooding, thus safeguarding lives and property.

   Promoting sustainable land use practices through these regulations also contributes to long-term resilience against water-induced disasters. Sustainable practices might include the implementation of green infrastructure, such as rain gardens and permeable pavements, which enhance water absorption and reduce runoff. These measures can significantly diminish the overall flood risk. Additionally, by encouraging the maintenance and restoration of wetlands and other natural water retention areas, we support biodiversity and improve the overall health of the environment. This holistic approach not only protects against immediate flood risks but also fosters a sustainable and resilient landscape capable of withstanding future climate challenges. By the end of 2050, the province should make functional all the mechanisms and institutions related to land use planning.

b. ***Implement early warning systems to forecast and alert communities about impending water-induced disasters such as floods, landslides, and flash floods, enabling timely evacuation and emergency response.***

Implementing early warning systems to forecast and alert communities about impending water-induced disasters, such as floods, landslides, and flash floods, is vital for ensuring timely evacuation and effective emergency response. These systems leverage advanced technologies, including meteorological forecasting, hydrological modeling, and real-time data collection, to provide accurate and timely warnings. By alerting communities in advance, early warning systems allow individuals and authorities to take necessary precautions, such as evacuating vulnerable areas, securing property, and mobilizing emergency services. This proactive approach not only saves lives but also mitigates the economic impact of disasters by minimizing damage to infrastructure and property. For example, in countries like Japan, sophisticated early warning systems have significantly reduced fatalities and economic losses associated with water-related disasters, demonstrating the crucial role of these systems in disaster risk management and community resilience. So that province should develop an early warning system in major rivers within 20 years or before.

c. ***Construct and maintain infrastructure such as dams, levees, embankments, and drainage systems to mitigate the impact of water-induced disasters by diverting floodwaters, controlling river flow, and reducing erosion.***

To mitigate the impact of water-induced disasters in Gandaki Province, a comprehensive plan to construct and maintain critical infrastructure such as dams, levees, embankments, and drainage systems is essential. The initial phase involves conducting a thorough risk assessment to identify flood-prone areas and evaluate the potential severity and frequency of disasters. This assessment will utilize historical data, satellite imagery, and hydrological models. Engaging with local communities and stakeholders through public consultations will ensure that the infrastructure plans address the specific needs and concerns of the affected populations. The design phase will focus on developing engineering designs that meet international safety standards and are environmentally sustainable. This includes performing an Environmental Impact Assessment (EIA) to mitigate any adverse effects on local ecosystems and biodiversity.

Once the designs are finalized, the construction phase will commence, starting with the building of multipurpose dams to control river flow and store water, and the construction of levees and embankments along vulnerable riverbanks to prevent overflow and protect communities. Drainage systems will be developed in urban and rural areas to manage stormwater runoff effectively. Post-construction, a robust maintenance and monitoring program will be established, involving regular inspections, routine maintenance, and the use of advanced technologies such as drones and sensors for real-time data collection. Community training programs will be implemented to ensure residents and authorities are equipped to maintain the infrastructure and respond to emergencies. This holistic approach not only aims to divert floodwaters and control river flow but also significantly reduces erosion, enhancing the long-term resilience and safety of Gandaki Province.

Conduct community-based training programs to raise awareness about water-induced disasters, build local capacity for disaster preparedness and response, and develop community evacuation plans and emergency shelters.

d. Restore and maintain natural ecosystems such as wetlands, mangroves, and forests that act as natural buffers against water-induced disasters by absorbing excess water, stabilizing soil, and providing habitat for biodiversity.

Restoring and maintaining natural ecosystems such as wetlands, mangroves, and forests, which serve as vital buffers against water-induced disasters, involves several integrated steps. First, reforestation and afforestation projects can re-establish forested areas, enhancing soil stability and water absorption. Wetland restoration includes rehydrating drained wetlands, removing invasive species, and reintroducing native vegetation to restore their natural hydrology and ecological functions. Protecting mangrove forests requires replanting mangroves in degraded areas and implementing strict conservation policies to prevent further destruction. These efforts are complemented by enforcing sustainable land use practices and preventing deforestation and pollution. Engaging local communities through education and involving them in conservation activities is crucial for long-term success.

e. Sustainable Conservation and Management of Ecosystem Services provided by River Basins

The sustainable conservation and management of ecosystem services provided by river basins in Gandaki Province are critical for maintaining the region's ecological balance, supporting livelihoods, and ensuring long-term environmental sustainability. Gandaki Province, with its diverse topography and rich biodiversity, benefits immensely from the ecosystem services provided by its river basins, including water purification, flood regulation, soil fertility, and habitat provision. To sustainably conserve these services, it is essential to adopt an integrated management approach that considers the interdependencies between water, land, and biodiversity. This involves implementing strategies that promote sustainable land use practices, restore degraded habitats, and enhance water quality and quantity. Engaging local communities in conservation efforts through education and capacity-building programs ensures that traditional knowledge is incorporated and that the benefits of healthy ecosystems are equitably shared.

Furthermore, the establishment of river basin management committees that include stakeholders from various sectors—such as agriculture, forestry, fisheries, and tourism—can facilitate coordinated efforts to manage and conserve river basin ecosystems. These committees can develop and enforce regulations to control pollution, manage water withdrawals, and protect critical habitats. Monitoring and evaluation systems are also crucial to track the health of the ecosystems and the effectiveness of conservation measures. By leveraging scientific research and technological advancements, such as remote sensing and geographic information systems (GIS), authorities can make informed decisions to optimize resource use and minimize environmental impacts. Ultimately, the sustainable conservation and management of ecosystem services in Gandaki Province's river basins not only preserve the natural heritage but also enhance the resilience of communities to climate change and other environmental challenges.

f. Climate Change Adaptation, Flood Disaster Risk Reduction and Management for ensuring adaptive and resilient basin community and ecosystems Strategies

Climate change adaptation, flood disaster risk reduction, and management strategies are crucial for ensuring adaptive and resilient communities and ecosystems in the Gandaki Basin, Nepal. The Gandaki Basin, characterized by its diverse topography and significant water resources, is particularly vulnerable to the impacts of climate change, such as increased frequency and intensity of floods. To address these challenges, a comprehensive approach that integrates climate change adaptation and disaster risk management is essential. This involves enhancing early warning systems and flood forecasting capabilities to provide timely information to communities at risk. Investments in resilient infrastructure, such as flood embankments, drainage systems, and sustainable land management practices, can mitigate the impact of floods. Additionally, promoting community-based disaster risk management programs that empower local populations with knowledge and resources to respond effectively to flood events is crucial for building resilience. These programs should include training on emergency preparedness, evacuation plans, and the use of local knowledge to identify safe zones and shelter areas.

Another critical strategy is the restoration and conservation of ecosystems that provide natural flood protection and climate adaptation benefits. Reforestation and afforestation efforts in upstream areas can reduce soil erosion and enhance water retention, while the protection and restoration of wetlands and riparian zones can act as natural buffers against floodwaters. Implementing integrated water resource management (IWRM) principles ensures that water use is optimized, and ecological health is maintained, balancing the needs of communities and ecosystems. Supporting research and monitoring programs to understand climate change impacts and develop adaptive strategies is also essential. Collaboration among government agencies, non-governmental organizations, and local communities is vital for the successful implementation of these strategies. By adopting a holistic approach that combines structural and non-structural measures, the Gandaki Basin can become more resilient to the adverse effects of climate change and flood disasters, ensuring sustainable development and the well-being of its communities and ecosystems.

2. **To implement comprehensive infrastructure and policy initiatives to ensure equitable access to safe drinking water and sanitation services for all communities.**

Activities

a. ***Invest in the construction and maintenance of water supply and sanitation infrastructure, including piped water systems, boreholes, wells, and latrines, to ensure access to safe drinking water and sanitation facilities in all communities.***

Investing in the construction and maintenance of water supply and sanitation infrastructure in Gandaki Province, Nepal, is critical to ensuring all communities have access to safe drinking water and proper sanitation facilities. As of recent data, approximately 70% of the population in Gandaki Province has access to basic drinking water services, with significant disparities between urban and rural areas. Urban areas often rely on piped water systems, while rural communities depend on boreholes, wells, and springs. However, many of these water sources are not consistently safe or reliable due to contamination and seasonal variability.

To address these issues, the plan includes the installation of new piped water systems in densely populated areas and the construction of boreholes and wells in remote villages to improve water access. Ensuring the quality of these water sources is paramount, necessitating regular water quality testing and maintenance. Additionally, building latrines and improving sanitation facilities is essential to reduce waterborne diseases and enhance overall public health. In Gandaki Province, only about 45% of households have access to improved sanitation facilities. By investing in these infrastructures, including the provision of proper waste disposal systems and hygiene education programs, the aim is to achieve universal access to safe water and sanitation, thereby improving the quality of life and health outcomes for all residents in the region.

b. ***Involve local communities in decision-making processes and infrastructure planning to ensure that water and sanitation services meet their needs and preferences, and to foster a sense of ownership and responsibility for the maintenance of facilities.***

Involving local communities in decision-making processes and infrastructure planning is crucial for ensuring that water and sanitation services in Gandaki Province meet their needs and preferences, fostering a sense of ownership and responsibility for the maintenance of these facilities. One effective approach is to establish community water and sanitation committees that include representatives from different segments of the population, such as women, elders, and marginalized groups. These committees can actively participate in identifying water sources, selecting appropriate technologies, and deciding on the locations of infrastructure projects, ensuring that the solutions are tailored to the unique needs of each community.

For example, in the village of Sikles in Gandaki Province, a community-led initiative successfully improved water and sanitation services by involving residents in every stage of the project. The community conducted a needs assessment to identify critical issues, such as the lack of reliable water sources and inadequate sanitation facilities. Based on their findings, they collaborated with local NGOs and government agencies to design and implement a piped water system and construct latrines. The residents contributed labor and local materials, which reduced costs and increased their investment in the project's success. Training programs were also provided to educate the community on proper maintenance and hygiene practices. As a result, the project not only met the immediate needs of the villagers but also empowered them to take responsibility for the upkeep and sustainability of the water and sanitation facilities, leading to long-term improvements in public health and community well-being

c. ***Provide training and support to local authorities, water committees, and community members on water management, sanitation practices, and hygiene education to improve knowledge and skills for sustainable water and sanitation services.***

To provide training and support to local authorities, water committees, and community members on water management, sanitation practices, and hygiene education in Gandaki Province, a comprehensive and structured program needs to be established. This program should start with the development of tailored training materials that address the specific water and sanitation challenges of the region. Collaborate with experts and local NGOs to create modules covering topics such as water source protection, efficient water usage, maintenance of water infrastructure, and safe sanitation practices. Training sessions should be conducted regularly, combining theoretical knowledge with practical demonstrations. For example, workshops can teach participants how to maintain and repair boreholes and wells, manage piped water systems, and implement effective waste disposal methods. These sessions can be held in local community centers or schools, ensuring they are accessible to all.

In addition to technical training, it is essential to incorporate hygiene education to improve community health outcomes. Organize awareness campaigns and educational programs that highlight the importance of handwashing, safe drinking water practices, and proper sanitation. Use diverse methods such as posters, community theater, and radio broadcasts to reach a wider audience, including those in remote areas. Establish a network of local health educators and volunteers who can provide ongoing support and mentorship to community members, ensuring that the knowledge and skills imparted are continually reinforced and applied. By empowering local authorities and community members with the necessary skills and knowledge, the program will foster a culture of sustainable water and sanitation practices, ultimately leading to healthier and more resilient communities in Gandaki Province.

d. Implement measures to make water and sanitation services affordable for all, such as subsidy programs, tariff structures based on ability to pay, and cost-sharing arrangements between government, communities, and private sector partners.

Implementing measures to make water and sanitation services affordable for all in Gandaki Province, Nepal, involves creating subsidy programs, developing tariff structures based on the ability to pay, and establishing cost-sharing arrangements among the government, communities, and private sector partners. One effective approach is the introduction of a tiered tariff system where households are charged based on their income levels and water usage. For example, low-income families in Gandaki Province could receive water and sanitation services at a subsidized rate or even free of charge, while higher-income households pay a standard or premium rate. This ensures that basic services are accessible to all, regardless of economic status.

