Thesis for the Degree of Master of Science in Environmental Science and Management

FLOOD PREDICTION USING CLIMATE MODEL IN RAJAPUR MUNICIPALITY, BARDIYA

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P.U Registration No: 2020-1-25-0039

Exam Roll No:21250011

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Faculty of Science and Technology

Pokhara University, Nepal

Sep, 2023

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Supervised by Bipin Dulal

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Environmental Science and Management

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Dedication

This thesis is dedicated to everyone who has helped and motivated me along the way. I am very appreciative of my supportive parents, Mr. Rajesh Rai and Mrs. Pratima Rai, for their constant love, support, and sacrifices. Your belief in me has served as a constant inspiration. Thank you to my instructors and mentors for their advice, insight, and priceless expertise. I want to express my gratitude to my friends for their friendship, tolerance, and unwavering support. I would like to express my gratitude to all of the contributors and participants for giving their time and knowledge to this study. May it enhance public knowledge and have a good effect. Lastly, I present this work with heartfelt gratitude and appreciation to everyone who believe in the power of knowledge and the pursuit of truth.

Nisha Rai

Declaration

I, Nisha Rai, hereby declare to the School of Environmental Science and Management (SchEMS) affiliated to Pokhara University (PU) that the thesis entitled **"FLOOD PREDICTION USING CLIMATE MODEL IN RAJAPUR MUNICIPALITY, BARDIYA",** submitted as a partial fulfillment for the degree of Master of Science in Environmental Science and Management. The work presented in this project is done originally by myself and has not been submitted elsewhere for the award of any degree or professional qualification All sources of information or work done by others are cited within the report and listed in the reference section.

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P.U. Registration Number: 2020-1-25-0039

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Recommendation

This is to recommend that the thesis entitled **"FLOOD PREDICTION USING CLIMATE MODEL IN RAJAPUR MUNICIPALITY"** has been carried out by Ms. Nisha Rai for the partial fulfillment of the degree of Master of Science in Environmental Science and Management. This original work was conducted under my supervision. To the best of my knowledge, this thesis work has not been submitted for any other degree.

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Supervisor

Bipin Dulal

Date: Sep, 2023

Certification

This is to certify that the thesis entitled **“FLOOD PREDICTION USING CLIMATE MODEL IN RAJAPUR MUNICIPALITY”** submitted by Nisha Rai is examined and accepted as partial fulfillment for the degree of Master of Science in Environmental Science and Management. The thesis in part or full is the property of the School of Environmental Science and Management and should not be used to award any other academic degree in any other institution.

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Letter of Approval

This dissertation paper submitted by Ms. Nisha Rai entitled "**FLOOD PREDICTION USING CLIMATE MODEL IN RAJAPUR MUNICIPALITY"** has been accepted for the partial fulfillment of a Master of Science in Environmental Management from Pokhara University.

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Abstract

Flooding refers to the condition where a certain area is partially or entirely submerged in water, which can occur naturally or as a result of human activities. Throughout history, rivers have been a critical source of energy, irrigation, hydroelectricity, and drinking water, but people living near rivers are often exposed to the danger of floods. Therefore, evaluating flood risk is essential for assessing the benefits of flood prevention methods and identifying any remaining hazards. Flood forecasting is a vital component of flood management and disaster risk reduction as it provides advance notice of flood events, protects people's lives and properties, and reduces the impacts of floods while improving the overall effectiveness of emergency response efforts. This study aims to predict future floods hazard zone in Rajapur municipality by using precipitation predicted by climate models This method can help manage weather fluctuations in the coming days and long-term climate shifts. The research focuses on predicting flooding in Rajapur through a flood inundation map, which can assist in understanding, assessing, and forecasting flood events and their effects on the Rajapur Municipality.

HEC-HMS software is employed to construct the current hydrological model for the Karnali River basin. Utilizing a Python script with the CORDEX model, future precipitation data for the period 2022-2054 is projected, facilitating the estimation of future discharge within the HEC-HMS model. The HEC-RAS model is then utilized to create flood inundation maps for seven distinct flood return periods. These maps reveal that wards 1, 3, 4, 7, 9, and 10, situated along the Karnali and Geruma Rivers, experience significant inundation during various return periods. The flood inundation maps provide valuable information for disaster preparedness, land-use planning, and decision-making to mitigate flood-related risks.

Keywords*: CORDEX, Flood, Future Prediction, HEC-HMS, HEC-RAS, Inundation map, Climate model*

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Acronym

CORDEX	Coordinate Regional Climate Downscaling Experiment
DHM	Department of Hydrology and Meteorology
DEM	Digital Elevation Model
GCM	Global Climate Change
HEC-HMS	Hydrological Engineering Center- Hydrological Modeling System
HEC-RAS	Hydrological Engineering Center- River Analysis System
GLoFAS	Global Flood Awareness System
ICRAF	International Center for Agroforestry Research
IPCC	Intergovernmental Panel on Climate Change
ICMOD	International Centre for Integrated Mountain Development
LULC	Land Use Land Cover
RCD	Regional Climate Downscaling
SSP	Shared Socioeconomic Pathways
WCRP	World Climate Research Program
WMO	World Meteorological Organization

CHAPTER 1

INTRODUCTION

1.1 Background

Climate Change refers to the long-term shifts in average global temperatures, precipitation, and other weather patterns, largely caused by both natural and human activities such as burning fossil fuels, and deforestation. Climate change is a complex phenomenon. The scientific community is studying it closely because of the threat it poses to the long-term progress of mankind [1].

Climate change affects the water resources capacity of a river basin by changing the pattern of precipitation**,** temperature and snow melt, transpiration, and river discharge of factors interact to cause extreme precipitation changes, so changes are uneven and regionally variable. It eventually has an impact on the availability of both quantity and quality water resources, as well as related water use industries like agriculture, hydropower, environmental usage, etc. Therefore, understanding changes in hydrological properties due to climate change is important for sustainable use and the management of water resources in the country.

A Flood is a condition when an area is fully or partially submerged in water for a period of time due to man-made or natural causes, leading to hazardous diseases and loss of lives and property. Sometimes, floods are triggered by other natural disasters, such as earthquakes and tsunamis. Flooding can be defined as the spontaneous occurrence of water rising and overflowing the boundaries of a stream, river, lake, or drainage system [2]. In addition to having insufficient warning systems and knowledge of flood threats, people who reside in floodplains or non-resistant buildings are more at risk from flooding. The most vulnerable regions are those that experience frequent floods and those that have not flooded for many years. In the first case, the environment does not have time to recover between floods and in the second case, the environment may not be able to adapt to flood conditions. Due to floods, many people have to flee their homes, affecting their lives and their livelihood, massive economic losses, and the loss of thousands of animals. Flood is not always possible to prevent but it is possible to minimize flood damage by giving awareness and early warning systems to the vulnerable people.

The extreme rainfall event intensified the stress in aquatic and terrestrial ecosystems, human societies, and economies. Changes in flood characteristics depend not only on spatial distribution, temporal development and rainfall rarity, but also on prevailing soils [3] snowmelt timing [4] and snowpack size [5] in humid conditions and snowy areas. Global-scale flood assessments report both future flood declines and increase under global warming [6], [7]. Accurate rainfall estimation can play a significant role in flood forecasting. A rainfall runoff modeling (hydrological) anticipates evaluating the runoff from precipitation in a catchment and hydraulic modeling aims to evaluate the magnitude of floods and the area inundated by them. A combination of both will result in runoff simulation and flood inundation levels. In addition, many flood forecasting mechanisms are traditionally and manually operated, making timely flood forecasting difficult [8].

Karnali river basin drains most of the mid and far-western development region of Nepal. Karnali basin consists of 1,459 glaciers and 742 glacial lakes in Nepal (CBS, 2019). The Karnali River is the longest (507 km) flowing through Nepal along with another snow-fed river that forms the Karnali River system. More than 90% of the basin area is in Nepal [10]. The basin receives approximately 80% of precipitation during the summer monsoon. This region suffers most from winter drought. The average annual rainfall in the basin is about 1479mm.[11] the mean annual flow of the Karnali basin is about 1392m^3/s at Chisapani. According to the yearly discharge trend, the discharge of the Karnali River is declining by -2.665(m^3 /s) annually[12]. The basin supports a large population of rural communities, who depend on the river for their livelihood and basic need such as water for irrigation, drinking, and hydropower generation. The Karnali River basin is the most vulnerable to climate change in Nepal. The Upper Karnali Watershed, Mugu Karnali Watershed, and Budi Ganga Watershed are the most vulnerable and are at higher risk from Hazards like landslides, flood droughts, food insecurity, and frequent intense rainstorms [13].

The climate model is a mathematical representation of the Earth’s climate system. Climate models are used to simulate and predict the behavior of the climate system under different conditions such as changes in greenhouse gas concentrations, land use patterns, and ocean circulation. They can also be used to investigate past climate changes and understand the mechanisms that drive climate variability. Climate models are an essential tool for policymakers, as they provide a scientific basis for decision-making on issues such as greenhouse gas mitigation and adaptation to climate change. These models are based on fundamental laws of physics and chemistry, and they incorporate a wide range of factors that influence climate, such as atmospheric circulation, ocean currents, and the exchange of energy and moisture between the earth's surface and the atmosphere. Various studies have examined how climate change will affect global water scarcity in the future, using population projections and simulated changes in climate from global climate change models (GCMs) with water resources models [14]. The effects of climate change on water resources system have been largely attempted in the last few decades [15]–[17]. Climate models help to predict an increase in monsoon precipitation in Nepal and expected extremes resulting in risk of flood, landslide during monsoon while water shortage in dry season. [18]. HI-Aware (Himalayan Adaptation, Water & Resilience) climate model main aims are to contribute to enhance adaptative capacities and climate resilience of the poor and vulnerable women, men & children living in the mountains and flood plains of Indus, Ganges and Brahmaputra river basins. CORDEX (Co-ordinate Regional Climate Downscaling Experiment) is a project of the World Climate Research Programme. The 4th conference was held on 14-18 October 2019 in Beijing, China where all the international community came to discuss regional climate research and to share the latest progress on regional climate modeling for impact and adaptation planning. The Working Group on Coupled Modeling developed the Coupled Model Inter comparison project (CMIP) inside the World Climate Research Program framework to better understand using a multi-model context which is now at the 6th phase. CMIP6 data is based on a new set of scenarios based on various Socioeconomic assumptions (Shrestha et al., 2017). The Shared Socioeconomic Pathways (SSPs) generate several socio-economic scenarios and radioactive forcing pathways through the end of 21st century. This Scenarios focuses on change in drought risk, intensity and changes in precipitation and hydrological runoff [20]. Scientists, decision-makers, and stakeholders use the results of CMIP6 simulations, which include elements like temperature, precipitation, sea ice extent, and atmospheric composition, to research the effects of climate change, develop adaptation plans, and assist in global climate negotiations.