Additionally, subsidy programs can be implemented to reduce the financial burden on vulnerable populations. For instance, the government could provide direct subsidies to cover part of the construction and maintenance costs of water and sanitation infrastructure in impoverished communities. Cost-sharing arrangements can also be beneficial, where the government, local communities, and private sector partners collaborate to fund and manage water and sanitation projects. In Gandaki Province, a successful example is the partnership between the local government and non-governmental organizations (NGOs) to install community-managed water supply systems. These systems are co-financed, with the government and NGOs providing initial capital and technical support, while the community contributes labor and a small portion of the cost. This model not only makes services more affordable but also ensures community ownership and sustainability of the infrastructure. Through these measures, Gandaki Province can achieve equitable access to safe water and sanitation for all its residents.

e. Establish monitoring and evaluation systems to track progress towards achieving equitable access to safe drinking water and sanitation, identify gaps and challenges, and inform decision-making processes for targeted interventions and improvements.

Establishing robust monitoring and evaluation (M&E) systems in Gandaki Province to track progress towards achieving equitable access to safe drinking water and sanitation involves several key activities. First, comprehensive baseline data collection is essential to understand the current status of water and sanitation services across different communities. This involves mapping existing infrastructure, water sources, and sanitation facilities, and conducting household surveys to gather data on access and usage patterns. Utilizing geographic information systems (GIS) and remote sensing technologies can enhance the accuracy of this data. Regularly updating this information is crucial for tracking changes over time. For instance, in Gandaki Province, local authorities can partner with universities and NGOs to deploy mobile data collection tools that enable real-time updates on the condition of water supply systems and sanitation facilities.

To identify gaps and challenges, the M&E system should incorporate community feedback mechanisms, such as participatory rural appraisal (PRA) sessions, where residents can voice their concerns and suggestions. This community engagement ensures that the data collected reflects the actual needs and experiences of the people. For example, if a village reports frequent breakdowns of their water pumps, this issue can be flagged for targeted intervention. Analyzing the collected data helps in identifying trends, such as areas with consistently low access to safe water or high incidences of waterborne diseases. Decision-makers can use these insights to prioritize and design targeted interventions, such as repairing or upgrading infrastructure in underserved areas. Additionally, regular public reports on the progress towards water and sanitation goals can enhance transparency and accountability, ensuring that all stakeholders remain committed to achieving equitable access for all residents of Gandaki Province.

3. **To provide year-round irrigation to all potentially feasible agriculture areas. This enhances crop yields and ensures sustainable use of water resources.**

Activities

a. ***Construct reservoirs, ponds, and check dams to capture and store water during the monsoon season for use during dry periods, ensuring year-round availability of water for irrigation.***

Constructing reservoirs, ponds, and check dams in Gandaki Province is crucial for capturing and storing water during the monsoon season, ensuring a reliable water supply throughout the year. This strategy mitigates the impacts of seasonal variability, securing water availability during dry periods, which is essential for sustainable agricultural practices. By harnessing monsoon rains, these water storage structures support irrigation, improve crop yields, and enhance food security. Additionally, they help in groundwater recharge, reduce soil erosion, and prevent flooding by controlling excess runoff. Overall, these constructions play a vital role in promoting agricultural productivity, supporting livelihoods, and fostering resilience against climate change impacts in Gandaki Province.

To construct reservoirs, ponds, and check dams in Gandaki Province, the first set of activities involves site selection, feasibility studies, and detailed planning. This begins with identifying suitable locations based on topographical and hydrological data to ensure effective water capture and minimal environmental impact. Geological surveys and environmental impact assessments follow, determining the feasibility of the projects. Once viable sites are confirmed, detailed engineering designs are created, considering the required capacity, safety measures, and construction materials. Land acquisition and site preparation are crucial next steps, involving the clearing of vegetation, leveling, and ensuring the land is ready for construction.

The second phase focuses on the actual construction and subsequent maintenance of the water storage structures. Building reservoirs, ponds, and check dams involves implementing engineered designs with robust construction techniques to guarantee durability and efficiency. Concurrently, water diversion systems are established to channel monsoon water into these structures. Post-construction, a comprehensive maintenance plan is essential to manage siltation, structural integrity, and operational efficiency. Additionally, involving local communities throughout the process fosters sustainable management and ensures that the structures meet the needs of the residents, thereby securing a reliable water supply for irrigation during dry periods.

b. Undertake rehabilitation and maintenance of existing irrigation canals to prevent water loss due to leakage and ensure efficient water distribution to agricultural fields throughout the year.

Undertaking the rehabilitation and maintenance of existing irrigation canals in Gandaki Province is vital for preventing water loss due to leakage and ensuring efficient water distribution to agricultural fields throughout the year. Properly maintained canals minimize water wastage, ensuring that the maximum amount of available water reaches the crops, thereby improving irrigation efficiency. This is crucial for enhancing agricultural productivity, especially in a region where water availability can be inconsistent due to seasonal variations. Efficient water distribution supports consistent crop growth, boosts yields, and helps farmers sustain their livelihoods. Furthermore, well-maintained canals reduce the risk of structural failures and the associated repair costs, promoting the long-term sustainability of the irrigation infrastructure. Overall, these efforts are essential for optimizing water resources, supporting food security, and fostering economic stability in Gandaki Province.

Rehabilitating and maintaining existing irrigation canals involve several key activities aimed at preventing water loss and ensuring efficient distribution. Initially, a thorough assessment of the canals is conducted to identify areas of leakage, structural damage, and sediment buildup. Based on these findings, a detailed rehabilitation plan is developed, outlining the necessary repairs and upgrades. This may include sealing cracks, reinforcing canal linings, and removing obstructions to improve water flow. Implementing these repairs ensures that the canals can effectively transport water without significant losses. Regular maintenance activities, such as clearing debris, controlling vegetation growth along canal banks, and periodic inspection of the structures, are essential to sustain their functionality. Engaging local communities and water user associations in these efforts fosters a sense of ownership and ensures the sustainability of the irrigation system. Through these comprehensive rehabilitation and maintenance activities, the efficiency of water distribution to agricultural fields is significantly enhanced, supporting consistent crop irrigation throughout the year

c. ***Explore alternative water sources such as groundwater pumping, rainwater harvesting, and water recycling to supplement surface water supplies and enhance irrigation reliability during periods of water scarcity.***

Exploring alternative water sources such as groundwater pumping, rainwater harvesting, and water recycling is crucial for supplementing surface water supplies and enhancing irrigation reliability during periods of water scarcity. Groundwater pumping provides a dependable backup when surface water levels are low, ensuring that crops receive sufficient water even during dry spells. Rainwater harvesting captures and stores rainfall, reducing dependence on conventional water sources and providing an additional water reserve. This method also helps in recharging groundwater levels and mitigating the effects of drought. Water recycling, by treating and reusing wastewater, offers a sustainable way to augment water supplies, reducing the overall demand on freshwater resources. Together, these alternative sources create a diversified water supply system, increasing resilience against climate variability and water shortages. This multifaceted approach ensures that farmers have a reliable and continuous water supply for irrigation, promoting consistent agricultural productivity and food security in the region.

Exploring alternative water sources involves several critical activities aimed at supplementing surface water supplies and enhancing irrigation reliability. First, assessing the potential for groundwater pumping includes conducting hydrogeological surveys to identify viable aquifers and implementing sustainable extraction practices to avoid overexploitation. Establishing rainwater harvesting systems entails designing and constructing infrastructure such as rooftop collection systems, storage tanks, and recharge pits to capture and store rainfall effectively. This also involves community training on maintenance and efficient usage. Water recycling activities focus on installing treatment facilities to purify wastewater from agricultural, industrial, and domestic sources, making it safe for irrigation purposes. This includes setting up pipelines and distribution networks to deliver treated water to fields. Integrating these systems requires coordinated planning, investment in technology, and collaboration with local stakeholders to ensure their successful implementation and management. These activities collectively bolster water availability, reduce dependence on single water sources, and provide a reliable supply during periods of scarcity, thereby supporting sustainable agriculture in the region.

d. ***Promote the adoption of water-efficient irrigation technologies such as drip irrigation, sprinkler systems, and micro-irrigation techniques to maximize water use efficiency and minimize water wastage.***

Promoting the adoption of water-efficient irrigation technologies in Gandaki Province, Nepal, is crucial for maximizing water use efficiency and minimizing water wastage. Given the region's vulnerability to seasonal water scarcity and the dependence of its agriculture on reliable irrigation, technologies like drip irrigation, sprinkler systems, and micro-irrigation techniques are essential. These methods deliver water directly to the plant roots, reducing evaporation and runoff compared to traditional flood irrigation. This not only conserves water but also improves crop yields and quality by ensuring consistent moisture levels. Efficient irrigation systems contribute to the sustainability of water resources, enhance agricultural productivity, and support the livelihoods of farmers, fostering overall economic stability in the province. Following activities will require for promote and adaptation the water efficient irrigation technology.

- Conduct comprehensive assessments to identify areas and crops that would benefit most from water-efficient irrigation technologies. Develop detailed implementation plans tailored to local conditions and crop requirements.
- Organize training programs for farmers, extension workers, and local agricultural officials to educate them about the benefits, installation, and maintenance of drip irrigation, sprinkler systems, and micro-irrigation techniques.
- Implement subsidy programs and financial incentives to make these technologies more affordable for small and marginal farmers. This could include grants, low-interest loans, or cost-sharing arrangements.
- Facilitate the setup of the necessary infrastructure, including the procurement and distribution of equipment such as drip lines, sprinklers, pumps, and control systems. Ensure the availability of spare parts and technical support.
- Establish pilot projects and demonstration plots to showcase the effectiveness of water-efficient irrigation systems. These sites can serve as practical learning centers for farmers and stakeholders.
- Develop a monitoring and evaluation framework to track the adoption rates, water savings, and impacts on crop yields and farmer incomes. Use this data to refine and improve the implementation strategy.
- Involve local communities and water user groups in the planning and implementation process to ensure acceptance and sustainability. Promote collective action and knowledge sharing among farmers.

By focusing on these activities, Gandaki Province can significantly enhance its irrigation efficiency, conserve precious water resources, and improve agricultural productivity, ensuring long-term sustainability and resilience against water scarcity.

e. ***Encourage farmers to adopt climate-resilient crop varieties and implement crop rotation practices that are better suited to local climatic conditions and water availability, optimizing water use and increasing agricultural productivity.***

Encouraging farmers to adopt climate-resilient crop varieties and implement crop rotation practices tailored to local climatic conditions and water availability is vital for optimizing water use and increasing agricultural productivity. Climate change presents unprecedented challenges to agriculture, including unpredictable rainfall patterns and rising temperatures. By promoting the adoption of resilient crop varieties, such as drought-tolerant or heat-resistant cultivars, farmers can mitigate the adverse effects of climate variability. These varieties are specifically bred to thrive in challenging conditions, requiring less water while maintaining yield potential. Moreover, implementing crop rotation practices helps to diversify agricultural systems, enhance soil fertility, and reduce the risk of pest and disease outbreaks. By alternating crops with varying water and nutrient requirements, farmers can optimize water use efficiency and minimize water wastage, thereby ensuring sustainable agricultural production in the face of climate uncertainty.

Furthermore, encouraging the adoption of climate-resilient crop varieties and crop rotation practices aligns with the principles of sustainable agriculture and promotes ecosystem resilience. By selecting crops that are well-adapted to local climatic conditions, farmers can reduce their dependence on external inputs such as water, fertilizers, and pesticides. This not only minimizes production costs but also reduces the environmental impact of agriculture, including water pollution and soil degradation. Additionally, adopting crop rotation practices enhances soil health and biodiversity, contributing to the long-term sustainability of agricultural systems. Overall, by empowering farmers to adopt climate-smart agricultural practices, we can build resilience to climate change, improve water use efficiency, and ensure food security for present and future generations.

f. ***Implement integrated water management approaches that consider the needs of different water users, prioritize water allocation for agriculture, and incorporate sustainable water management practices to ensure equitable access to irrigation water for all stakeholders throughout the year.***

Implementing integrated water management approaches is crucial for addressing the diverse needs of various water users and ensuring equitable access to irrigation water throughout the year. By considering the requirements of different stakeholders, such as farmers, industries, and households, these approaches facilitate effective water allocation and utilization. Prioritizing water allocation for agriculture is particularly important as it sustains livelihoods, supports food production, and contributes to economic development. By incorporating sustainable water management practices, such as water conservation, efficient irrigation techniques, and watershed management, these approaches promote the efficient use of water resources while minimizing environmental degradation. Overall, implementing integrated water management approaches fosters equitable access to irrigation water, enhances agricultural productivity, and supports the long-term sustainability of water resources and livelihoods.

Implementing integrated water management approaches entails a series of activities aimed at addressing the diverse needs of various water users while ensuring equitable access to irrigation water throughout the year. Firstly, conducting comprehensive stakeholder consultations and participatory assessments helps to identify the water requirements and priorities of different user groups, including farmers, industries, and households. This information forms the basis for developing tailored water management plans that prioritize water allocation for agriculture, recognizing its pivotal role in sustaining livelihoods and food security. Secondly, implementing sustainable water management practices involves the adoption of efficient irrigation techniques, such as drip irrigation and canal lining, to minimize water wastage and enhance water use efficiency. Additionally, watershed management initiatives, including afforestation and soil conservation measures, help to protect water sources and maintain water quality. Integrating these practices into water management strategies ensures the equitable distribution of irrigation water while promoting the long-term sustainability of water resources and livelihoods in the region.

4. **To promote the development of sustainable hydropower projects through comprehensive planning, environmental impact assessments, and community engagement to ensure minimal ecological disruption and maximum local benefits.**

Activities

a. ***Conduct comprehensive resource assessments to identify potential hydropower sites and assess their technical, economic, and environmental feasibility. Develop long-term strategic plans for hydropower development in Gandaki Province, considering factors such as available water resources, topography, and energy demand projections.***

The implementation of hydropower development in Gandaki Province involves several key activities aimed at identifying suitable sites and planning for sustainable energy generation. Firstly, conducting comprehensive resource assessments is essential to identify potential hydropower sites across the province. This includes hydrological studies to assess water availability, topographical surveys to determine site suitability, and environmental impact assessments to evaluate potential ecological consequences. These assessments provide crucial data to assess the technical, economic, and environmental feasibility of hydropower projects.

Secondly, developing long-term strategic plans for hydropower development is necessary to ensure coordinated and sustainable energy generation. These plans consider various factors such as available water resources, topography, energy demand projections, and socio-economic considerations. By analyzing these factors, strategic plans can identify priority areas for hydropower development, determine optimal project sizes, and establish timelines for implementation. Additionally, strategic planning allows for the integration of hydropower development with other sectors, such as water resource management and environmental conservation, to maximize benefits and minimize negative impacts.

Overall, conducting comprehensive resource assessments and developing long-term strategic plans are critical implementation activities for hydropower development in Gandaki Province. By undertaking these activities thoughtfully and systematically, the province can harness its abundant water resources to meet energy demand sustainably, contribute to economic growth, and enhance regional development while minimizing environmental degradation.

b. Create an attractive investment environment for hydropower development by offering incentives such as tax breaks, streamlined permitting processes, and public-private partnership opportunities. Facilitate access to financing mechanisms such as government grants, loans, and international investment partnerships to fund hydropower projects.

Creating an attractive investment environment for hydropower development is essential for unlocking the potential of renewable energy resources and fostering economic growth. By offering incentives such as tax breaks, streamlined permitting processes, and public-private partnership opportunities, governments can attract private investment in hydropower projects. These incentives reduce financial barriers and regulatory hurdles, making investments in hydropower more appealing to investors. Moreover, facilitating access to financing mechanisms such as government grants, loans, and international investment partnerships provides additional support for project funding. This enables hydropower developers to secure the necessary capital to initiate and complete projects, thereby accelerating the development of clean energy infrastructure. Overall, creating an attractive investment environment for hydropower development not only promotes sustainable energy generation but also stimulates economic activity, creates jobs, and contributes to energy security and environmental sustainability.

Creating an attractive investment environment for hydropower development in Gandaki Province involves several essential works. Firstly, implementing policies that offer incentives like tax breaks, investment subsidies, and tariff incentives can significantly attract private investment. Streamlining permitting processes and regulatory frameworks is equally crucial to expedite approval procedures, reducing bureaucratic delays, and uncertainties. Public-private partnerships (PPPs) provide opportunities for joint ventures or concession agreements, leveraging the expertise and resources of both sectors. Moreover, facilitating access to financing mechanisms such as government grants, concessional loans, and international investment partnerships is essential. This ensures that developers can secure the necessary capital for project initiation and completion. By undertaking these efforts, Gandaki Province can foster an environment conducive to hydropower investment, promoting economic growth, and sustainable energy development.

c. ***Invest in the construction of necessary infrastructure for hydropower development, including dam structures, reservoirs, powerhouses, transmission lines, and substations. Improve road networks and transportation systems to facilitate construction activities and enhance project accessibility.***

Investing in the construction of necessary infrastructure for hydropower development in Gandaki Province is a strategic endeavor aimed at unlocking the region's hydropower potential and promoting sustainable energy generation. This strategy involves the construction of vital infrastructure such as dam structures, reservoirs, powerhouses, transmission lines, and substations, which are essential components of hydropower projects. These infrastructure investments enable the harnessing of water resources to generate electricity, thereby contributing to the province's energy security and economic development. Additionally, improving road networks and transportation systems is crucial to facilitate construction activities and enhance project accessibility. By upgrading transportation infrastructure, such as roads and bridges, and expanding logistical capabilities, construction materials, and equipment can be efficiently transported to project sites, reducing construction time and costs. Furthermore, enhanced accessibility improves project monitoring and supervision, ensuring that construction progresses smoothly and adheres to safety and environmental standards. Overall, investing in the construction of necessary infrastructure for hydropower development in Gandaki Province lays the foundation for sustainable energy production, economic growth, and regional prosperity.

d. ***Conduct thorough environmental and social impact assessments for proposed hydropower projects to mitigate potential negative effects on ecosystems, biodiversity, and local communities. Implement measures to minimize environmental degradation, protect natural habitats, and ensure the social welfare of affected populations.***

Conducting thorough environmental and social impact assessments for proposed hydropower projects is essential for ensuring sustainable development and minimizing adverse effects on ecosystems, biodiversity, and local communities. By assessing the potential environmental and social impacts beforehand, decision-makers can make informed choices to mitigate negative effects and maximize project benefits. Environmental impact assessments help identify potential risks such as habitat destruction, water pollution, and loss of biodiversity, allowing for the implementation of measures to minimize environmental degradation. Similarly, social impact assessments evaluate the project's effects on local communities, including displacement, livelihood changes, and cultural heritage preservation. Implementing measures to mitigate these impacts, such as community engagement, livelihood restoration programs, and cultural heritage preservation initiatives, ensures the social welfare of affected populations and fosters inclusive and sustainable development. Overall, conducting thorough environmental and social impact assessments for hydropower projects is essential for responsible decision-making, environmental protection, and social equity.

Strategic activities for conducting thorough environmental and social impact assessments for proposed hydropower projects and implementing measures to mitigate negative effects encompass several key steps. Firstly, engaging with stakeholders and local communities through participatory processes to understand their concerns and incorporate their perspectives into the assessment process is crucial. Secondly, conducting comprehensive environmental assessments to identify potential impacts on ecosystems, biodiversity, water quality, and natural habitats. This involves field studies, biodiversity surveys, and hydrological assessments to accurately assess the project's environmental footprint. Similarly, social impact assessments evaluate potential socio-economic impacts on local communities, including livelihoods, cultural heritage, and land use. Thirdly, based on the findings of these assessments, implementing mitigation measures such as habitat restoration, pollution control measures, and biodiversity conservation efforts to minimize environmental degradation and protect natural habitats. Additionally, implementing socio-economic measures such as livelihood restoration programs, community development initiatives, and cultural heritage preservation efforts to ensure the social welfare of affected populations. By incorporating these strategic activities, hydropower projects can be developed in a sustainable and responsible manner, balancing energy needs with environmental conservation and social equity.

e. ***Embrace technological advancements and innovation in hydropower generation, such as the use of advanced turbine designs, digital monitoring systems, and smart grid technologies, to enhance efficiency, reliability, and sustainability of hydropower operations in Gandaki Province. Collaborate with research institutions and industry experts to promote the adoption of cutting-edge technologies and best practices in hydropower development***.

Embracing technological advancements and innovation in hydropower generation is crucial for enhancing the efficiency, reliability, and sustainability of hydropower operations in Gandaki Province. This entails adopting advanced turbine designs, digital monitoring systems, and smart grid technologies to optimize energy production, minimize environmental impacts, and improve system reliability. By harnessing these cutting-edge technologies, hydropower facilities can operate more efficiently, ensuring maximum utilization of available water resources while minimizing waste.

Furthermore, collaborating with research institutions and industry experts to promote the adoption of these technologies and best practices fosters innovation and knowledge exchange, positioning Gandaki Province at the forefront of sustainable hydropower development. Overall, embracing technological advancements in hydropower generation not only enhances energy production but also contributes to the province's economic growth and environmental sustainability.

Activities to embrace technological advancements and innovation in hydropower generation in Gandaki Province involve several key steps. Firstly, establishing partnerships with research institutions and industry experts to facilitate knowledge exchange and collaboration in identifying and promoting cutting-edge technologies and best practices. This collaboration enables access to the latest research findings, technological developments, and innovative solutions tailored to hydropower generation challenges. Secondly, conducting feasibility studies and pilot projects to assess the applicability and effectiveness of advanced turbine designs, digital monitoring systems, and smart grid technologies in local hydropower contexts. These studies provide valuable insights into the potential benefits and challenges of adopting these technologies in Gandaki Province. Thirdly, integrating advanced technologies into hydropower projects through strategic planning, investment, and implementation. This involves incorporating advanced turbine designs to optimize energy conversion, deploying digital monitoring systems for real-time performance monitoring and predictive maintenance, and implementing smart grid technologies to enhance grid stability and reliability. By embracing technological advancements and innovation in hydropower generation and fostering collaboration with research institutions and industry experts, Gandaki Province can enhance the efficiency, reliability, and sustainability of its hydropower operations, positioning itself as a leader in sustainable energy development.

5. **To optimize water usage for industries, tourism, fisheries, and navigation by implementing efficient water management practices and promoting sustainable economic activities.**

Activities

a. ***Maintain and upgrade navigation infrastructure such as rivers, lake and manmade reservoir for efficient transportation of goods and passengers.***

Maintaining and upgrading navigation infrastructure in Gandaki Province's lakes involves several key strategies. Firstly, regular dredging is essential to remove sediment buildup, ensuring adequate water depth for navigation. This dredging process should be complemented by periodic maintenance of navigation aids such as buoys and markers to guide vessels safely. Additionally, investing in infrastructure upgrades such as jetties, docks, and boat ramps enhances accessibility and facilitates loading and unloading activities. Collaborating with local communities and stakeholders is crucial to ensure that maintenance and upgrade efforts align with their needs and priorities. Furthermore, implementing safety measures and environmental conservation initiatives helps mitigate risks and preserve the ecological integrity of lakes, supporting sustainable navigation activities.

For rivers and man-made reservoirs in Gandaki Province, maintenance and upgrade efforts require similar approaches tailored to their specific characteristics. Regular dredging of rivers is necessary to maintain navigable channels and prevent sediment accumulation, while repairing and upgrading lock and dam systems enhances efficiency and safety for commercial shipping and recreational boating. Installing and maintaining navigation aids such as beacons and signage helps guide vessels through waterways, especially in areas with complex topography or hazards. Furthermore, implementing safety regulations and emergency response protocols ensures the well-being of passengers and goods transported on these water bodies. Collaborating with research institutions and industry experts can facilitate the adoption of cutting-edge technologies to improve navigation infrastructure and optimize transportation efficiency.

b. Promote ecotourism initiatives that highlight the natural beauty and biodiversity of water-related ecosystems, such as wetlands, rivers, and lakes. Encourage responsible tourism practices that minimize environmental impact and contribute to the conservation of water resources and aquatic habitats.