1.2 Statement of the Problem

Flooding is one of the world's most devastating hydro-meteorological phenomena in terms of human well-being, socio-economic activity and environmental impact. Rivers have historically been important sources of irrigation, hydroelectricity, energy and drinking water. The river flow is not always constant with respect to water speed, runoff and rainfall

[21]. On the other hand, people living near rivers are often threatened by flooding. Flooding is due to excessive precipitation that can occur in the form of continuous rain that exceeds the carrying capacity of the rain bed, causing water flows over riverbanks into adjacent areas [22]. Pre-monsoon and monsoon rainfall patterns are growing, according to a study from Chisapani Station, whereas winter and post-monsoon rainfall trends are falling (Chapagain, P 2022).

The recent flood in Pakistan on June 14, 2022 had killed around 1,717 people.[24] This flood was caused by heavier than usual monsoon rains and melting glaciers that caused by severe heat waves, linked to climate change. [25]

The Karnali River Basin lies in the western region of Nepal. The basin has a serious problem in having a good network of stations and has less specific ground observations of Climate variables such as precipitation and temperature [26]. Some of the available stations have missing data [27].

Bardiya district is ranked in 4th position in terms of loss and damage in Nepal (NPC, 2017). Research has shown that the Terai area was heavily affected due to the monsoon floods in 2017. Due to continuous rain, on 12 October 2022 about 800 houses have been submerged in water in the Rajapur Municipality of Bardiya [29]. Due to incessant rains in the terai districts, normal life is affected due to flood. The Rajapur municipality is also one of the most flood-prone areas as well as highly vulnerable because of seasonal floods in rivers like Karnali and Geruwa. High discharge from the effects of heavy rainfall over the Karnali River basin is what causes flooding.

The Rajapur area, in particular, faces notable difficulties concerning floods and inundation as a consequence of an increase in extreme weather events, along with rising temperatures and precipitation. Flood occurrences have become more frequent and severe in this region, leading to the loss of lives and substantial property damage.[12] In Nepal's Rajapur region, the weather and precipitation patterns are shifting, which threatens the farmers' means of livelihood [23]. Flood forecasting helps for effective flood management and disaster risk reduction by providing advance warning of flooding events, protecting lives and properties, reduces the impacts of floods and improving the overall effectiveness of emergency response efforts. Accurate flood forecasting allows for the implementation of appropriate mitigation measures like building flood barriers or flood gates, shifting people to shelter homes by knowing where and when a flood is likely to occur and which are high-risk areas. This all helps the authorities and communities to prepare and mitigate the impact of flooding. Future floods may occur more frequently and have more severe effects. Farmers in flood-prone areas should receive proper training and awareness campaigns to prepare for and be aware of the likelihood of such climatic events, be given training on flood-resistant crops and crops with short maturation periods, and emphasize spring rice due to its higher productivity.[12]

1.3 Research Questions

- ▶ What is the present hydrological condition in Karnali basin?
- ▶ What will be the future climate change scenario in Rajapur municipality?
- ▶ What will be the future Karnali river discharge at Chisapani Bridge?
- ▶ What will be the flooding scenario in Rajapur municipality in future?

1.4 Objective

Broad Objective:

The broader objective of the study is to make flood prediction using climate model in Rajapur municipality, Bardiya.

Specific Objectives:

The specific objectives of this study are:

- To develop a hydrological model of Karnali basin in HEC-HMS.
- To obtain time series data for future precipitation from CORDEX (50 km resolution, RCP 8.5 climate models.
- To estimate the future discharge at Chisapani bridge using precipitation from CORDEX (50 km resolution, RCP 8.5) climate models.
- To develop the flood inundation map for Rajapur municipality based on Karnali river basin obtained from CORDEX climate model precipitation for future scenarios.

1.5 Rationale of study

Rajapur area is mostly flooded during monsoon followed by post-monsoon [12]. More flood events were recorded during the monsoon season because precipitation trends were found to increase during the monsoon season. However, post-monsoon rainfall is trending downward, but flooding events are increasing. This may be due to increased temperatures in the post-monsoon season, which contributed to the melting of glaciers, increased river runoff, and caused flooding [11]. The worst-affected flood was in 2014, with the largest maximum discharge of 17900 m^3/s spill resulting in 12 deaths and property losses worth $24.6 million (NPR 3 billion) [30]. It is important to improve the flood preparedness and response measures to mitigate the impact of future flood events.

As water resources play a vital role, it is important to understand the likely impacts of climate change for future water availability as well as for water resources management and planning. Climate models are used to make projections of future climate change under different scenarios of greenhouse gas emissions, land use and other factors. By employing climate models, it becomes feasible to examine past climate data, recognize patterns, and improve the precision of future weather forecasts. The models provide assessment of past climate variability and projections for future climate change. Its helps to manage weather fluctuation over coming days and plan for long term climate change.

This study focuses on prediction of flood through flood inundation map which helps to understand, assess, and predict flood events and their impacts on the Rajapur Municipality. Flood maps can help design floods risk management strategies and their implementation. Preparedness and timely response can be undertaken if there will be the forecast information of flood. Flood risk mapping also plays an important role in recovery and damage assessment. Flood prediction can help people and authorities to prepare emergency planning and proactive adaptation planning from flooding events before they occur. The adaptation measures like early warning system and embankment have helped Rajapur’s people to prevent human casualties [12].

Overall, the aim of this study is to understand the impacts of climate change on the hydrology of the Karnali basin, and develop strategies to manage and adapt to the changing water resources the information generated could help decision-makers to develop effective strategies for water resource management, flood risk management, and disaster preparedness. The implementation of a flood prediction system in Rajapur municipality, Bardiya, utilizing climate models will play a significant role in reducing the impact of floods, strengthening disaster preparedness, and safeguarding the lives and livelihoods of the local population.

1.6 Limitation

The limitation of the study is;

- The LULC data of 2019, provided by ICIMOD RDS is used to model future discharge and flood inundation. This may not consider changes in land use and land cover which can slightly affect flood patterns and intensities.
- The flood inundation map generated may not include the flood hazard maps for other municipalities, particularly municipalities in Bardiya, which could limit its overall effectiveness.
- The inherent uncertainties in climate models, stemming from the complex nature of climate processes, introduce uncertainties into flood predictions and hinder the ability to make precise projections.
- Future local factors, including topography, land-use patterns, and human interventions, can significantly influence flooding patterns, but these factors are missing in the models.
- The dynamic nature of urbanization, changes in drainage systems, and deforestation can alter flood dynamics, making it challenging to accurately predict future flood events and their impacts.

CHAPTER 2

LITERATURE REVIEW

2.1 Climate Change

Climate Change refers to long-term changes in the average weather patterns that have come to define Earth's local and regional climates. The World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) established the IPCC, an intergovernmental group, in 1988. Scientists from all around the world evaluate climate change articles to provide a referenceable report that policymakers may use to develop a strategy to combat climate change. The IPCC creates comprehensive assessment reports on the current state of knowledge in the scientific, technical, and socioeconomic fields of climate change, its effects and potential threats in the future, as well as strategies for slowing its progression. According to International Panel on Climate Change (IPCC) climate change is "A change in the state of climate that can be identified (using statistical tests) by changes in the mean and/or variability of a characteristic and that persists over long periods of time (usually decades or longer)"[31]. The impacts of climate change include rising global temperatures, changes in precipitation, rising sea levels and more frequent and severe weather events. These changes have significant impacts on ecosystems, human societies and the economy. Some of the impacts of climate change include loss of biodiversity, melting of polar ice caps and glaciers, sea level rise, ocean acidification, more frequent and severe heat waves, hurricanes and droughts, increased spread of diseases and decreased crop yields and food security.

Climate change is an inevitable phenomenon of natural and anthropogenic origins against which reduction and adaptation are needed to reduce the severity of its impacts and vulnerability [32].

2.1.1 Impact of Climate Change in Hydrological Characteristics

Climate change affects hydrological characteristics, such as changes in the frequency and severity of floods and droughts, changes in the timing and amount of river flow, and changes in water availability for ecosystems, agriculture and human use. Due to change in precipitation patterns, including more/ less rainfall, changes in temperature or longer dry will leads to changes in the timing and volume of river flows which leads to increased risk of flooding, drought, water availability for drinking purpose, irrigation & other uses. These impacts can have significant impacts on ecosystems, agriculture biodiversity and population that depend on water resources. Adaptation strategies such as improved water management and conservation are important for mitigating the impacts of climate change on hydrological properties.

Climate change is affecting the hydrology and hydrological cycle which makes challenges for future water availability. Water resources are the sectors most dependent on climate as it directly determines the temporal and spatial availability of resources (Bantin et al., 2017). Climate change will have a significant influence on the sustainability of water supply, both quantitatively and qualitatively, human health, and the food supply in future decades [34]. The direct physical effects of climate change on water resources have indirect implications on social, economic, and environmental systems, thereby changing the management and allocation of land and water resources.

Variation and rate of change in precipitation and precipitation patterns are higher in the Himalayan region than the world average. Because precipitation and temperature are the most important control factors for water. It is important to understand resource impacts in both upstream and downstream regions due to climate change in water resource [35].

The Himalayas are the water towers of Asia [36] and the source of several major rivers in Asia. The snow and glacier controlled stream contributes as reservoir that stores the water and releases it as discharge runoff, significantly affecting the hydrological properties of the stream [37]. The impacts of climate change are higher in Himalayan region since due to change in temperature pattern there will be higher runoff due to glacier and melting of snow. Rising global temperature hugely influence glacial basin due to acceleration in melting [38], [39] making the Himalayan region a major threat for future water availability [36], [38], [40]. Due to highly diverse topographic and climatic variation, one of the most vulnerable region for climate change is Hindu Kush Himalayan region [41]. Changes in river discharge affects water resources that support the livelihoods of people living downstream.

2.2 Climate Models

The assessment of the causes of historical climate variability and the estimates of future climate change are provided by climate models. Based on various projections of how greenhouse gas emissions would rise, it can replicate both the climates we have currently experienced and those we may experience in the future. The models aid in our ability to manage daily weather fluctuations, comprehend historical climate variability, and prepare for long-term climate change. Scientists employ climate models, in order to respond to a variety of concerns, including why the Earth's climate is changing and how it might change in the future if greenhouse gas emissions continue. Models can be used to determine the historical causes of observed warming as well as the relative contributions of natural and human sources. The models generate a nearly complete picture of the Earth’s climate, including thousands of different variables across hourly, daily and monthly timeframes. The main inputs of the model are the external factors that change the amount of the sun’s energy that is absorbed by the Earth or how much is trapped by the atmosphere. A difficult task is choosing a suitable Global Climate Model (GCM) or Regional Climate Model (RCM) for a region from a variety of GCMs/RCMs. An ensemble of numerous climate models is frequently used to lessen uncertainty in the selection of climate models [42]. The uncertainty in flood hazard projections makes it difficult to make informed decisions about flood risk management. So, decision makers take a precautionary approach and focus on adaptation measures that can reduce flood risk regardless of the future climate [43].