In Gandaki Province, promoting ecotourism initiatives involves a multifaceted approach aimed at showcasing the region's natural beauty and biodiversity while encouraging responsible tourism practices. Firstly, through targeted marketing campaigns and promotional materials, the province can highlight the pristine landscapes and diverse ecosystems of its water-related habitats, including wetlands, rivers, and lakes. These efforts raise awareness among potential visitors about the unique ecological features and cultural heritage associated with these areas, attracting tourists interested in nature-based experiences. Secondly, encouraging responsible tourism practices is essential to minimize environmental impact and contribute to the conservation of water resources and aquatic habitats. This can be achieved through education and outreach programs that promote sustainable tourism behaviors, such as waste reduction, water conservation, and respecting wildlife habitats. Additionally, establishing regulations and guidelines for ecotourism activities ensures that visitors adhere to ethical and environmentally friendly practices while enjoying the natural wonders of Gandaki Province. Through these activities, the province can leverage ecotourism as a tool for both economic development and environmental conservation, fostering a harmonious relationship between tourism and nature.

c. ***Implement water-efficient technologies and practices in industries to minimize water consumption and optimize production processes. Conduct regular water audits and assessments to identify areas for improvement and implement water reuse and recycling systems wherever feasible.***

Implementing water-efficient technologies and practices in industries in Gandaki Province is crucial for minimizing water consumption and optimizing production processes. Firstly, by adopting advanced water-saving technologies and practices, industries can significantly reduce their water usage while maintaining or even improving production output. This includes implementing measures such as installing water-efficient equipment, optimizing cooling systems, and implementing process modifications to minimize water waste. Secondly, conducting regular water audits and assessments allows industries to identify areas for improvement and prioritize water-saving initiatives. By analyzing water usage patterns and identifying inefficiencies, industries can implement targeted measures to enhance water efficiency and reduce operating costs. Additionally, implementing water reuse and recycling systems wherever feasible further minimizes water consumption and maximizes resource utilization, contributing to sustainable water management practices in the region. Through these efforts, industries in Gandaki Province can mitigate water scarcity risks, enhance resource efficiency, and contribute to environmental sustainability.

d. ***Invest in the development of water-related infrastructure and facilities to support tourism activities, such as recreational water sports, eco-tourism, and waterfront amenities. Construct marinas, docks, and boat ramps to facilitate water-based recreational activities and enhance visitor experiences.***

Investing in the development of water-related infrastructure and facilities in Gandaki Province to support tourism activities involves several key activities. Firstly, constructing marinas, docks, and boat ramps along water bodies such as lakes and rivers facilitates water-based recreational activities such as boating, kayaking, and fishing, enhancing visitor experiences. These facilities provide convenient access points for tourists to launch watercraft and explore the natural beauty of the region's aquatic environments. Additionally, developing waterfront amenities such as promenades, picnic areas, and viewing platforms enhances the attractiveness of these locations and encourages visitors to spend more time enjoying the scenic surroundings. Furthermore, investing in eco-tourism initiatives that promote responsible tourism practices and highlight the biodiversity and cultural heritage of water-related ecosystems further enriches the tourism experience in Gandaki Province. Overall, investing in water-related infrastructure and facilities supports the growth of tourism activities, stimulates economic development, and promotes the sustainable use of natural resources in the region.

e. ***Establish robust water quality monitoring programs to assess the health of water bodies used for tourism, fisheries, and navigation. Implement measures to prevent water pollution from industrial discharges, agricultural runoff, and other sources to safeguard water quality for recreational and ecological purposes.***

Establishing robust water quality monitoring programs in Gandaki Province is crucial for assessing the health of water bodies utilized for tourism, fisheries, and navigation. These programs involve regular monitoring of various water quality parameters such as pH, dissolved oxygen levels, nutrient concentrations, and pollutant levels. By collecting comprehensive data on water quality, authorities can evaluate the overall condition of water bodies and identify potential sources of pollution or degradation. This information is essential for making informed decisions regarding water resource management and conservation efforts, ensuring the sustainability of aquatic ecosystems and supporting the diverse activities reliant on these water bodies.

Implementing measures to prevent water pollution from industrial discharges, agricultural runoff, and other sources is essential to safeguard water quality for recreational and ecological purposes in Gandaki Province. This involves implementing regulations and guidelines to control and minimize pollutant discharges into water bodies, such as setting effluent standards for industries and implementing best management practices for agricultural activities. Additionally, investing in infrastructure and technologies for wastewater treatment and runoff management helps to reduce the impact of human activities on water quality. Public awareness campaigns and education programs can also play a vital role in promoting responsible behavior and encouraging stakeholders to adopt practices that protect water resources. By proactively addressing sources of pollution and implementing preventative measures, Gandaki Province can ensure the long-term health and integrity of its water bodies, supporting both tourism and ecological conservation efforts.

f. ***Engage local communities, industry stakeholders, and relevant government agencies in collaborative efforts to manage water resources sustainably for industrial, tourism, fisheries, and navigation purposes. Foster partnerships and dialogue to address common challenges, share knowledge and resources, and develop joint initiatives for water resource management and conservation.***

Engaging local communities, industry stakeholders, and relevant government agencies in collaborative efforts is essential for sustainable water resource management in Gandaki Province. Firstly, fostering partnerships and dialogue among these stakeholders creates a platform for sharing knowledge, expertise, and resources. Through open communication and cooperation, common challenges related to water resource management can be identified and addressed collaboratively. By leveraging the collective wisdom and experiences of diverse stakeholders, more effective solutions can be developed to ensure the sustainable use of water resources for industrial, tourism, fisheries, and navigation purposes.

Secondly, engaging local communities in decision-making processes empowers them to actively participate in water resource management initiatives. Community involvement fosters a sense of ownership and responsibility for local water resources, leading to more effective conservation and stewardship efforts. By incorporating traditional knowledge and local practices, community-based approaches can complement scientific methods and enhance the resilience of water management systems. Furthermore, involving industry stakeholders and relevant government agencies ensures that policies and regulations are informed by practical insights and sector-specific needs, leading to more comprehensive and effective water resource management strategies.

Thirdly, collaborative efforts among stakeholders can lead to the development of joint initiatives and projects aimed at improving water resource management and conservation. These initiatives may include watershed restoration programs, water quality monitoring networks, or community-based conservation projects. By pooling resources and expertise, stakeholders can implement more impactful and sustainable solutions to address shared water challenges. Additionally, fostering partnerships between government agencies, industry, and non-governmental organizations (NGOs) can facilitate the mobilization of funding and technical support for water management initiatives. Overall, engaging local communities, industry stakeholders, and relevant government agencies in collaborative efforts is essential for promoting sustainable water resource management practices and ensuring the long-term health and availability of water resources in Gandaki Province.

6. To formulate inclusive and adaptive water resource policies that address current and future needs, promote sustainable management, and ensure equitable access for all stakeholders.

Activities

a. Conduct a thorough review and analysis of existing water resource policies, laws, and regulations to identify gaps, inconsistencies, and areas for improvement. Assess policy effectiveness in addressing current and emerging water challenges, including climate change impacts, population growth, urbanization, and ecosystem degradation.

Conducting a thorough review and analysis of existing water resource policies, laws, and regulations for Gandaki Province in coordination with the Nepal government involves several key activities. Firstly, conducting a comprehensive review of current policies, laws, and regulations related to water resource management to identify gaps, inconsistencies, and areas requiring improvement. This entails examining legal frameworks at both the provincial and national levels to ensure alignment and coherence in water governance practices. Secondly, assessing the effectiveness of existing policies in addressing current and emerging water challenges, including climate change impacts, population growth, urbanization, and ecosystem degradation. This involves analyzing policy outcomes, implementation mechanisms, and enforcement mechanisms to identify strengths and weaknesses in current approaches to water resource management.

Furthermore, engaging stakeholders from various sectors, including government agencies, local communities, civil society organizations, and the private sector, is essential for gathering diverse perspectives and insights. Consultations and dialogues with stakeholders facilitate the identification of priority areas for policy reform and the development of consensus-driven solutions to water-related challenges. Additionally, integrating scientific research and data analysis into the policy review process provides evidence-based insights into the complex dynamics of water resources in Gandaki Province. This interdisciplinary approach ensures that policy recommendations are informed by sound scientific evidence and practical considerations, enhancing their effectiveness and relevance in addressing current and future water challenges. Overall, conducting a comprehensive review and analysis of water resource policies, laws, and regulations in coordination with the Nepal government lays the foundation for evidence-based decision-making and policy reform initiatives aimed at promoting sustainable water resource management in Gandaki Province.

b. Enabling Environment and Inclusive Institutional Framework for Good Basin Governance

Creating an enabling environment and an inclusive institutional framework for good basin governance in the Gandaki Province is essential for sustainable water resource management. This involves establishing clear policies and regulations that promote equitable and efficient use of water resources, ensuring that all stakeholders, including marginalized communities, have a voice in decision-making processes. An inclusive institutional framework must prioritize transparency, accountability, and participation, fostering trust and collaboration among government agencies, local communities, non-governmental organizations, and private sector entities. By integrating traditional knowledge with modern scientific approaches, governance structures can be more adaptive and responsive to the unique challenges faced by the Gandaki Basin, such as climate change, population growth, and increased demand for water.

To achieve good basin governance, it is crucial to strengthen the capacity of local institutions and empower community-based organizations to take an active role in water management. This can be done through training programs, technical assistance, and financial support that enable local stakeholders to develop and implement effective water management strategies. Additionally, promoting cross-sectoral coordination and cooperation among various governmental and non-governmental entities can lead to more holistic and integrated water management approaches. Implementing robust monitoring and evaluation systems ensures that policies and programs are continually assessed and improved based on feedback and changing conditions. By fostering an enabling environment and building an inclusive institutional framework, the Gandaki Province can achieve sustainable and equitable water resource management, enhancing the resilience and well-being of its communities and ecosystems.

c. *Integrated Water Resources Management (IWRM) for Sustainable Development and Equitable Management of Water Resources of the Basin*

Integrated Water Resources Management (IWRM) for sustainable development and equitable management of water resources in a basin involves a holistic approach that coordinates the development and management of water, land, and related resources. One crucial activity is the establishment of comprehensive water management plans that consider the social, economic, and environmental needs of the entire basin. This involves engaging stakeholders from all sectors, including agriculture, industry, and local communities, to ensure that their needs and concerns are addressed. Public participation and collaboration among different water users are essential for creating a sense of ownership and responsibility towards water resources. Additionally, implementing policies that promote efficient water use, reduce pollution, and protect ecosystems are critical for maintaining the health of the basin. Regular monitoring and data collection on water quality and quantity, land use changes, and ecological health are necessary to inform decision-making and adapt management strategies as needed.

Another key activity is the development of infrastructure and technologies that support sustainable water management. This includes the construction of reservoirs and dams for water storage and flood control, the installation of irrigation systems that optimize water use, and the implementation of wastewater treatment facilities to prevent pollution. Promoting the use of innovative technologies, such as remote sensing for water monitoring and smart irrigation systems, can significantly enhance the efficiency and effectiveness of water resource management. Capacity building and training programs for local communities and water managers are also vital to ensure that they have the knowledge and skills needed to implement and maintain these technologies. Furthermore, establishing financial mechanisms and incentives, such as water pricing and subsidies for sustainable practices, can encourage water conservation and efficient use. By integrating these activities into a cohesive IWRM framework, it is possible to achieve sustainable development and equitable management of water resources in the basin, ensuring that the needs of both current and future generations are met.

d. *Conduct comprehensive stakeholder consultations involving diverse groups such as government agencies, local communities, indigenous peoples, civil society organizations, and the private sector to gather input and perspectives for formulating water resource policies. Ensure inclusivity and representation from marginalized and vulnerable groups to address their specific needs and concerns.*

Conducting comprehensive stakeholder consultations for formulating water resource policies in Gandaki Province involves a systematic and inclusive process. Firstly, identifying and engaging diverse stakeholder groups such as government agencies, local communities, indigenous peoples, civil society organizations, and the private sector is essential. This involves mapping out key stakeholders and establishing communication channels to facilitate meaningful engagement throughout the policy formulation process. Secondly, organizing stakeholder consultations through a variety of mechanisms such as workshops, focus group discussions, public hearings, and online surveys to gather input and perspectives from a broad range of stakeholders. These consultations provide opportunities for stakeholders to express their views, share knowledge and experiences, and contribute to the development of inclusive and equitable water resource policies.

Ensuring inclusivity and representation from marginalized and vulnerable groups is critical to addressing their specific needs and concerns in water resource policy formulation. This requires proactive efforts to reach out to marginalized communities, including women, indigenous peoples, ethnic minorities, and people with disabilities, and create spaces for their meaningful participation. Providing language interpretation services, accessibility accommodations, and targeted outreach strategies can help overcome barriers to participation and ensure that diverse voices are heard. Additionally, adopting participatory approaches such as community-based mapping, participatory rural appraisals, and citizen science initiatives can empower marginalized groups to actively engage in the policy process and contribute their perspectives towards more inclusive and equitable water resource policies. By prioritizing inclusivity and representation in stakeholder consultations, Gandaki Province can foster greater social cohesion, equity, and sustainability in water governance processes, leading to more effective and responsive policy outcomes.

e. Integrate climate change considerations into water resource policies by incorporating climate resilience and adaptation strategies. Develop mechanisms for assessing climate risks, implementing adaptive measures, and building capacity to manage climate-related impacts on water availability, quality, and ecosystems.

Integrating climate change considerations into water resource policies is of paramount importance for Gandaki Province due to the region's vulnerability to climate-related impacts on water availability, quality, and ecosystems. By incorporating climate resilience and adaptation strategies into water resource policies, the province can effectively mitigate risks and build resilience against the adverse effects of climate change. This ensures the long-term sustainability of water resources and enhances the province's ability to cope with extreme weather events, changing precipitation patterns, and other climate-related challenges.

To achieve this, several key activities can be undertaken. Firstly, developing mechanisms for assessing climate risks specific to Gandaki Province is essential. This involves conducting vulnerability assessments, hydrological modeling, and scenario planning to understand how climate change will impact water resources and associated ecosystems. Secondly, implementing adaptive measures to address identified risks and vulnerabilities is crucial. This may include investing in water-saving technologies, enhancing water storage capacity, restoring degraded ecosystems, and diversifying water sources to reduce dependency on rainfall-dependent systems. Additionally, building capacity among relevant stakeholders, including government agencies, local communities, and water user groups, is essential for effectively managing climate-related impacts on water resources. This involves providing training, technical assistance, and knowledge-sharing platforms to empower stakeholders to implement adaptive strategies and respond effectively to emerging challenges posed by climate change. Overall, integrating climate change considerations into water resource policies in Gandaki Province strengthens the province's resilience to climate variability and ensures the sustainable management of water resources for future generations.

f. ***Establish a robust monitoring and evaluation framework to track the implementation and effectiveness of water resource policies. Define clear indicators, targets, and benchmarks for measuring progress towards policy objectives and outcomes. Conduct regular assessments and reviews to identify successes, challenges, and areas needing adjustment or refinement to ensure policy relevance and effectiveness over time.***

Establishing a robust monitoring and evaluation framework is essential for tracking the implementation and effectiveness of water resource policies in Gandaki Province. Firstly, defining clear indicators, targets, and benchmarks is crucial to measure progress towards policy objectives and outcomes. Indicators may include metrics such as water quality parameters, water availability, ecosystem health, and community access to water services. Setting specific targets and benchmarks provides a clear roadmap for assessing policy performance and identifying areas for improvement.

Secondly, conducting regular assessments and reviews at predetermined intervals allows policymakers to evaluate the effectiveness of implemented policies. These assessments involve collecting relevant data, analyzing trends, and comparing outcomes against established targets and benchmarks. Regular reviews enable policymakers to identify successes, challenges, and areas needing adjustment or refinement. By identifying gaps or inefficiencies in policy implementation, adjustments can be made to ensure policy relevance and effectiveness over time.

Furthermore, engaging stakeholders throughout the monitoring and evaluation process is essential for garnering diverse perspectives and ensuring transparency and accountability. Stakeholder involvement can include consultations, feedback mechanisms, and participatory monitoring approaches, allowing for meaningful engagement and input from affected communities, government agencies, civil society organizations, and the private sector.

Overall, establishing a robust monitoring and evaluation framework ensures that water resource policies in Gandaki Province are effectively implemented, continuously assessed, and adapted to evolving needs and challenges. By defining clear indicators, targets, and benchmarks, conducting regular assessments, and engaging stakeholders, policymakers can enhance policy relevance and effectiveness, ultimately contributing to the sustainable management of water resources in the region.

INSTITUTIONAL AND FINANCIAL MANAGEMENT FOR WATER RESOURCE STRATEGY

8.1 Institutional setup

To effectively implement the water resource strategy in Gandaki Province, a comprehensive and coordinated institutional arrangement is crucial. This arrangement should encompass multiple layers of governance, involving provincial, district, and local stakeholders to ensure holistic and inclusive management. At the core, a Provincial Water Resource Management Authority (PWRMA) should be established as the central coordinating body responsible for policy formulation, strategic planning, and oversight. This authority would work closely with District Water Resource Committees (DWRCs) that handle local implementation and monitoring, ensuring that district-specific water resource projects align with provincial and national objectives. Additionally, Local Water User Associations (LWUAs) should be empowered to participate in decision-making processes, manage local water infrastructure, and promote sustainable practices at the grassroots level.

To support these entities, a Provincial Department of Water Resources (PDWR) would provide technical and administrative assistance, conducting research and feasibility studies to inform policy and project development. A Multi-Stakeholder Advisory Council (MSAC), comprising representatives from government, academia, the private sector, and civil society, would offer diverse insights and recommendations, ensuring that all perspectives are considered in the strategic planning process. Engagement with the private sector through partnerships is essential for financing, constructing, and managing water infrastructure projects. Additionally, establishing a Provincial Water Resource Information System (PWRIS) for data collection and analysis, an Environmental and Social Safeguards Unit (ESSU) for compliance monitoring, Capacity Building and Training Centers (CBTCs) for skill enhancement, and a Provincial Finance and Budgeting Office (PFBO) for financial management will ensure that the strategy is implemented efficiently and sustainably. These integrated efforts will ensure the sustainable and equitable management of water resources in Gandaki Province.

The implementation of a water resource strategy in Gandaki Province requires a coordinated institutional setup involving various government levels, agencies, and stakeholders. Here's an outline tailored for Gandaki Province:

Table 3: Institutional settings for the proposed strategies.

SN	Name of The Institution	Role of Institution	Members of the Institution	Function of the Institution
1	Provincial Water Resources Council (PWRC)	Oversee the implementation of the water resource strategy in Gandaki Province, ensuring	Representation from political, administrative, academia sector.	Policy formulation, strategic planning, inter-sectoral coordination, and

		alignment with provincial goals.		monitoring and evaluation.
2	Provincial Ministry of Water Resources	Making and implementation the water resource policies	Lead by minister and bureaucratic hierarchal structure of different groups.	Policy implementation, regulation, capacity building, technical support, and coordination with other ministries and stakeholders.
3	River Basin Committees (RBCs):	Manage water resources within specific river basins in Gandaki Province, ensuring integrated and sustainable use	Representatives from affected regions, water user groups, environmental organizations, and industry	Basin-level planning, water allocation, conflict resolution, data collection, and monitoring.
4	Local Water User Associations (WUAs):	Represent local water users in the management and distribution of water resources.	Formed by local farmers, communities, and other water users.	Local water management, maintenance of irrigation infrastructure, conflict resolution, and capacity building.
5	Technical Advisory Committees (TACs):	Provide scientific and technical expertise to support the implementation of the water resource strategy.	Experts from universities, research institutions, technical agencies, and the private sector.	Research and development, technology transfer, capacity building, and advisory services
6	Monitoring and Evaluation Unit (MEU):	Track progress, evaluate outcomes, and ensure accountability in the implementation	Bureaucratic hierarchal structure of different groups.	Develop and maintain monitoring systems, conduct regular assessments, provide feedback for

		of the water resource strategy.		policy adjustments, and report on progress to stakeholders.
7	Intergovernmental Coordination Mechanisms	Ensure effective collaboration between provincial and local governments.	Representation from provincial and local government bodies.	Regular meetings, joint planning sessions, information sharing, and conflict resolution mechanisms.
8	Provincial Disaster Management Authority (PDMA):	Implement and coordinate disaster management plans related to water resources, focusing on resilience and mitigation.	Representatives from relevant provincial ministries, local governments, and emergency services.	Risk assessment, emergency preparedness, response planning, and capacity building.
9	Academic and Research Institutions:	Provide research support, data collection, and policy recommendations.	Representation from University, Research Institute and free lancer	Conduct studies, develop innovative solutions, and offer training programs

8.2 Financial requirement to implement the strategy

Implementing the water resource strategy in Gandaki Province necessitates a comprehensive and well-coordinated financial plan. The provincial government will need to allocate a significant portion of its budget towards water resource management, focusing on infrastructure development, maintenance, and capacity building. Major projects such as the construction of dams, reservoirs, irrigation systems, and water treatment facilities will require substantial capital investments. To ensure these projects are adequately funded, a dedicated provincial water resource fund can be established, allowing for the streamlined allocation of resources and prioritization of essential projects.

In addition to government funding, private sector investment will play a crucial role in meeting the financial requirements of the strategy. Public-private partnerships (PPPs) can attract investments in large-scale infrastructure projects and the deployment of water-efficient technologies. Incentives such as tax breaks, subsidies, and guarantees will be necessary to encourage private sector participation. These partnerships will not only bring in much-needed capital but also leverage private sector expertise in project management and technological innovation, thereby enhancing the efficiency and effectiveness of water resource management in the province.

International aid and development grants from organizations such as the World Bank, Asian Development Bank, and United Nations will be pivotal in supporting the implementation of the water resource strategy. These funds can finance critical projects aimed at improving water access, sanitation, and resilience against climate change. Additionally, international assistance can provide technical support and capacity-building programs, helping to develop local expertise and institutional frameworks. To ensure transparency and accountability, robust financial management systems will be essential. Regular audits, financial reporting, and performance monitoring will help track progress, make necessary adjustments, and ensure the efficient use of resources. Through a combination of government funding, private sector investment, and international aid, Gandaki Province can successfully implement its water resource strategy and achieve its long-term goals for sustainable water management.

The estimate is grounded in past experience and the expertise of consultants who bring extensive knowledge of similar projects or scenarios. This approach leverages historical data, lessons learned, and the insights gained from previous engagements to forecast costs, timelines, and potential challenges accurately.

8.2.1 Estimated program cost for Water induced disaster mitigation plan

The cost required for implementing a comprehensive water-induced disaster mitigation plan in Gandaki Province over the next 25 years is estimated to be substantial, considering the diverse and complex nature of the region's hydrological and geological features. Initial estimates suggest that a detailed and robust plan, encompassing river training, flood control infrastructure, early warning systems, and community-based disaster risk management, could require an investment ranging from NRs 20 billion to 30 billion. This figure calculated from the scope of the work under the province jurisdiction and includes the construction of embankments, levees, and floodwalls, installation of advanced meteorological and hydrological monitoring systems, and development of resilient infrastructure in flood-prone areas. Additionally, significant resources will be allocated towards capacity building and training programs to enhance local communities' resilience and response capabilities.

Beyond structural measures, the plan will also emphasize non-structural approaches such as watershed management, reforestation, and sustainable land use practices to mitigate the risk of landslides and erosion, which are prevalent in the hilly terrain of Gandaki Province. The integration of these activities into the broader framework of climate change adaptation will be crucial to ensuring the long-term effectiveness of the disaster mitigation strategy. The cost will also cover the implementation of robust policies and regulatory frameworks to ensure sustainable water resource management, fostering coordination among various stakeholders, including government agencies, local communities, and international organizations. Investing in these preventive measures is anticipated to save significant costs in the long run by reducing the frequency and impact of water-induced disasters, thereby safeguarding lives, livelihoods, and infrastructure in Gandaki Province.

8.2.2 Estimate program cost for equitable access to safe drinking water and sanitation services

The cost estimation for such programs typically involves a comprehensive assessment that considers various factors, including existing infrastructure, population size, geographic conditions, technological requirements, and the scale of the proposed interventions. To estimate the program cost accurately, a detailed feasibility study or project appraisal would be necessary. This process involves conducting field surveys, analyzing data on water availability and quality, assessing community needs and preferences, evaluating potential solutions (such as infrastructure upgrades or new constructions), and determining the operational and maintenance costs over the project's lifespan. Government agencies, international organizations, non-governmental organizations (NGOs), and development partners often collaborate to fund and implement such initiatives. They conduct thorough financial planning to ensure that the allocated resources meet the project's objectives and achieve sustainable outcomes in terms of safe drinking water access and improved sanitation services for all communities in Gandaki province.

The total area of the province is 21,504 km^2 - constituting 14.57% of Nepal's total area. According to the latest census, the population of the province was 2,479,745. The newly elected Provincial Assembly adopted Gandaki Province as the permanent name by replacing its initial name Province No. 4 on 27 April 2023.. Among them 91% people get the drinking water and around 9% are still deprive from the clean drinking water. The province should supply drinking water for around 2.25 lakh people and maintenance the already constructed system. he cost to supply drinking water per person can vary significantly depending on factors such as the region, infrastructure needs, water quality requirements, and the type of water supply system implemented (e.g., piped water network, boreholes, hand pumps, etc.). Generally, estimating the exact cost per person requires a detailed analysis of these factors. From literature review we adopted the cost around NRs 2100 million to provide the drinking water in the province.