2.2.1 CORDEX (Coordinate Regional Climate Downscaling Experiment)

CORDEX is a valuable tool for understanding and responding to climate change. CORDEX is a coordinated framework for evaluating and improving regional climate downscaling (RCD) techniques and producing a new generation of RCD-based detailed climate projections for specific regions around the world. CORDEX was launched in 2009 by the World Climate Research Program (WCRP) in response to the need for a coordinated approach to RCD. The project is coordinated by the World Meteorological Organization (WMO) and the International Center for Agroforestry Research (ICRAF).

CORDEX is implemented through a network of Regional Climate Centers (RCCs) around the world. Each RCC is responsible for developing and running his RCD simulation of a specific region. RCCs share data and results with each other, allowing for a more comprehensive and informed evaluation of RCD technology. CORDEX has produced a wealth of data and information on regional climate change. This data will be used by scientists, policy makers, and other stakeholders to better understand the impacts of climate change and develop adaptation strategies. The goals of CORDEX are;

- To better understand relevant regional/ local climate phenomena their variability and changes through downscaling.
- To evaluate and improve regional climate downscaling models & techniques.
- To produce co-ordinate sets of regional downscaled projections worldwide
- To faster communication and knowledge exchange with users of regional climate information.

The research findings provide valuable insights into the performance of CORDEX-Africa RCMs in simulating West African rainfall. This also helps to improve the accuracy of future projections of rainfall in West Africa and to help policymakers and communities develop adaptation strategies to the impacts of climate change (Ilori, 2021).

The Hindu Kush Himalayan (HKH) region is a major source of water for billions of people in South Asia. It is also very sensitive to climate change. A study in 2021 used CORDEX regional climate models to predict how climate change will affect the HKH region. The finding can be used for adaptation planning by mitigating the negative impacts of climate change and build resilience to the regional changing climate (Sanjay, 2017)

2.2 Global context of flood

Floods are a big issue around the world, and they have very adverse impacts. Flood impact on both individuals and communities, and have social, economic, and environmental consequences. The consequences of floods, both negative and positive, vary greatly depending on the location and extent of flooding and the vulnerability and value of the natural and constructed environments they affect. They vary greatly depending on their locations, duration, depth and speed, as well as the vulnerability and value of the affected and constructed environments. Floods are considered as one of the most severe and most frequent water-induced natural disasters, causing major damage to habitat, infrastructures and properties world-wide regardless of geographic or hydrological locations and having direct economic impacts [44].

Statistics show a recent increase in the frequency and impact of extreme flood events worldwide [45]. Recent, including flooding in the UK (2019, 2003, 2000), US (2011, 1993), Europe (2010, 1995), China (2017, 1998), Pakistan (2010), Thailand (2011), Australia (2011) of the many extreme floods) highlighted the need for a better understanding of the global hydro-meteorological phenomena responsible for these extreme floods (CWC, 2018).

2.2.1 Flood in Asian Countries

Flood is considered as one of the most severe and frequent water-induced natural disasters, causing major damage to habitat, infrastructures, and properties having direct economic impacts [44]. Floods have become more frequent and severe and this trend is expected to continue due to climate change. The risk of death from flooding, particularly in low- and middle-income countries, is increased because of flood-prone areas and weak or limited capacity to heat, evacuate or protect communities in developing states. An analysis of flood trends in Asia shows that most Asian countries have significantly increased flood disasters ,especially in the last few years Asia witnessed a rapid increase of flood disasters[46].

Central Asia (CA) is one of the most vulnerable regions in the world to current and future climate change impacts. This is the result of a combination of factors such as: i) The region's inherent aridity ii) Existing environmental management; iii) Environmental degradation - legacy of central planning in the region. iv) Under investment in housing and infrastructure, due to limited maintenance. v) existing development challenges; vi) biophysical stress; vii) high frequency of disaster events.

The enormous populations in South-Asia depend on the monsoon season for agriculture and industrial development, hydroelectricity generation, as well as human needs and require coping mechanisms to deal with changes in the monsoon's frequency, severity, and length. The floods in Pakistan in July and August 2010 have drawn attention to the South Asian monsoon [47].Understanding how the monsoon will develop in the future is a critical question for climate science. Increased greenhouse gas emissions, changes in land use, and the effects of aerosols are all likely contributing factors to the decrease in rainfall in South

Asian monsoon, which will result in increased flooding, droughts, and human migration as well as conflict.[42]

Developing countries such as Nepal, Bangladesh and Myanmar are still struggling to minimize the impact due to effects of flood, while other developed countries manage the flood risk with proper flood forecasting models and methods to protect the larger floodplains (Devkota et al., 2012). Flooding is a serious and serious development challenge, and this challenge is especially acute for residents of rapidly growing cities in developing countries [49]. Over three decades (1976-2005), 943 natural disasters were reported in South-Asia, one third of that was mainly due to flooding, primarily in the Indus, Ganges and Brahmaputra basins [50].

2.2.2 Flood in Nepal

In Nepal, the level of poverty is due to lack of proper land and employment, so people often settle in areas that are particularly vulnerable to natural disasters [51]. Over the last 50-year period (1970-2019) total of 4,631 flood events were reported 4058 dead, 45,166,887 households affected, 178,833 evacuated Nepal ranks 30th in terms of Risk and Vulnerability to Floods[52]

Flooding is common throughout Nepal during monsoons when the land becomes saturated and surface runoff gradually increases. In Nepal, floods are triggered by different mechanism which can be classified into five major types: i) continuous rainfall and cloudburst, ii) glacial lake outburst floods (GLOFs), iii) landslide dam outburst floods (LDOFs) iv) floods triggered by the failure of infrastructure and v) sheet flooding or inundation in lowland areas due to an obstruction imposed against the flow. Nepal is extremely vulnerable to water related hazards; its hydrology is highly variable, with the monsoon bringing 80% of Nepal's rainfall in less than three months during summer season (MoHA, 2013). Annual rainfall has been increasing in eastern, central, western & decreasing in far-western regions (Pradhan & Pokharel et al., 2017).
According to the Ministry of Home Affairs data, between June to 27 October 2021, 262 people (152 men, 101 women and 9 unknown) lost their lives and 195 people were injured due to the water induced disaster. Nepal's Department of Hydrology and Meteorology said that the Babai River at Chepang in Bardiya stood at 6.56 meters as of 17 September,

exceeding the danger mark of 6.10 meters. An analysis of flood events over decades shows that the number of flood events increased by 0.87 per year [55]. In Nepal the situation is completely different with very little action against flooding, building flood models and mapping small and medium rivers in particular. Even the flood models developed for large river basins do not work well for flooding warning and decision support systems. Up to now, the coverage of the hydrometeorological station network is quite sparse throughout Nepal and the country lacks the time series of runoff and precipitation data. Flooding with inundation is a common problem in the lower parts of the river basin [56].
The major water resources in Nepal, snow and glaciers play a vital role, whereas rainfall water is directly discharged to the rivers in a very short time span that leads to flash floods. Floods and landslides during the monsoon season affected 72 districts across the country, especially the Terai and hilly areas, with rainfall in June, July, August and September. In addition, unexpected heavy rains occurred in late October, causing huge losses of agricultural products, human lives and goods, and seriously affecting people's lives [57]. Monsoon rains continue to affect most parts of Nepal, causing flooding, causing landslides and increasing casualties and damage. According to the Ministry of Interior and an initial rapid assessment, 783 displaced families had taken refuge in various public buildings, significantly increasing their risk of COVID-19 transmission, leaving 58 dead, 34 missing and 3,150 are affect (UN RC/HC Nepal, 2021). Light to moderate rains is expected for most of Nepal on August 30-31, with localized heavy rains expected in western and central provinces, especially Bagmati, Gandaki, Lumbini and Sudurpashchim provinces. Floods and landslides occurred in the Darchula district (Sudurpashchim province in western Nepal), leading to fatalities.

The Melamchi River flooded in June 2021, damaging the Melamchi Bazar in Nepal's Sindhupalchowk District and killing a number of residents as well as some foreigners. Numerous homes, two concrete motorable bridges, and perhaps half a dozen suspension bridges collapsed in addition to seven casualties[59]. On Sunday 14 August 2023 in Mustang, the Kagbeni River flooded, destroying 29 homes and uprooting more than 150 people. The catastrophe happened when the river burst, drowning the lower reaches after being blocked upstream by a landslide[60]. According to Nepal's National Disaster Risk Reduction and Management Agency (DRR) and media reports, three people have died and two are missing; several houses and buildings, two hydroelectric power plants and five bridges were damaged or destroyed [61].

Nepal has the National Disaster Risk Reduction and Management Act (NDRRMA), which has been updated in 2017, as a new act with the function of six-layers of government system from the federal to the local level (i.e., top-down approach). NDRRMA, 2017 is recently formulated in Nepal which replaced the Natural Calamity Act (NCA) 1982

2.2.3 Flood in Bardiya District

Considered the most fertile land in Nepal is Bardiya district and mostly inhabited primarily by the Tharu community, who make their living mainly from agriculture and animal husbandry. About 80% of the population are farmers out of the total area of 202,500 hectares, the suitable area for agriculture is 75,000 hectares, equivalent to about 37.03% of 100 hectares. Agriculture was practiced on a land area of 60,100 ha (80.13% of the available agricultural area). The Prime Minister Agricultural Modernization Project (PMAMP) has declared Rajapur Municipality and Geruwa Municipality in Bardiya District as a rice super zone due to its high agricultural productivity [62]. Agriculture is the main source of income for people in this region. However, frequent flooding can adversely affect agricultural production and threaten food security.

Nepal faces several hazards. Each year, the southern plains of the country accumulate vast amounts of debris during the monsoon season and suffer heavily from flooding caused by rivers flowing down the hills from the Himalayan region. Historically, Bardiya has regularly flooded due to the extensive network of Karnali tributaries in the region. People are having a terrible time because of frequent floods in Rajapur district of Bardiya. Each year they deal with loss of life and property, especially farmland. [63]. The trend of flood events in Rajapur, Bardiya shows from 1992 to 2021, 16 major flood events were observed in 2021 and the trend is rising. The deadliest flood occurred in 2014 with a discharge rate of 17900m^3/s. Post-monsoon season floods occurred in 2009 and 2021, causing loos and damage in a variety of sectors, especially paddy production.[64].

The heavy rainfall and floods in the Banke and Bardiya districts were a major disaster. They call for increased investment in disaster preparedness and mitigation in Nepal. The heavy rainfall and floods were caused by a combination of factors, including the El Niño-Southern Oscillation (ENSO), the Indian Ocean Dipole (IOD), and the Madden-Julian Oscillation (MJO). The floods destroyed crops, homes, and, infrastructure, thousands of people were displaced and the total economic losses from the floods were over $1 billion so there should be increased investment in disaster preparedness and mitigation in Nepal.[65]. The most recent cyclone to hit Nepal was Sitrang, a tropical storm with 74 kilometers per hour maximum sustained winds that left major destruction in the country's eastern and central regions [66]. Cyclones are large, rotating storms that form over warm tropical or subtropical waters. They can be very destructive and have a significant impact on human life and property. Cyclones are not common in Nepal, but they can occur. Cyclones were the main cause of flooding in the Banke-Bardiya region of Nepal, which flooded many settlement areas, silted riverbanks, farms, forests, roads and houses. The location of the cyclone indicates that heavy rains fell overnight in the midwest of the country, causing severe flooding in the study area. The Bay of Bengal monsoon system and other associated regional moisture transport systems may have caused heavy rainfall in Terai and surrounding areas.[65].

Due to the large variation in river speed from Chisapani to Rajapur municipality, more flooding occurs downstream of the river than upstream, resulting in severe flooding in the area [64]. The climate and precipitation pattern is changing in Rajapur municipality which suppresses the farmers livelihoods [23]. In mountainous countries like Nepal, the GLoFAS forecasting tool can estimate river flows before extreme flood damage occurs in monsoon regions, forecast weather conditions, and provide appropriate hydrological forecasts to save community livelihoods from disasters program (Chhetri et al., 2020).

2.3 Flood prediction

It is projected that Nepal will warm more rapidly than the typical country. The highest emission scenario, RCP8.5, predicts that Nepal will rise by 1.2°C to 4.2°C by the 2080s compared to the baseline period of 1986–2005. The wide range of potential temperature increases emphasizes the noticeably slower rates of warming anticipated on lower emission paths for the twenty-first century [17], [67][17], study from Shrestha et.al 2012 focused primarily on the Himalayan region (much larger than the Nepal national territory), shows greater average temperatures showing the rate of warming. by 1.5°C in between 1982 and 2006 [68]

Flood Prediction is the process of estimating the likelihood, magnitude and timing of future flood events in a given area. It is an important part of flood risk management as it helps communities and authorities to prepare and respond to potential flood disasters. The annual average discharge in rivers is increasing due to climate change, so an increasing pattern of river discharge poses a risk of natural hazards such as floods, landslides, and soil erosion in the future [69].

There are a variety of data sources used for flood prediction such as remote sensing, rainfall data, stream flow data and historical flood data. There are different flood modeling techniques, such as hydraulic, hydrological, and statistical methods which cover various software packages and tools used for flood modeling, including HEC-RAS, HEC-HMS, MIKE 11, Flood Modeller by Jacobs and others. It also covers different data assimilation techniques used to integrate various data sources into the flood prediction models. Different machine learning and artificial intelligence techniques used for flood prediction, such as neural networks, support vector machines, and decision trees. Flood forecasting is an important aspect of flood research because it provides a comprehensive understanding of the various modeling techniques, data sources, and tools used in flood forecasting. It helps researchers and practitioners identify the strengths and weaknesses of different approaches and develop more accurate and reliable flood forecasting models.

2.4 Hydrological Modelling

In Hydrological Modelling, hydrologists use mathematical models to simulate the behavior of rivers and streams, which help predict water levels and flood extent. Hydrological modeling is the process of using mathematical and statistical techniques to simulate the movement and behavior of water in a river basin or watershed. It is used to estimate water resources availability, assess water quality and predict the impacts of land use changes and other environmental factors on water resources. Hydrological models are used to estimate the movement of water through different components of the hydrological cycle, including precipitation, evapotranspiration, infiltration, runoff, ground water recharge, and stream flow.

Hydrological models can be used for a variety of purposes, such as predicting flood events, assessing the impacts of land use changes and climate change on water resources, designing water management systems, and evaluating the performance of different water management strategies. To develop a hydrological model, data on various hydrological processes and the physical characteristics of the study area are collected and inputted into the model. Model calibration and validation are then performed by comparing model outputs to observed data.

This process is iterative, and model parameters may be adjusted to improve the model's accuracy.

2.4.1 HEC-HMS

Hydrological Engineering Center- Hydrological Modeling System (HEC-HMS) is developed by the US Army Corps of Engineers. It has been extensively utilized in numerous hydrological research projects. The HEC model is designed to simulate the surface runoff response of a catchment to precipitation by representing the catchment with interconnected hydrologic and hydraulic components. It is primarily applicable to flood simulations. Hydrologic model is a semi-distributed conceptual hydrological model that is capable of simulating hydrological processes of a watershed to derive river discharge and water balance. HEC- HMS project must have the following components before it can run: a basin model, a meteorological model, and control specifications. Daily precipitation, long-term average monthly potential evapotranspiration, basin runoff flow (for calibration and validation) and basin geographic information are all included in the simulated runoff as production. A basin model is used to provide a physical representation of a watershed. Configuration of HEC-HMS model consisting of basin model, weather model, control parameters and input data (time series data). HEC-HMS is widely used by government agencies, consulting firms and academic institutions for planning, design and analysis of water resources projects.

HEC-HMS model is an open-source software and widely used to simulate and forecast rainfall & runoff processes of watershed systems in humid, tropical, subtropical and arid watersheds [70]. It can be used for a single watershed or a system of multiple complex watersheds. The first step in this model is to define the basin and sun-basin, a stream network and other hydrological elements. The model is used to determine increase or decrease in peak discharge and to assess how each sub-basin contributes to peak discharge and runoff volume under different return periods by using two indexes to rank sub-basins with regards to their contribution to the outlet [71]. The model helps to understand the hydrological characteristics of River and future benefit associated with increase in average annual discharge in the river like, hydropower production, irrigation scheme etc., and adaption measure that can reduce risks associated with increase in hydrological flow in the river [69]. Additionally, the report recommends the use of the HEC-HMS hydrological model for studies on flood risk reduction and management of infrastructure facilities. [72]

2.4.2 HEC-RAS

Hydrological Engineering Center (HEC) in Davis, California developed the River Analysis System (RAS) to aid hydraulic engineers in channel flow analysis and floodplain determination. It is a computer program that models the hydraulics of water flow through natural rivers and other channels. Some of the additional uses are: bridge and culvert design and analysis, levee studies and channel modification studies. This software is widely used by government agencies, consulting firms and academic institutions for the analysis of water resources projects and for floodplain mapping. The use of Hydrologic Engineering Center's River Analysis System (HEC-RAS) has frequently been used in monsoon flood forecasting in Nepal, with the help of SRTM/ASTER DEM data, because it is simple, fast, reliable and cost effective and also suitable for steep mountains rivers for flash flood. The HEC-RAS model is able to accurately simulate the historical floods and also able to identify the areas that are most vulnerable to flooding [21]. An effective tool for simulating complex river systems is HEC-RAS, which also forecasts the effects of various management and development initiatives on the water flow in rivers and streams. Due to its ability and capacity to simulate unsteady flow, which helps identify flood-prone areas where the surface ground level is lower than the computed water profile and to visualize the flood extent along a river channel. The results of HEC-RAS could serve as a foundation for decision-making in disciplines like managing rivers and floodplains, designing bridges and culverts, producing hydropower, and other pertinent ones. This model is a helpful tool for safety and management planning during major flooding events.[73]

CHAPTER 3

METHODS AND MATERIALS

3.1 Study Area

The Karnali River, Nepal's longest river, originates south of Lake Mansarovar and Lokas in China (Tibet). The three major basins in Nepal are the Gandaki, Koshi and Karnali River Basin. The KRB (Karnali River Basin) extends from Mount Dhaulagiri in the east to Mount Nanda Devi in the west and has a total area of 45,269 km^2. There are six major watersheds (West Seti, Kawadi, Humla Karnali, Mugu Karnali, Thira, and Bheri), all others originate from Nepal, except Humla Karnali, which originates from China. Interestingly, most of Nepal's rivers, which generally flow north-south, Mugu Karnali flows from east to west, and the Humla Karnali from west to east. The Karnali River flows through western Nepal and joins Mahakali River, which is called Ghaghara in the lower reaches of India.

Bardiya district is a part of Lumbini Province in Nepal. It covers 2025 sq. km and lies west of Banke district, south of Surkhet district of Karnali Province, east of Kailali district of Sudurpashchim Province. Rajapur municipality is one of the eight municipality located in Bardiya district of Lumbini state of South-Western Nepal. It is formed by merging 7 VDCs and consists of 10 wards.