For precise figures or estimates, it would be advisable to refer to recent reports, studies, or assessments conducted by relevant authorities or organizations involved in water supply and sanitation development in Gandaki province. These documents typically outline the estimated costs, funding sources, and timelines for achieving equitable access to safe drinking water and sanitation services.

8.2.3 Estimated program cost for irrigation sector

Gandaki Province, known for its diverse topography and abundant water resources, offers substantial irrigation potential that can significantly boost agricultural productivity. The province is endowed with numerous perennial rivers, such as the Kali Gandaki, Seti, and Marsyangdi, which provide a reliable source of water for irrigation. The varied climatic conditions, ranging from subtropical in the lower regions to alpine in the higher altitudes, allow for the cultivation of a wide range of crops, necessitating efficient irrigation systems. Traditional irrigation practices, combined with modern techniques like drip and sprinkler systems, are being promoted to optimize water use and enhance crop yields. Additionally, small-scale water storage projects, such as ponds and tanks, are being developed to capture and store rainwater, providing a crucial water source during dry periods. By harnessing its rich water resources and investing in sustainable irrigation infrastructure, Gandaki Province has the potential to transform its agricultural landscape, ensuring food security and improving the livelihoods of its farming communities. There are 14 districts in the Gandaki province. The following table shows the agriculture area, potential feasible area etc.

District	Agriculture land (ha)	Irrigation by source						Irrigation around the year	Total
		gravity	pumping	Dam /reservoir	Tube well/ boring	Others	Mixed		
	173,773	**35,125**	**5,975**	**7,812**	**2,700**	**9,170**	**1,619**	**31,841**	**62,401**
Gorkha	26,094	3,412	1,183	483	56	1,836	164	3,456	7,133
Manag	489	39	9	43		0	0	72	91
Mustang	1,182	616	140	113		17		839	886
Myagdi	8,953	1,583	114	239		300	17	1,132	2,253
Kaski	19,164	5,795	457	537	17	3,110	400	4,313	10,316
Lamjung	11,083	3,711	443	347	15	894	113	2,880	5,524
Tanahu	26,100	6,003	293	597	36	472	292	3,629	7,693
Nawalparasi East	21,090	4,601	1,844	3,309	2,424	1,088	465	7,396	13,731
Syangja	24,457	4,058	594	1,176	69	747	73	3,898	6,717
Parbat	9,552	2,736	326	853	76	483	76	1,982	4,549
Baglung	25,609	2,570	573	114	8	223	20	2,245	3,509

Out of 173,773 ha of agriculture land, around 70% land is the potential irrigable area which is around 120,000 ha. Irrigation facilities have already reached around 62,000 ha land. The cost require for the development of the irrigation system in the remaining 58,000 ha land is around 29,000 millions (as per irrigation master plan the average irrigation system development cost is around 5 lakhs per ha) as per the present cost.

8.2.4 Estimated cost for Hydropower/ Energy sector

Gandaki Province, located in central Nepal, is blessed with abundant water resources, making it a prime location for hydropower development. The province is traversed by several major rivers, including the Trishuli, Marshyangdi, Seti, and Kali Gandaki, which collectively offer significant hydropower potential due to their high flow rates and steep gradients. Estimates suggest that the province has the capacity to generate several thousand megawatts (MW) of hydropower. Notably, the Kali Gandaki River alone has the potential to produce over 1,000 MW of electricity through various projects along its course. The province's mountainous terrain further enhances its suitability for both run-of-the-river and storage-type hydropower projects, allowing for a diversified approach to harnessing this renewable energy source.

As of now, Gandaki Province has made considerable strides in tapping into its hydropower potential. Several significant projects have been completed or are under construction. The Kali Gandaki 'A' Hydropower Plant, with an installed capacity of 144 MW, is one of the largest operational projects in the province and plays a crucial role in Nepal's national grid. Additionally, the Upper Marsyangdi-A project, with a capacity of 50 MW, and the Upper Marsyangdi-II project, planned to generate 600 MW, highlight the province's ongoing efforts to expand its hydropower infrastructure. List of constructed and ongoing projects are presented in the annex 1 and 2 of the report

Despite these advancements, the province still faces challenges in fully realizing its hydropower potential. Issues such as funding constraints, logistical difficulties due to the rugged terrain, and regulatory hurdles can slow project implementation. Furthermore, environmental and social considerations, including the impact on local communities and ecosystems, must be carefully managed to ensure sustainable development. The provincial government, in collaboration with private sector partners and international agencies, is actively working to address these challenges through comprehensive planning, capacity building, and infrastructure development initiatives. With continued investment and strategic management, Gandaki Province is poised to become a major hub for hydropower generation, contributing significantly to Nepal's energy security and economic development.

Gandaki province is the second-largest producer of hydroelectricity with a total generation of 687 MW. Hydropower Potential of Nepal 2019 report of Water and Energy Commission secretariat shows, out of a country's total generation capacity of 72,544 MW, Gandaki province has a gross hydropower potential of about 14,981 MW, which is 20.7% of the total hydropower potential of the country.

The production cost of 1 megawatt (MW) of hydropower in Nepal typically ranges between $1 million to $3 million. This cost variation depends on the type of project, such as run-of-the-river or storage-type projects, and the specific conditions of the project site. Run-of-the-river projects, which are generally easier and quicker to construct with lower environmental impacts, tend to be on the lower end of this cost range. In contrast, storage-type projects, which require more complex construction and have higher environmental and social impacts, tend to be more expensive. For example, the Upper Tamakoshi Hydroelectric Project, with an installed capacity of 456 MW, had an average cost of about $1.4 million per MW, while other projects may fall within a higher range due to additional infrastructure and logistical challenges.

On average, the production cost for hydropower in Nepal is around $2 million per MW, encompassing both the easier run-of-the-river and more complex storage projects. These costs include pre-construction expenses such as feasibility studies and environmental impact assessments, as well as construction costs, land acquisition, resettlement, financing charges, and long-term operation and maintenance expenses. Understanding these costs is crucial for planning and financing future hydropower projects in Nepal, ensuring they are both economically viable and environmentally sustainable. By considering the above data, we assume that only 142.9 MW (1% of the total potential will do by province as a showcasing an effective example of hydro project) will be developed by the province level and remaining will developed by the central government and private sector and total cost require is 37,164 million.

8.2.5 Estimated cost for sustainable water use in industries, fisheries, tourism, and other economic activities

The cost required for ensuring sustainable water use in industries, fisheries, tourism, and other economic activities in Gandaki Province over the next 25 years is projected to be considerable. Initial estimates suggest that the overall investment could range from 5000 million to 7000 million, considering the diverse needs and the region's economic development goals. This investment will encompass the construction of water supply and distribution systems tailored to industrial and commercial needs, including advanced treatment facilities to ensure water quality standards are met. For the fisheries sector, substantial funding will be allocated to developing aquaculture infrastructure, including hatcheries, ponds, and water recycling systems, to enhance productivity and sustainability. Similarly, for the tourism sector, investment in eco-friendly water facilities and waste management systems will be crucial to promoting sustainable tourism practices.

Moreover, this cost will also cover initiatives aimed at improving water use efficiency and promoting sustainable practices across these sectors. This includes research and development of water-saving technologies, capacity-building programs for stakeholders, and the implementation of policies and regulatory frameworks that encourage efficient water use and pollution control. Investments will also focus on integrating water management practices with the broader objectives of environmental conservation and climate resilience. For instance, ensuring that industrial water use does not compromise the ecological health of water bodies, which is vital for sustaining fisheries and tourism activities. By prioritizing sustainable water management, Gandaki Province aims to balance economic growth with environmental stewardship, ensuring the long-term availability and quality of water resources for all sectors

8.2.6 Estimated cost for formulate inclusive and adaptive water resource policies

Formulating inclusive and adaptive water resource policies for Gandaki Province entails substantial financial commitment to address current and future water challenges comprehensively. Over the next 25 years, an estimated investment of 2,000 million to 3,000 billion will be necessary to develop policies that cater to diverse stakeholder needs while promoting sustainable water management practices. This funding will support extensive stakeholder consultations, technical studies, and policy development processes aimed at integrating environmental, social, and economic considerations into water governance frameworks. It will also include capacity-building initiatives to enhance governance structures and ensure effective implementation and enforcement of water policies.

Furthermore, the financial resources will facilitate the establishment of monitoring and evaluation mechanisms to track policy effectiveness and adapt strategies as per evolving water resource dynamics. Investments will be directed towards promoting water-efficient practices, watershed management initiatives, and community-based water management programs to enhance resilience against climate change impacts. Equitable access to water resources will be prioritized through targeted interventions such as water supply infrastructure development in underserved areas, promotion of gender-sensitive policies, and empowering marginalized communities in decision-making processes related to water resource management. By ensuring inclusive and adaptive policies, Gandaki Province aims to foster sustainable development, safeguard water resources for future generations, and promote social equity through equitable access to water services and opportunities for all stakeholders.

8.3 Conclusion

The total cost of implementing the water resource strategy in Gandaki Province is around 103,264 million rupees for 25 years. And around Nrs 4.1 Arab per year. Activities-wise distribution is shown in the table below.

Table 4: Activity wise budget distribution table

SN	Strategies	Estimated cost (NRS Millions)	Remarks
1	Develop and enforce water-induced disaster mitigation plans integrating early warning systems, resilient infrastructure, and community-based preparedness programs.	25,000.00	
2	Implement comprehensive infrastructure and policy initiatives for equitable access to safe drinking water and sanitation services across all communities.	2,100.00	
3	Provide year-round irrigation to all potentially feasible agricultural areas, enhancing crop yields and ensuring sustainable water resource utilization.	29,000.00	
4	Promote sustainable hydropower projects through comprehensive planning, environmental impact assessments, and community engagement to minimize ecological disruption and maximize local benefits.	37,164.40	
5	Optimize water usage for industries, tourism, fisheries, and navigation by implementing efficient water management practices and promoting sustainable economic activities.	7,000.00	
6	Formulate inclusive and adaptive water resource policies addressing current and future needs, promoting sustainable management, and ensuring equitable access for all stakeholders.	3,000.00	
	Total	103,264.40	4,130.58
			per year

It reflects a comprehensive investment in the region's sustainable development, encompassing infrastructure, human resources, environmental sustainability, and community well-being. This strategy aims to address critical areas such as potable water supply, irrigation, hydropower development, water-induced disaster mitigation, and industrial water use, ensuring that the diverse needs of Gandaki Province are met effectively. The estimated financial requirements are substantial but essential to foster economic growth, improve living standards, and build resilience against climate change and natural disasters.

The financial commitment required for this strategy underscores the importance of multi-stakeholder collaboration, including government bodies, international donors, private sector partners, and local communities. By securing adequate funding and efficiently allocating resources, Gandaki Province can achieve equitable access to water resources, support sustainable agricultural practices, and harness hydropower potential. Ultimately, the successful implementation of this strategy will lead to long-term economic benefits, environmental sustainability, and enhanced quality of life for all residents of Gandaki Province, thereby contributing significantly to the national goal of sustainable development in Nepal.