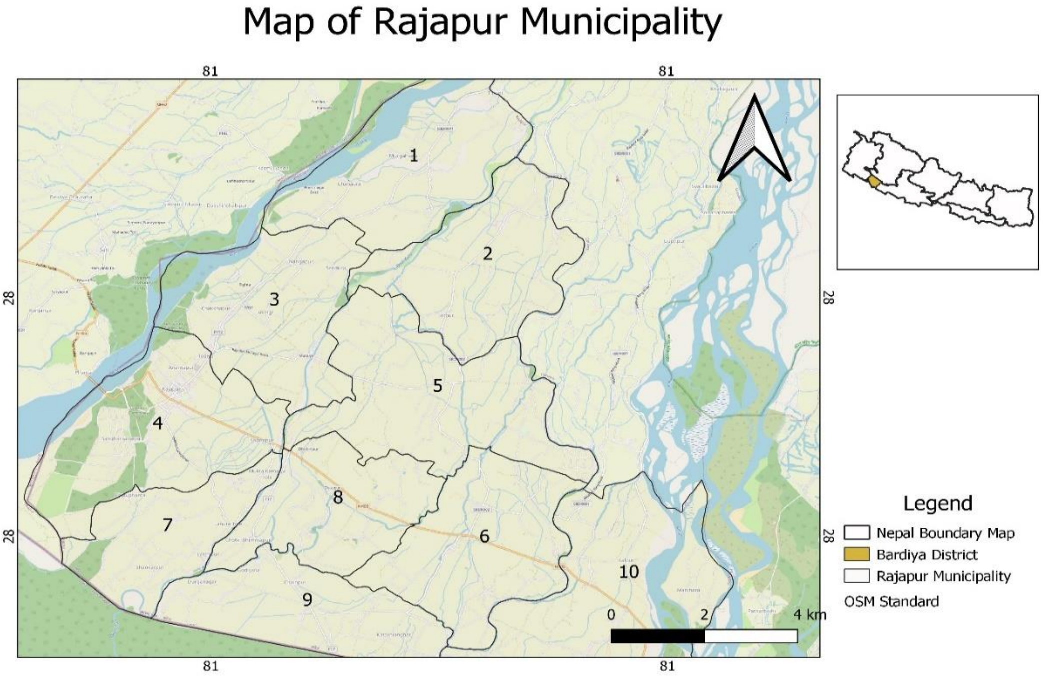


Figure 3.1: Map of Rajapur Municipality

3.2 Research Methodology Design

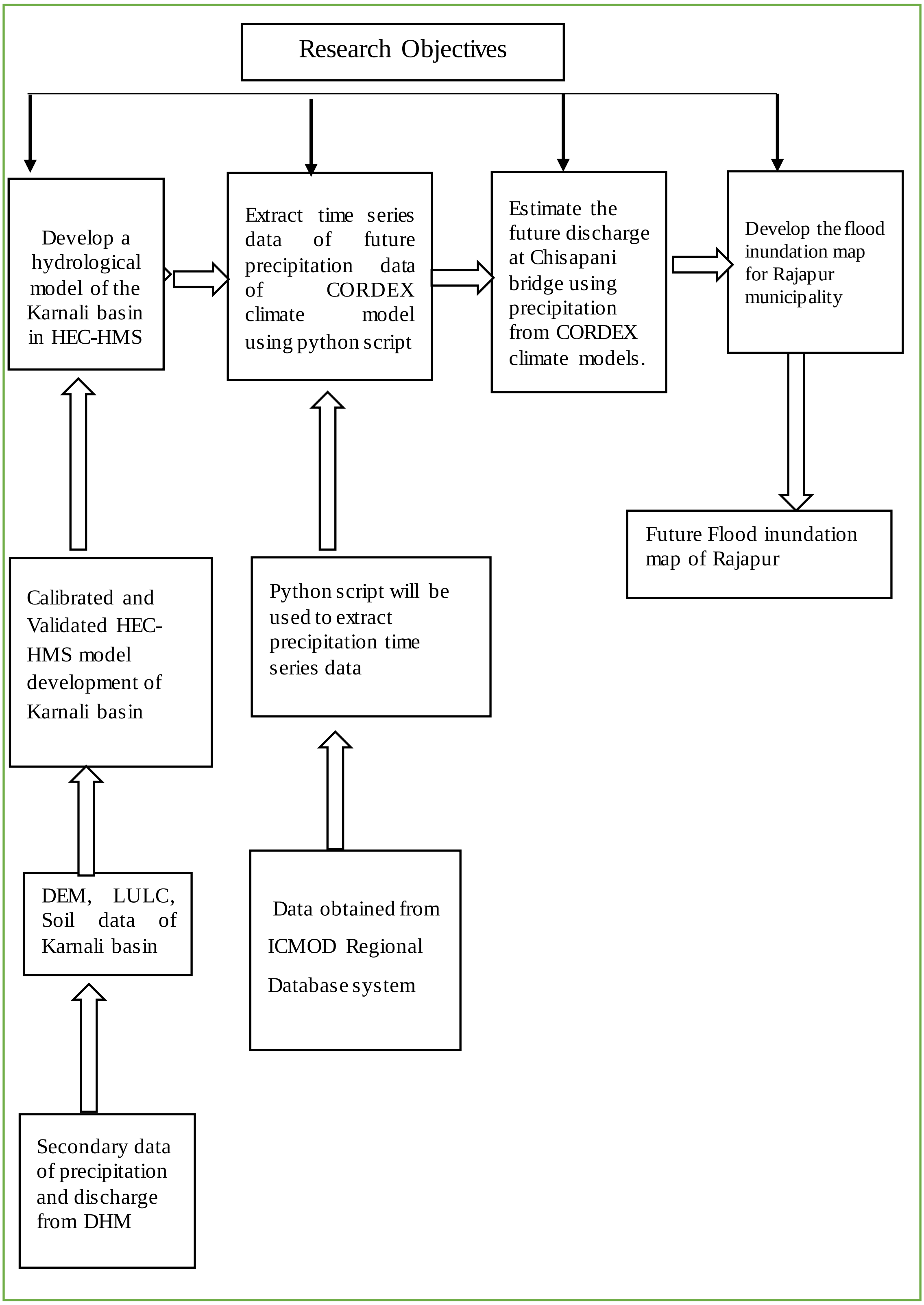


Figure 3.2: Research Design

3.3 Objective Wise Research Matrix

Table 3.1: Objective Wise Research Matrix

Objectives	**Data needed**	**Data Collection Method**	**Data Analysis Tools**	**Expected Outcome**
To develop Hydrological model in HEC-HMS	DEM LULC Precipitation Soil data	Rainfall and discharge data at Chisapani station from DHM	HEC-HMS MS-Excel	Simulated discharge
Extract time series of future precipitation data from CORDEX climate model using python	CORDEX time series data for precipitation and temperature	From Regional Database System of ICIMOD	Python, MS-Excel	Future time series data of temperature and precipitation
To simulate future discharge for Chisapani station	The validated HEC-HMS model obtained from first objective Future time series data of precipitation and temperature from second objective	Prepared in objective one and two	HEC-HMS. MS-Excel	Future discharge at Chisapani station
To develop the flood inundation map at Rajapur	Future discharge at Chisapani bridge obtained from third objective	Prepared in objective three	HEC-RAS, QGIS	Flood Inundation map at Rajapur

3.4 Data Sources

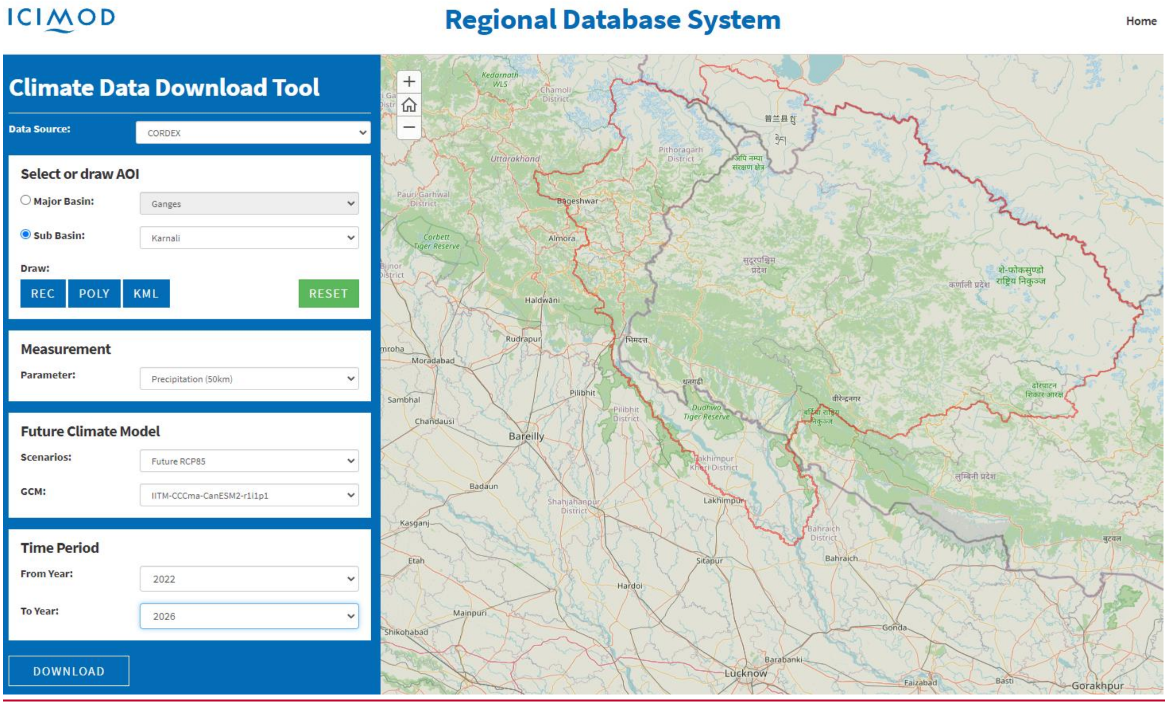
3.4.1 DHM (Department of Hydrology and Meteorology, Nepal)

The 30th year (1992-2021) time series of precipitation and river discharge data of Chisapani Karnali area was used to prepare the Karnali river basin model.

3.4.2 ICMOD (International Centre for Integrated Mountain Development)

LULC (Land Use Land Cover) data of year 2019 Chisapani Karnali area was collected from ICMOD Regional Database System. From climate change model, CORDEX climate mode for Karnali basin time series precipitation data for the future was collected through following steps;

- Major Basin = Ganges
- Sub Basin = Karnali
- Measurement parameter = Precipitation (50 km)
- Future Climate Model, Scenarios = future RCP8.5
- GCM = IITM-CCCma-CanESM2-r1i1p1
- Download precipitation data = 2022 – 2054



ICIMOD Regional Database System Home

Climate Data Download Tool

Data Source: CORDEX

Select or draw AOI

○ Major Basin: Ganges

● Sub Basin: Karnali

Draw: REC POLY KML RESET

Measurement

Parameter: Precipitation (50km)

Future Climate Model

Scenarios: Future RCP85

GCM: IITM-CCCma-CanESM2-r1i1p1

Time Period

From Year: 2022

To Year: 2026

DOWNLOAD

(source ICIMOD RDS)

Figure 3.3: ICIMOD Regional Database System

3.4.3 Other Data Sources

Other data sources are books, journals, annual reports and other publications from different governmental and non-governmental organizations, websites, records and libraries. Some published as well as unpublished literature are also reviewed in order to add further more information related to the topic like thesis, reports and documents from different institutions.

3.5 Data used for research

3.5.1 DEM (Digital Elevation Model)

It is a digital representation of the surface of the Earth, created by combining information from multiple sources, such as aerial & satellite imagery, ground surveys and radar data. It provides hydrological information like stream networks, drainage directions, flow accumulations river topology etc. in a consistent and comprehensive format of a region [74]. DEMs provide a 3-dimensional view of Earth’s surface, showing the elevation and shape of the terrain. DEM data is used in a variety of applications, such as land use planning, natural resource management, geological and environmental studies, and navigation. It can be used to create topographic maps, to model the flow of water and other materials across the terrain, and to analyze the effects of changes in the terrain on natural and human systems. 30m resolution DEM was used.

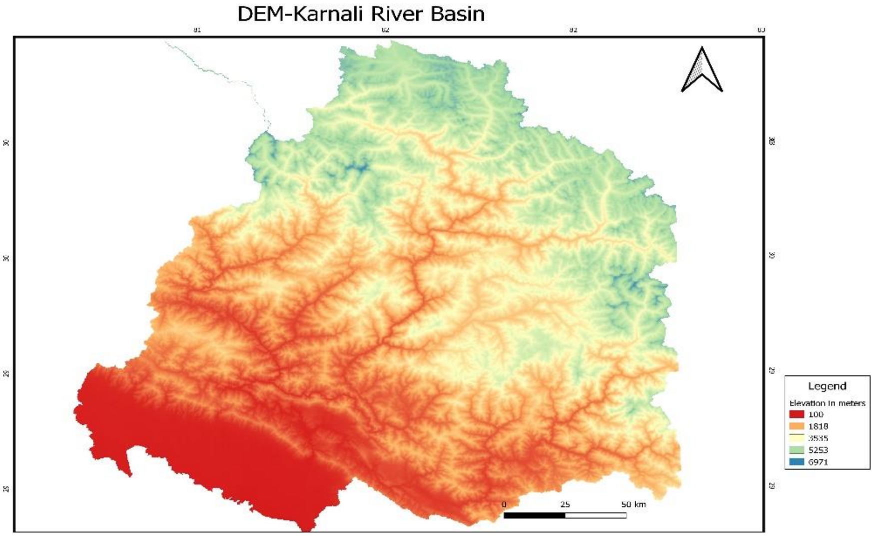


Figure 3.4: DEM- Karnali River Basin

3.5.2 Land Use and Land Change (LULC) map

LULC refers to the types of land cover such as forests, croplands, wetlands, urban areas etc. and land use such as agriculture, residential, commercial, industrial etc. in given area. LULC data can also be used as input for various models, such as hydrological models, climate models, and ecological models. It can be used to assess the impacts of land use changes on the environment, to identify areas of high conservation value and to develop strategies for sustainable land use and management. LULC map of study area is collected from ICMOD Regional Database System.