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ANNEXES

ANNEX I : Hydropowers with Survey License in Gandaki Province

S.No.	Project	Capacity (MW)	River	Promoter	Address	VDC/District
1	Masina HPP	0.8	Kotre Khola	Masina Tourism Cooperative Ltd.	Lekhnath-13, Tallo Gagangauda, Kaski. 61531599	Lekhnath (Kaski) Dulegauda (Tanahu)
2	Tirija Khola HEP	9.71	Tirija	Tirija Hydropower Private Ltd	9.85E+09	Mudi (Myagdi)
3	Mathillo Bhurundi HEP	3.75	Bhurundi	Ambe Hydropower Pvt. Ltd.	Tinkkune, Kathmandu, 01-4117979	Dangsing (Kaski)
4	Rudrawati Badigaad Hydropower	9.6	Badigad	Hanumante Power and Energy	Kathamandu-32, Pepsikola, Ph no. 5906214	
5	Marsyangdi River PRoR Hydropower	99.8	Marsyangdi	M.A. Power Pvt. Ltd.	Kantipath, Kathmandu, 9851026244	Palungtar (Gorkha), Bhanu (Tanahu)

ANNEX II: Hydropowers with Construction License in Gandaki Province

S.No	**Project**	**Capacity (MW)**	**River**	**Promoter**	**Address**	**VDC/ District**
1	Ghar Khola	14	Ghar	Myagdi Hydropower Ltd.	Pardi Pokhara, Phone 061-463429	Shikha (Myagdi)
2	Tanahu HEP	140	Seti Khola	Tanahu Hydropower Limited	4th Floor, Trade Tower, Thapathali, Kathmandu.	Damauli, Kahu Sivapur (Tanahu)
3	Upper Modi A	42	Modi Khola	Nepal Electricity Authority	Durbarmarga, Kathmandu	Lumle, Ghandruk (Kaski)
4	Daram Khola HEP	7.3	Daram	Daram Khola Hydro Energy Limited	Baglung, Nepal	Malm, Righa, Kandebas (Baglung) Arlangkot (Gulmi)
5	Rahughat Mangale	37	Rahughat	Tundi Power Company P.Ltd.	Sanepa Lalitpur, P.O.Box. 6341	Pakhapani, Chimkhola, Kuinemangale (Myagdi)
6	Middle Tara Khola SHP	1.7	Tara Khola	Pahadi Hydropower Company Pvt. Ltd.	Baglung-2, Phone No. : 068-520221, 9747628615	Tara (Baglung)
7	Nilgiri Khola	38	Nilgiri	Nilgiri Khola Hydropower Company Pvt. Ltd.	Panipokhari, Kathmandu, Phone: 4437705, 4441648	Narchyang (Myagdi)

8	Super Nyadi Hydropower Project	40.27	Nyadi	Siuri Nyadi Power Ltd	GPO Box no 14165, Anamnagar Kathmandu, Tel 4223608, 4238159, Email: supernyadi@siurihydro.com	Bahundada, Bhulbhule (Lamjung)
9	Marsyangdi Besi	50	Marsyangdi	Divyajyoti Hydropower Pvt. Ltd.	Bagdol Lalitpur, P.O.Box 23311, Phone no 5552175	Besisahar, Chandisthan, Bhulbhule, Gaunsahar, Bajhakhet, Hiletaxar (Lamjung)
10	Istul Khola HPP	1.506	Istul	Amar Jyoti Hydropower Pvt Ltd	Man Bhavan , Lalitpur -20, PO-134, Tel: 01-5552175	Aarupokhari (Gorkha)
11	Rele Khola	6	Rele Khola	Hym Consult Ltd.	SiphalKathmandu, Ph 4489327, 4491271 (Previous) House No. 280, Madan Bhandari Path, Babarmahal, Kathmandu, Ward No.11, 9	Narchyang (Myagdi)
12	Upper Modi HPP cascade project	18.2	Modi Khola	Nepal Electricity Authority	Kathmandu	Dangsing, Ghandruk, Lumle (Kaski)

13	Middle Daram Khola-A HPP	3	Daram	Dhaulagiri Cem Engineering Pvt Ltd	Baglung	Heel, Argal, Amarbhumi (Baglung)
14	Middle Daram Khola-B HPP	4.5	Daram	Milestone Hydropower Pvt. Ltd.	Baglung-11, Mobile 9745025919	Amarbhumi , Harichaur, Heel (Baglung)
15	Upper Khudi	26	Khudi	Super Khudi Hydropower Ltd.	P.O.Box 19554, Kathmandu, Phone 01-4434003, 4424644	Ghanpokhar a, Khudi (Lamjung)
16	Nilgiri Khola-II cascade Project	71	Nilgiri	Nilgirikhola Hydropower Company Limited	Heritage Plaza -1 Kamaladi, Kathmandu -28, GPO Box: 7970, Tel: 01-416908905	Narchyang (Myagdi)
17	Lower Manang Marsyang di	140	Marsy angdi	Butawal Power Company	Budhanagar, Kathmandu Tel: 4781776, 4785295	Tachi Bagarchhap, Dharapani, Thoche (Manang)
18	Manang Marsyang di	135	Marsy angdi	Manang Marsyangdi Hydropower Company Pvt.Ltd.	P.O.Box 12566 Kathmandu-4, Phone 9803298663, 9841286805;	Chame, Tachi Bagarchhap (Manang)

19	Garchyang Khola	6.6	Garchyang	Citizen Hydropower Company Pvt. Ltd.	Ring Road Naya Bato, Lalitpur; POB No 20732, Kathmandu Mobile No. 9851029387, Fax 0150014274649	Namarjung (Kaski)
20	Upper Marsyangdi 1	138	Marsyangdi	Upper Marsyangdi Hydropower Company Pvt. Ltd.	Kathmandu 4, Baluwatar, Phone 9841286805, 9844040118; email: mmhpp777@gmail.com	Taghring, Khudi, Ghermu, Bahundada (Lamjung)
21	Kaligandki Gorge	164	Kali Gandaki	Kaligandaki Hydropower P. Ltd	Charkhal, Dillibazar, Karhmandu	Dana, Narchyang, Dana (Myagdi)
22	Nyadi-Phidi HPP	21.4	Nyadi, Phidi	North Summit Hydro Ltd	Babarmahal-11, Kathmandu, POB: 2060 Phone: 01-5319143, 984151223, email: n.s.hydro2016@gmail.com	Bahundada, Bhulbhule (Lamjung)
23	Adhikhola -3	3	Adhikhola	Pacific Development Bank Limited	GPO Box: 1657, Kathmandu Tel: 4445571, 4431940 Fax: 4441127 Email: pacific@wlink.com.np	Chitre (Syangja)

24	Upper Tamor	106	Tamor	Upper Tamor Hydropower Company Pvt. Ltd.	Kathmandu - 4, Baluwatar, Tel: 9803298663, 9841286805 Email: mmhpp777@gmail.com	Chame (Manang)
25	Upper Daram Khola HEP	7.5	Daram	Upper Daram Khola Hydro Power Pvt. Ltd.	Sankhamul, Kathmandu	Malika, Righa, Harichaur (Baglung)
26	Upper Ghiling Khola HEP	7	Ghiling	Green Village Hydropower Pvt. Ltd.	Sundhara, Kathmandu	Galyang, Thuladihi (Syangja)
27	Sisne Khola (Taharpu) HEP	7	Sisne Khola	Green Village Hydropower Pvt. Ltd.	Sundhara, Kathmandu	Okharbot (Myagdi)
28	Chhote Khola HEP	5	Chhote Khola	Hydro Village Pvt. Ltd.	Sundhara, Kathmandu	Chhote (Baglung)
29	Sanjen Upper	14.8	Trishuli	Green Village Hydropower Pvt. Ltd.	Sundhara, Kathmandu	Chhote (Baglung)
30	Madkyu HEP	13	Madkyu Khola	Hydro Village Pvt. Ltd.	Sundhara, Kathmandu	Chitre (Myagdi)
31	Upper Seti HEP	20.6	Seti	Hydro Village Pvt. Ltd.	Sundhara, Kathmandu	Setidovan (Lamjung)
32	Upper Ghangri Khola HEP	20.1	Ghangri	Hydro Village Pvt. Ltd.	Sundhara, Kathmandu	Ghangri (Baglung)

33	Midim Khola Micro Hydro	0.1	Midim Khola	Deurali Bahu-uddesyiaya Sahakari Sanstha Ltd	Ishaneshwor-9, Karaputar, Lamjung	Isaneshwor (Lamjung)
34	Lower Midim Khola SHP	0.996	Midim Khola	Tallo Midim Jalbidhyut Company Pvt. Ltd.	Tirlingtar-7, Kathmandu	Karapu (Lamjung)
35	Idi Khola SHP	0.975	Idi Khola	Idi Hydropower Co.P. Ltd.	Thumakodada, Saimrang (Kaski)	Thumakoda da, Saimrang (Kaski)
36	Lower Chhote Khola Small HPP	0.997	Chhote	Pashupati Environmental Power Company Pvt. Ltd.	Kaaldhara, Manbu (Gorkha)	Manbu (Gorkha)
37	Saiti Khola Small	0.999	Saiti	Saiti Power Company Pvt. Ltd	Pokhara-12, Kaski	Lwangghale (Kaski)
38	Tara Khola Community (Mini) Hydropower Project	0.38	Tara Khola	Tara Khola Community Small Hydropower Consumer Committee	Tara-7, Baglung, 9847628615 (Bal B. KC)	Tara (Baglung)

ANNEX III: Hydropowers applied for Survey License in Gandaki Province

S No	Project	Capacity (MW)	River	Promoter	Address	VDC/District
1	Kisedi Khola Hydropower Project	0.998	Kisedi	CEDB Hydropower Development Company Limited (Dordi Rural Municipality)	Bluestar Complex, Tripureshwor Kathmandu	Pachok (Lamjung)
2	Sanlo Khola Hydropower Project	5	Sanlo Khola	Durga Laxmi Energy Private Limited	Tokha, Kathmandu	Sirdibas (Gorkha)
3	Budhi Gandaki Hydropower Project	1200	Budhi Gandaki	Budhigandaki Jalbidhyut Company Limited	Kathmandu, Nepal	Khari, Nalang, Sunaula Bazar, Kumpur, Sangkosh, Murali Bhanjyang, Salyantar, Salyankot, Aginchok (Dhading) Tandrang, Namjung, Darbhung, Borlang, Tanglichok, Aarupokhari (Gorkha)
4	Upper Yaru Hydropower Project	4.9	Yaru	Pelton Hydro Energy Private Limited	Lazimpat - 2, Kathmandu, Nepal, 01-6911637	Kerauja (Gorkha)
5	Landan Khola PRoR	5	Landan Khola	Best Hydropower Company	KMC -32, koteshwor	Chhaikampar, Kerauja (Gorkha)

	Hydropower Project			Private Limited		
6	Bhalu Khola Hydropower Project	4.96	Bhalun Paban Khola	Sisters Group For Energy Private Limited	Tokha - 7, Kathmandu, Nepal	Uiya, Sirdibas (Gorkha)
7	Dudh Marsyangdi Hydropower Project	5	Dudh Khola	Ecogen Consult Private Limited	Sanepa, Lalitpur	Thoche, Dharapani (Manang)
8	Lower Trishuli Hydropower Project	117.72	Trishuli	Gidro Energiya Company Limited	Kathmandu, Nepal (01-5705608)	Chandi Bhanjyang (Chitawan) Ambukhaireni, Chhimkeswori (Tanahu)
9	Manggala Myagdi Cascade Hydroelectric Project	4.81	Myagdi Khola	Harkaman Magar	Mangala RM - 4, Myagdi	Arman, Babiyachaur, Darwang (Myagdi)
10	Super Dordi Khola "E" Hydropower Project	9.259	Dordi	Khanadaha Hydropower Private Limited	Budhanilkanta Nagarpalika, Ward No - 3	Ghyalchok, Warpak (Gorkha)
11	Nar Phu Khola Hydropower Project	5	Nar Khola, Phu Khola	Venture Power Private Limited	Budhanilkantha - 10, Kathmandu	Fu, Nar (Manang)
12	Upper Kaligandaki Hydropower Project	65	Kali Gandaki	Tara Energy Private Limited	KMS, ard No. 13	Ranche, Histan Mandali, Rakhu Bhagawati (Myagdi) Baskharka (Parbat)

ANNEX IV: Hydropowers applied for Construction License in Gandaki Province

S No	Project	Capacity (MW)	River	Promoter	Address	VDC/District
1	Upper Marsyangdi -2	600	Marsyangdi	Himtal Hydropower Company Pvt. Ltd	Thapathali, Kathmandu, Nepal. Ph: 4247237	Ghermu, Taghring (Lamjung) (Manang)
2	Uttarganga Storage Hydropower Project	828	Uttar Ganga	Nepal Electricity Authority	Durbar Marg , Kathmandu, GPO Box: 10020	Bowang, Boharagaun, Nisi, Adhikarichaur (Baglung)
3	Adhikhola Storage HEP	180	Adhikhola	Nepal Electricity Authority	Nepal Electricity Authority, Central Office Durbarmarg, Kathmandu 4153054, 4153055, 4153007	Hungi (Palpa) Waling, Malunga, Tindobote, Shreekrishna Gandaki, Nibuwakharka, Jagatradevi, Thumpokhara, TulsiBhanjyang, Pelakot (Syangja)
4	Upper Seti-1 HEP	13	Seti Khola	Shrestha Energy Solution Pvt. Ltd	Budanilkantha-4, Kathmandu, 9851026329	Purachaur (Kaski)
5	Chyandi Khola HEP	4.2	Chyandi Khola	Chyadi Khola Hydropower Company Pvt. Ltd.	Bichour VDC-1, 9841285734	Kharibot (Gorkha) Dudhpokhari (Lamjung)