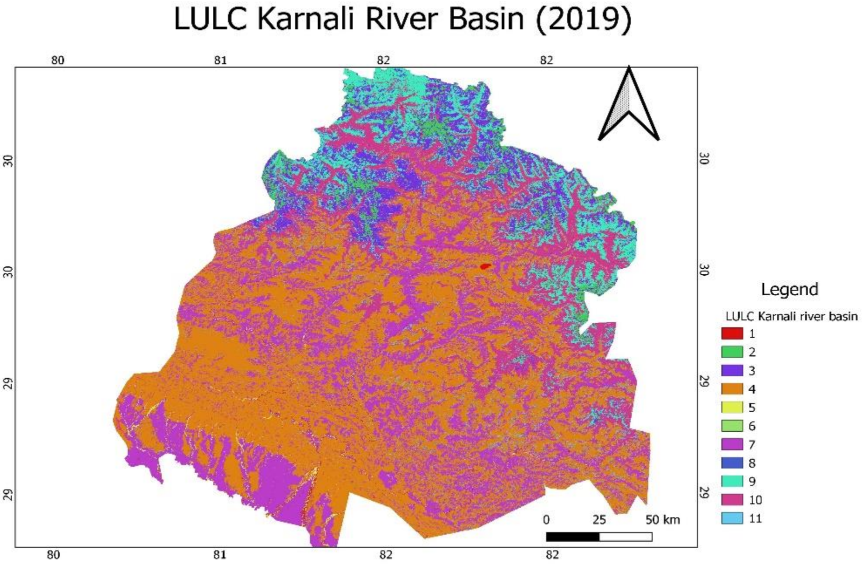


Figure 3.5: LULC Karnali River Basin

3.5.3 Hydrological Soil Group:

The United States Department of Agriculture (USDA) has developed a widely used classification system for hydrological soil groups, which is known as the USDA Soil Conservation Service (SCS) method or the Soil Taxonomy. Based on their hydrological characteristics and capacity to absorb and transmit water, hydrological soil groups (HSGs) divide soil into four major groups: A, B, C, and D.

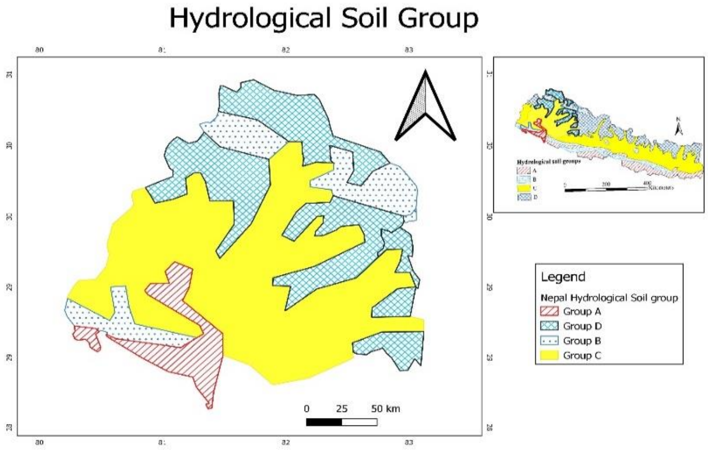


Figure 3.6: Hydrologic Soil Group

Table 3 2: The USDA-NRCS Hydrologic Soil Group Classification

[75]

Soil Group	Description	Final Infiltration Rate (mm/h)
A	Lowest Runoff Potential: Includes deep sands with very little silt and clay also deep, rapidly permeable loess.	8-12
B	Moderately Low Runoff Potential: Mostly sandy soils less deep than A, loess less deep or less aggregated than A, but the groups as a whole has above- average infiltration after through wetting	4-8
C	Moderately High Runoff Potential: Comprises shallow soils and soils containing considerable clay and colloids, though less than those of group D. The group has below- average infiltration after pre-saturation	1-4
D	Highest Runoff Potential: Includes mostly clays of high swelling percent, but the group also includes some shallow soils with nearly impermeable sub-horizons near the surface	0-1

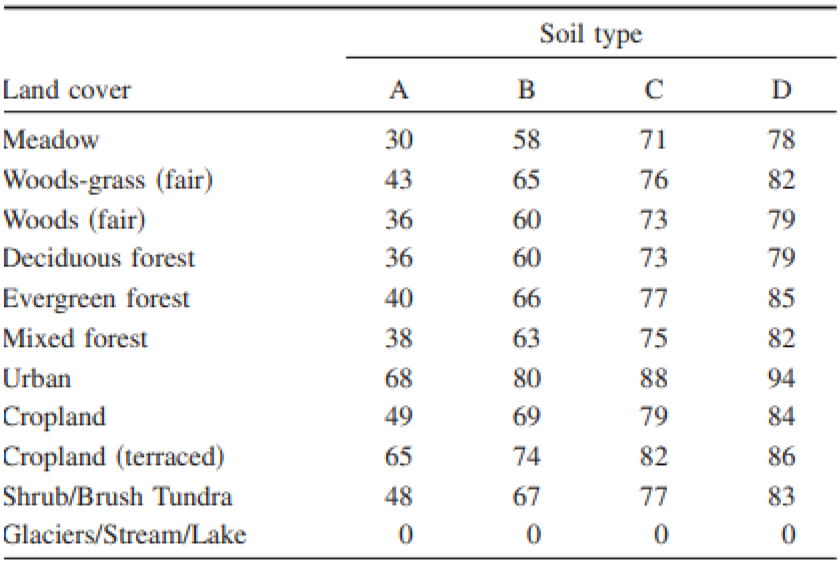
The Journal of Hydrologic Engineering was the source from which the raster map of Nepal produced by HSG was taken.2009's .[76].

3.5.4 Curved Number (CN)

Using HSG map and land use land cover map and lookup table, the CN map was prepared Below is the customized form of the CN table for the current scenario.

Table 3 3: Curved Number Table

[76]

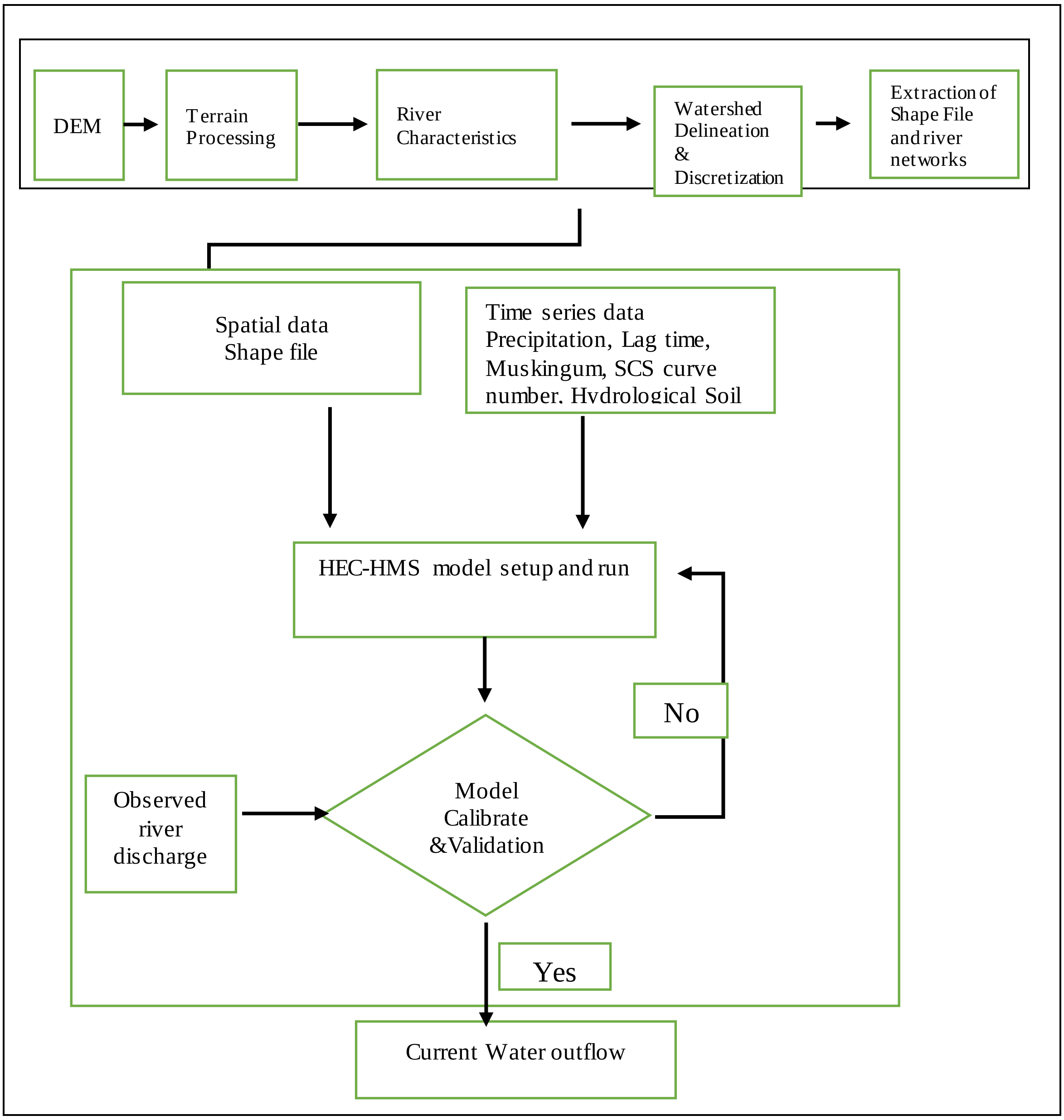


Land cover	Soil type A	B	C	D
Meadow	30	58	71	78
Woods-grass (fair)	43	65	76	82
Woods (fair)	36	60	73	79
Deciduous forest	36	60	73	79
Evergreen forest	40	66	77	85
Mixed forest	38	63	75	82
Urban	68	80	88	94
Cropland	49	69	79	84
Cropland (terraced)	65	74	82	86
Shrub/Brush Tundra	48	67	77	83
Glaciers/Stream/Lake	0	0	0	0

3.6 Data Analysis

3.6.1 Develop Hydrological Model

HEC-HMS software is used to make the hydrological flow of Karnali River Basin. Development of a hydrological model of the Karnali basin using HEC-HMS was used to simulate the flow of water in the basin, and to evaluate the impacts of climate change on water resources.. A hydrological model of the Karnali basin developed in HEC-HMS that simulates the water balance of the basin, including inflow, outflow, and storage of water. The model could also provide information on stream flow and water availability under different scenarios of climate and land use changes. A basin model, meteorological model, control parameters, and input data (time series data) make up the HEC-HMS model's configuration (US Army Corps of Engineers).