6	Lower Thulo Khola HEP	4.75	Thulo Khola	Chitwan Energy Limited	Kupondole Lalitpur, Contact No. 9851166725 (Subhash Chandra Baral)	Chimkhola, Kuinemangale (Myagdi)
7	Chhomron Khola Small HEP	4.894	Chhomron Khola	Ghandruk Hydro Private Limited	Banasthali, Kathmandu-16, Kathmandu	Ghandruk (Kaski)
8	Kalika Kaligandaki HEP	38.16	Kali Gandaki	Maulakalika Hydropower Company Pvt. Ltd	Purano Baneshwor, Kathmandu, 3851025301, 9813768555 (Santosh Paudel)	Gaidakot, Mukundapur, Ratnapur (Nawalparasi) Kota (Tanahu)
9	Upper Mudi HEP	12.73	Mudi & Ghurma	Fresh Water Energy Pvt. Ltd.	Ka. Ma. Na. Pa-30	Mudi (Myagdi)
10	Nar Khola HEP	58.9	Nar Khola, Soti Khola	Nar Khola Hydro Energy Pvt. Ltd	Narayanchaur Naxal-01, Kathmnadu, Contact No. 9851023781	Tachi Bagarchhap, Chame (Manang)
11	Budhi Gandaki Prok Khola HEP	81	Budhi Gandaki	Chilime Hydropower Company Limited	Dhumbarahi, Kathmandu, 01-4370720	Bihi, Lho, Prok (Gorkha)
12	Syalque Khola Small HEP	4.8	Syalque khola, Danque Khola	Alliance Energy Solutions Pvt Ltd	Putalisadak, Kathmandu	Chame (Manang)

13	Lodo Khola Sana HEP	1.6	Lodo	Liberty Energy Co. Ltd.	Kalikasthan-29, Kathmandu. Contact No.: 014443545, 4441988	Dhodeni, Faleni (Lamjung)
14	Lower Seti (Tanahu) HEP	126	Seti	Tanahu Hydropower Limited	Trade Tower 4th Floor, Thapathali, KTM, Ph- 01-5111117/8/9	Chhipchhipe, Dharampani, Kota (Tanahu)
15	Budhi Gandaki Nadi HEP	91.15	Budhi Gandaki	Surya Energy Pvt.Ltd,	Mharajgunj, Kathmandu	Sirdibas, Chunchet (Gorkha)
16	Nimrung Khola HEP	9.8	Nimrung	Kiran Power Company Pvt. Ltd.	Kaldhara-16, Kathmandu	Uiya (Gorkha)
17	Begnas-Rupa Storage HEP	150	Begnas - Rupa	Nepal Electricity Authority	Durbar Marg , Kathmandu	Lekhnath, Rupakot (Kaski)
18	Myagdi Khola A HEP	30	Myagdi	Dordi Khola Jalvidyut Company Limited	Blue Star Complex, Tripureshwar, Kathmandu, Ph. No. 01-4232748	Mudi (Myagdi)
19	Maygdi Khola- B HEP	12.5	Myagdi	Sushmit Energy Pvt. Ltd.	Sushmit Bhawan 166/40467 Subidhanagr-35, Kathmandu, Contact No.: 5199027	Mudi (Myagdi)

20	Nisi Khola HEP	8.8	Nisi	Nishi Khola Power Pvt. Ltd.		Burtiwang, Boharagaun, Devisthan, Bowang, Adhikarichaur (Baglung)
21	Dhaula Khola HEP	10.8	Dhaula, khewas	Dhaulashree Power Pvt. Ltd	Ka. Ma. Na. Pa- 03, Kathmandu	Gurja (Myagdi)
22	Lower Rupse Khola HEP	1.86	Rupse	Gulmi Hydro Pvt. Ltd	Anamnagar, Kathmandu	Dana (Myagdi)
23	Chunchet Syar Khola HEP	45	Syar Khola	Chilime Hydropower Company Limited	Dumbarahi Kathmandu, 014370773, 01-4370793	Sirdibas, Chunchet, Bihi (Gorkha)
24	Supreme Middle Seti HEP	18	Seti Khola	KC's Hotel and Multiple Industries P Ltd	Pokhara Metro. 14, Kaski, PH 01-5012027, 5520254; sharmanirajan929@gmail.com	Bharatpokhari, Lekhnath (Kaski)
25	Daraudi Nadi HEP	9.84	Daraundi	Manakamana Daraudi Hydropower Company Limited	Bagbazaar, Kathmandu	Palungtar (Gorkha)
26	Chepe Khola Cascade Hydropower Project	2	Chepe Khola	Aashutosh Energy Limited	KMC - 30, Gyaneshower, Kathmandu, 01-5245059	Hanspur (Gorkha) Dudhpokhari (Lamjung)

ANNEX V: Currently Operating Hydropower Plants in Gandaki Province

S No	Project	Capacity (MW)	River	Promoter	Address	VDC/District
1	Tatopani	2	Tatopani	Nepal Electricity Authority		(Myagdi)
2	Gandak	15	Narayani	Nepal Electricity Authority		(Nawalparasi)
3	Seti	1.5	Seti Khola	Nepal Electricity Authority		(Kaski)
4	Marsyangdi	69	Marsyangdi	Nepal Electricity Authority		(Tanahu)
5	Andhi Khola	9.4	Andhi Khola	Butwal Power Company		(Syangja)
6	Kali Gandaki A	144	Kali Gandaki	Nepal Electricity Authority		Shreekrishna Gandaki (Syangja)
7	Madhya Marsyangdi	70	Marsyangdi	Nepal Electricity Authority		(Lamjung)
8	Khudi Khola	4	Khudi	Khudi hydropower limited		Ghanpokhara, Khudi, Simpani (Lamjung)
9	Mardi Khola	4.8	Mardi	Gandaki Hydropower Development Co. P. Ltd		(Kaski)
10	Siuri Khola	5	Siuri	Nyadi Group Pvt Ltd	PO Box 14165, Kathmandu, Ph: 6219566	(Lamjung)
11	Bijayapur-1	4.5	Bijayapur	Bhagawati Hydropower Development Company		(Kaski)

12	Upper Madi	25	Madi Khola	Madi Power Pvt Ltd.,	GPO Box 2581, Gorakha Complex Minbhawan, Phone 01-4106507, 4106729, 4106731, Fax 01-4106640	Namarjung, Thumakodada, Sildujure (Kaski)
13	Radhi Small	4.4	Radhi	Radhi Bidyut Co. Ltd	P.O.Box: 20290, Phone-014232750, 4232749 , Fax: 014232748, Blue Star Complex, Room No. 523, Tripureshwor, Kathmandu	(Lamjung)
14	Dordi Khola	27	Dordi	Himalaya Power Partner Pvt. Ltd	POB 8975 EPC 4205 Marajaganj, Kathmandu, nepal Phoneand Fax: 4375874	Archalbot, Chiti, Dhodeni, Nauthar, Shree Banjyang, Udipur (Lamjung)
15	Mristi Khola	42	Mristi	Mountain Energy Nepal Limited	IME Complex 3rd Floor, Panipokhari, Kathmandu	, Dana, Narchyang (Myagdi)
16	Upper Marsya ngdi A	50	Marsyan gdi	Sinohydro-Sagarmatha Power Company Pvt Ltd	Sanepa , Lalitpur	Bhulbhule, Bahundada, Khudi (Lamjung)

17	Thapa Khola	11.2	Thapa Khola	Mount Kailash Energy Co. Ltd	Tupche -3, Nuwakot , Tel: 9841832093	(Mustang)
18	Daraun di A	6	Daraundi	Daraundi Kalika Hydro	Samakhusi, Kathmandu, Nepal. Ph: 4360076	(Gorkha)
19	Midim Khola	3	Midim Khola	Union Hydropower P.Ltd	P.O.B. No: 12637, Ph: 01-5543850	Karapu (Lamjung)
20	Namarj un Madi	12	Madi Khola	Himalayan Hydropower Pvt.Ltd	P.O. Box No.: 20225, Lazimpat, Kathmandu, Phone: 01-4441216, Fax: 01-4441217	Namarjung, Sildujure (Kaski)
21	Nyadi Khola	30	Nyadi	Nyadi Hydropower Limited	P.O.Box. 11728, Kathmandu, Phone 01-4781776, 4784026, Fax 01-4780994	Bahundada, Bhulbhule (Lamjung)
22	Daram Khola-A	2.5	Daram	Sayapatri Hydropower Pvt. Ltd.	Gongabu-29 Kathmandu, Phone 01-4364009	(Baglung)
23	Middle Modi	18	Modi Khola	Middle Modi Hydropower Limited	P.O.Box: 12268, Nepal. Ph:4038030, Fax:4038026	, Deupurkot, Tilahar (Parbat)

24	Sardi Khola	4	Sardi	Mandakini Hydropower Pvt. Ltd.	Baneswor Kathmandu, P.O.Box 7327, Phone 01-4461574	(Kaski)
25	Chhandi Khola	2	Chhandi	Chhyandi Hydropower Co. P. Ltd	Ph: 014424925, 9851095497, 014426483	(Lamjung)
26	Ghalemdi Khola	5	Ghalemdi	Ghalemdi Hydro Limited	P.O.Box 9560, Banasthatli, Kathmandu; Tel. 014362520; 69521079; ghalemdi@gmail.com	Narchyang (Myagdi)
27	Madkyu Khola	13	Madkyu	Silkes Hydropower Pvt.Ltd	P.O.Box. 170, Lekhnath Nagar Palika - 3, Kaski, Phone 061-560236, Fax 061-532466	(Kaski)
28	Theule Khola HPP	1.5	Theule	Barahi Hydropower Pvt Ltd	Lakeside Pokhra-6, Tel: 061-520872, 01-520872	Kusmi, Binamare, Sarkuwa (Baglung)
29	Bijaypur Khola-2 HPP	4.5	Bijaypur	Civil hydropower company	Lekhanath Nagarpalika, Phone no 0610465562, email : civilhydropower@gmail.com	Lekhnath (Kaski)

30	Upper Mardi Hydropower Project	7	Mardi	United Idimardi and R.B. Hydropower Pvt Ltd	Sanepa , Lalitpur Tel: 01-5520254, 52012027	Lwangghale (Kaski)
31	Super Madi	44	Madi Khola	Himal Hydro and General Construction Ltd.	Kupondole, Lalitpur-10, 01-4527090, 4523971	, Namarjung, Parche, Saimrang, Kalika (Kaski)
32	Upper Syange Khola SHP	2.4	Syange	Upper Syange Hydropower Pvt. Ltd.	Samakhusi, Kathmandu, P. O. Box: 8975, Phone: 4357646, Fax: 4354186	Taghring (Lamjung)
33	Richet Khola SHP	5	Richet	Richet Jalbidhyut Company Pvt. Ltd.	Lalitpur-15, Mahalaxmisthan, phone no 5527469, 55237849, 9851006013, email: richethydro@gmail.com	Manbu, Kashigaun (Gorkha)
34	Upper Chhyandi Small HPP	4	Chhyangdi	Chhyandi Hysropower LTD	Gairidhara-2, Kathmandu, 4426483, PO 19380	Bansar, Faleni (Lamjung)
35	Upper Midim Khola SHP	7.5	Midim Khola	Bhujung Hydro Power Ltd.,	Kathmandu-34, Baneshowr, Kathmandu, 4480564, 9851026587	Bhujung (Lamjung)

36	Upper Machha Khola HEP	4.55	Machha Khola	Bikash Hydropower Company Pvt. Ltd.	Maharajgunj-3, Kathmandu, 01-4445083, 4445084, 9851073099, Contact no; Krishna prasad ghimire	Gumda, Laprak (Gorkha)
37	Phewa	1	Seti Khola	Nepal Electricity Authority		(Kaski)
38	Seti-II	0.78	Seti Khola	Task Hydropower Co. Pvt. Ltd		(Kaski)
39	Chhote khola	0.993	Chhote	Pashupati Environmental Engineering Company Pvt. Ltd.	Kaldhara, Kathmandu, P.O. Box: 8975 EPC 5308 Phone : 4361915	(Gorkha)

ANNEX VI: Operating Solar Plants in Gandaki Province

S No	Project	Capacity (MW)	Promoter	Address	VDC/District
4	Bel Chautara Solar Farm Project	5	Solar Farm Pvt. Ltd.	Basundhara-3, Ktm. P.O.Box NO. 21498, Aash Bahadur Gurung Mob. NO. 9851046006	Khairenitar (Tanahu)
6	Som Radha Krishna Solar Farm Project (VGF)	4.4	Nepal Solar Farm Ltd.	Bafal, Kathmandu	Rupakot (Kaski)