Model source (Khatri & Prasad, 2021)

Figure 3.7: Flow diagram of HEC-HMS

3.6.1.1 Procedure of HEC-HMS

HEC-HMS Step

1. New Project

Name: Karnali River Basin > Description: Karnali River Basin> Located> Unit: Metric> Create

2. Component

Create Component > Terrain Data> DEM Karnali River Basin> Ok

Basin Model Manger> New> Name, Description> Create

3. GIS

Coordinate System> Predefine > UTM> UTM Zone 44 > WGS 84> Select

Then Click Set

Now Click on Basin Model > Karnali Basin from Watershed Explorer. Then, Select Terrain data from the component Editor. Now, Save the file and skip.

From Gis

Click Processing Sink, this will make the Sink location and Sink Fill

Click Processing Drainage, this will make flow direction and calculate flow accumulation.

Click Identify Streams> 50 sq km. >ok

This all can be seen by clicking right from Map (desktop) and unclick as per the requirement

Now using the Break Point Creation Tool make a break point and name the basin outlet.

From Gis

Click Delineate Elements> Sub-basin: Sub-basin> Reach Prefix: Reach> Junction Prefix: Junction > Click Delineate.

Rename as per the requirement.

By looking at the basin size select the basin that can be merged then from Gis click merge element

Click Export layer> save the shapefile of the HEC-HMS Basin and work on QGIS Software to calculate the Curve Number of the basin.

4. Tool

Program Setting> Defaults> Loss Method: SCS> Transform: SCS> Basin: No> Reach: Muskingum> Precipitation: Specified Hydrograph

5. Parameter

Loss> SCS Curve Number and sort in alphabetic and paste the value from Excel in Curve Number and initial abstraction is 0.

Transform> SCS Unit Hydrograph and paste the calculated Lag time (Min)

Note: Time of Concentration (Tc)=l^0.8(S+1) ^0.7/1140y^0.5

Lag= 0.6Tc

Where:

l= Flow length, ft

L= lag, h

Tc= time of concertation, h

Y= average watershed land slope, %

S= maximum potential retention, in

Routing> Muskingum> Muskingum K:0.5 and Muskingum X:0.25

From Component

Meteorological Model Manager> new>met 1> Create

Control Specification Manager> New> Control> Create

Time series Data Manager

Data type> Precipitation Gages> new> Gage 1>Create

Data type> Discharge Gages> new> Gage 1> Create

In Watershed Explorer

Click Time Series Data

Precipitation Gages> gage > in the component editor change the time interval to 1 day and change the data source to manual entry

Rename the start date time and end Click gage and, in the table, paste the precipitation data.

Repeat the same process to Discharge Gages as precipitation Gages

Click Meteorological Models

Met 1> Replace Missing: Set to Default

Basins> yes in Include Sub basins

Specified Hyetograph > connect sub basin to gage

Click Control Specifications

Control 1> Retype the start and date as per the requirement

Click sink of the basin and select gage 1

6. Component

Create Component> simulation run > run 1> basin > met1> control 1>Finished

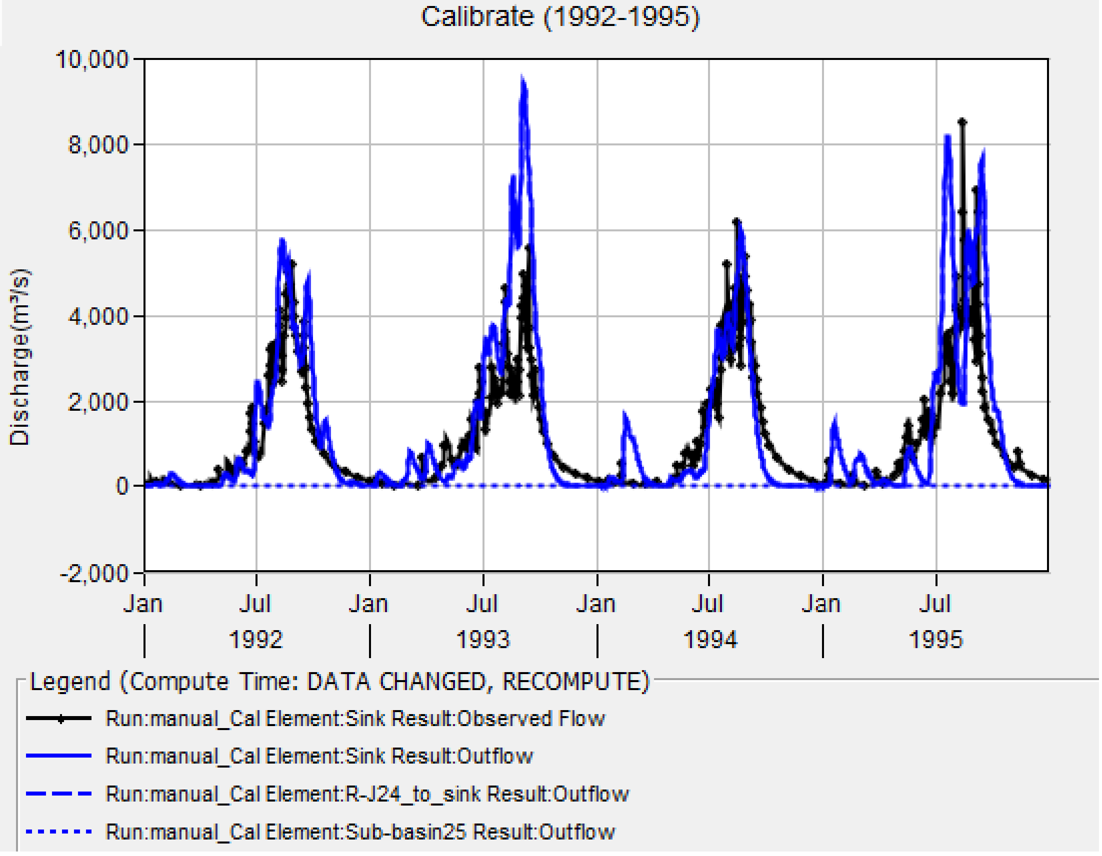
From Watershed Explorer

Click Compute> Simulation run >Run 1> Run

Click Results >Simulation Runs> Run 1> Sink> Graph, Summary table

7. HEC-HMS Karnali basin model Calibration

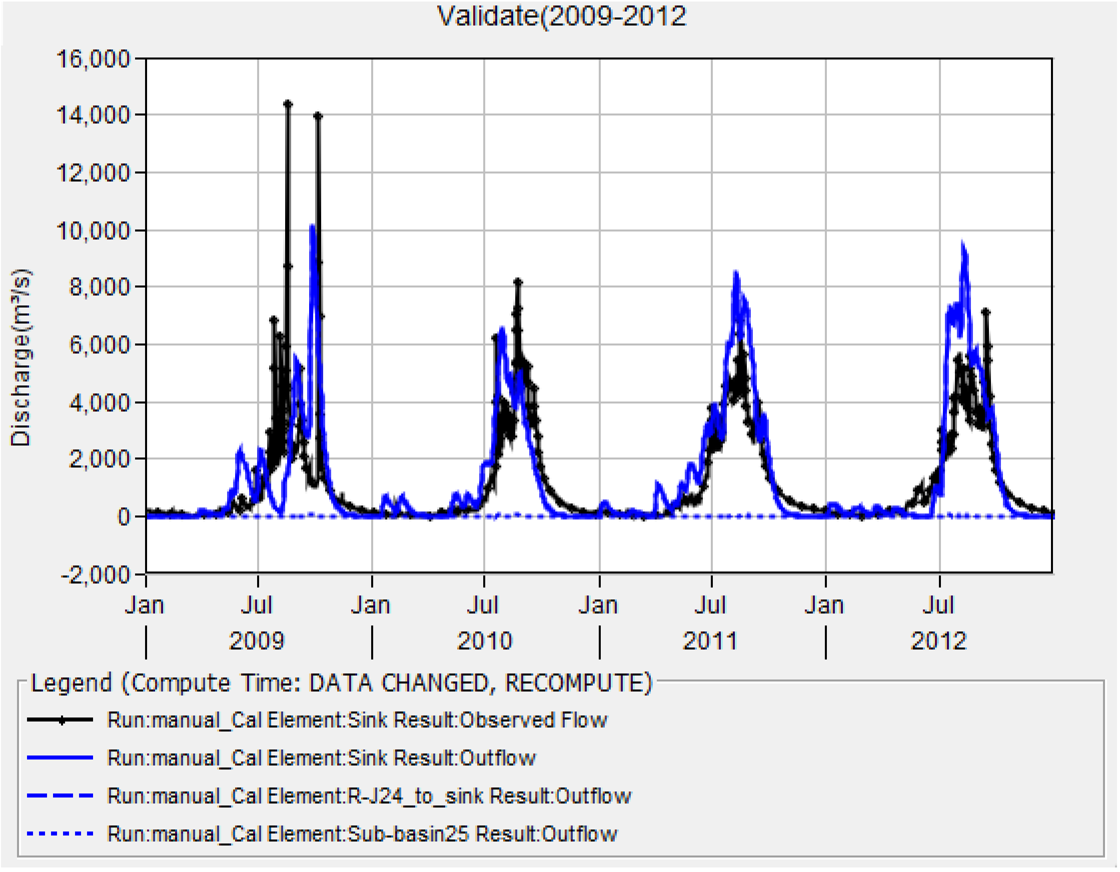
Run with some of the data by playing with Loss, Transform and Routing values and run the model unit the value meets the error.



8. HEC-HMS Karnali basin model Validation

Run the model without touching any parameter but using different start dates and end dates.

From this the HEC-HMS model is ready.



1. Evaluating Model Output

Statistics used for model evaluation:

- Coefficient of Determination (R^2)
- Nash-Sutcliffe Efficiency (NSE)
- Root Mean Square Error (RSR)
- Percent Bias (PBIAS)

1. Performance Statistics Parameter

Model Elevation	**Calibration (19921995)**	**Validation (2009-2012)**
Coefficient of Determination (R^2)	0.9	0.9
Nash-Sutcliffe Efficiency (NSE)	0.192	0.238
Percent Bias (PBIAS)	24.93%	22.95%

[78]

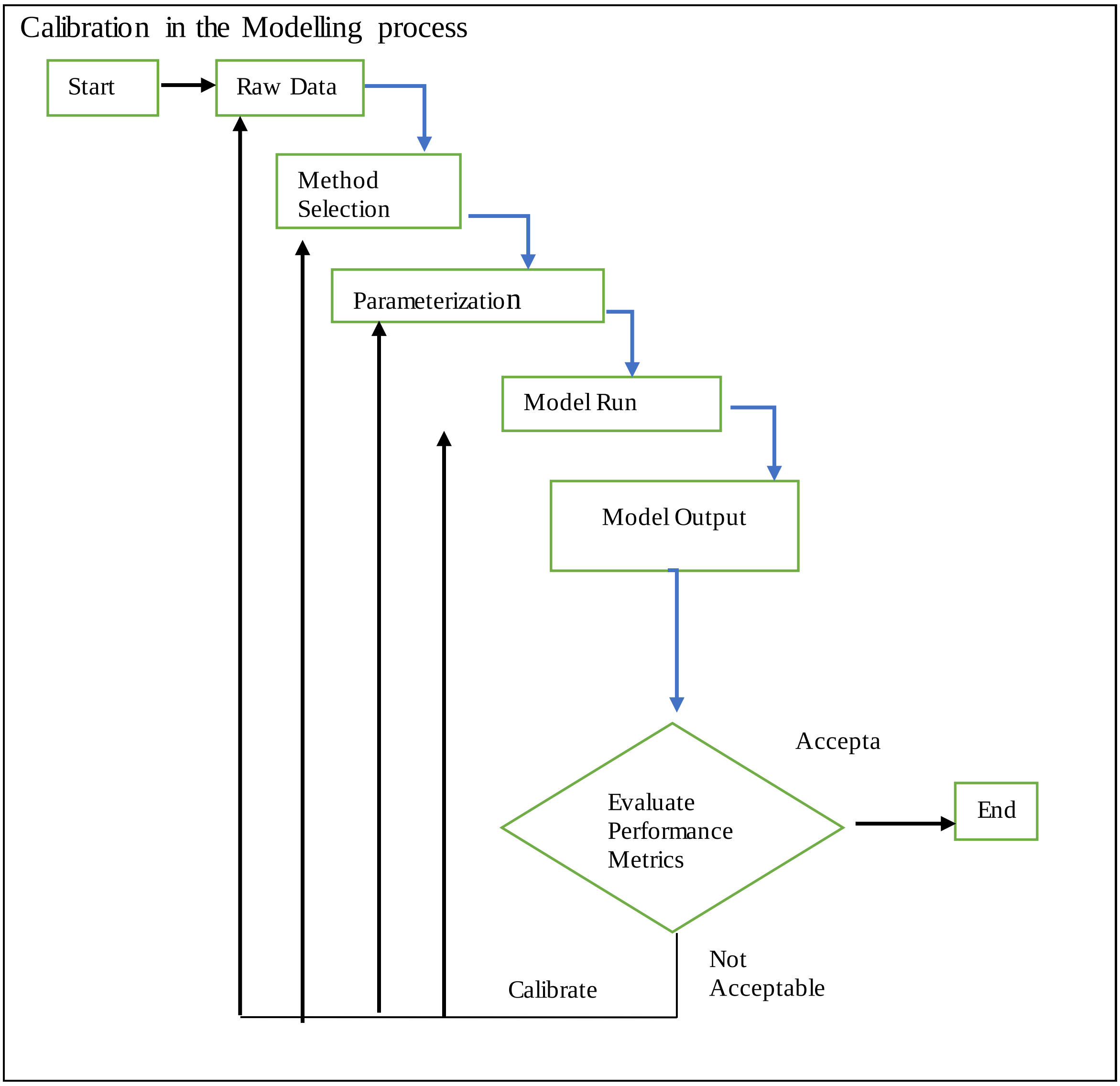
<table>
<tr><th colspan="5">Performance Ratings for Evaluation Metrics for a daily and weekly time step</th></tr>
<tr><th>Performance Rating</th><th>R^2</th><th>NSE</th><th>RSR</th><th>PBIAS</th></tr>
<tr><td>Very Good</td><td>$0.65<R^2 \leq 1.00$</td><td>$0.65<NSE\leq 1.00$</td><td>$0.00<RSR\leq 0.60$</td><td>$PBIAS< \pm 15$</td></tr>
<tr><td>Good</td><td>$0.55<R^2 \leq 0.65$</td><td>$0.55<NSE\leq 0.65$</td><td>$0.60<RSR\leq 0.70$</td><td>$\pm 15\leq PBIAS<\pm 20$</td></tr>
<tr><td>Satisfactory</td><td>$0.40<R^2 \leq 0.55$</td><td>$0.40<NSE\leq 0.55$</td><td>$0.70<RSR\leq 0.80$</td><td>$\pm 20\leq PBIAS<\pm 30$</td></tr>
<tr><td>Unsatisfactory</td><td>$R^2\leq 0.40$</td><td>$NSE\leq 0.40$</td><td>$RSR>0.80$</td><td>$PBIAS\geq \pm 30$</td></tr>
</table>

3.6.2 Calibration & Validation

Time series data of daily discharge of Chisapani hydrological station is used for calibration and validation of the model. Model calibration is carried by using four years past data and validation will be carried by using a year past data (1992-1995) and validation is carried by using four years past data (2009-2012).

Validation is performed after the model has been calibrated. The calibration and validation period were chosen after obtaining, analyzing and pre-processing the data.

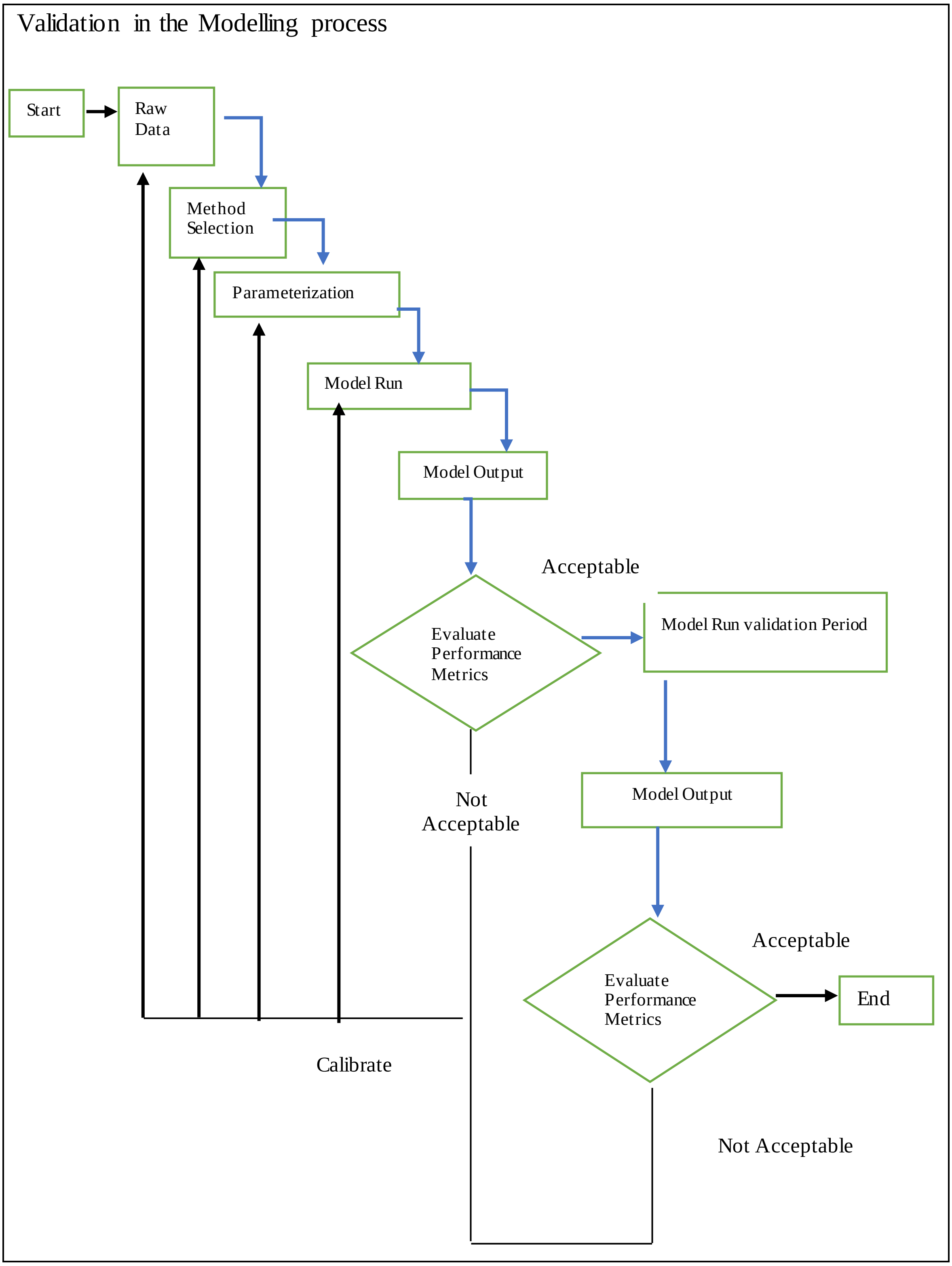
Calibration is the process of estimating and modifying model constants and parameters to enhance the agreement between the model's output and a collection of data. [79]



Source: HEC-HMS Manual

Figure 3.3: Model Calibration Process

A model that has been calibrated for one set of data is evaluated against another set of data containing the same variables at the same location as the calibration (the classical "split-record test") is Validation [80]



Source: HEC-HMS Manual

Figure3. 4 :Model Validation Process

3.6.3 Estimated Future Precipitation and Discharge

The estimated future precipitation was obtained from the ICMOD Regional Database System of CORDEX model by using Python script. Application of time series data of future precipitation from climate models using Python script, which could help in understanding the changes in weather patterns, and how they may affect the hydrological cycle in the Karnali basin. Then from this precipitation data the simulated discharge in Chisapani is obtained from HEC-HMS model Estimation of future discharge at Chisapani bridge using precipitation data from climate models, which help in predicting the water level in the river at a specific location, and inform flood management strategies.

3.6.4 Inundation Map

The future discharge at Chisapani bridge using precipitation data from climate models help to predict future river flow and identify periods of high and low flow. This could also help to assess the risk of flooding and inform the development of flood management strategies. Development of flood inundation maps for Rajapur municipality for future scenarios as predicted by CORDEX climate model, which could help in identifying the areas that are vulnerable to flooding under different climate scenarios, and inform the development of flood risk management plans. The maps help in planning for emergency response and evacuation procedures in the event of a flood. The simulated discharge of Chisapani is used in the HEC-RAS model. Through this model, future flood inundation area is obtained and then an inundation map of Rajapur is created. This model is a useful tool in the creation of safety and management during extreme flooding events.[73] Current models can perform hydrological studies on a regional scale and can also be integrated into regional models or provide boundary conditions. The successful integration of map-to-map technology at the regional level demonstrates the versatility of this tool for flood inundation studies at the city, county, and regional levels.[81]

In this study, HEC-RAS version 6.3.1 was used to calculate water surface profiles and QGIS version 3.22.9 was used for the GIS data processing. This software is the freely available and mostly recommended package for data processing. The Methodology flow chart for HEC-RAS mapping is shown in below figure.

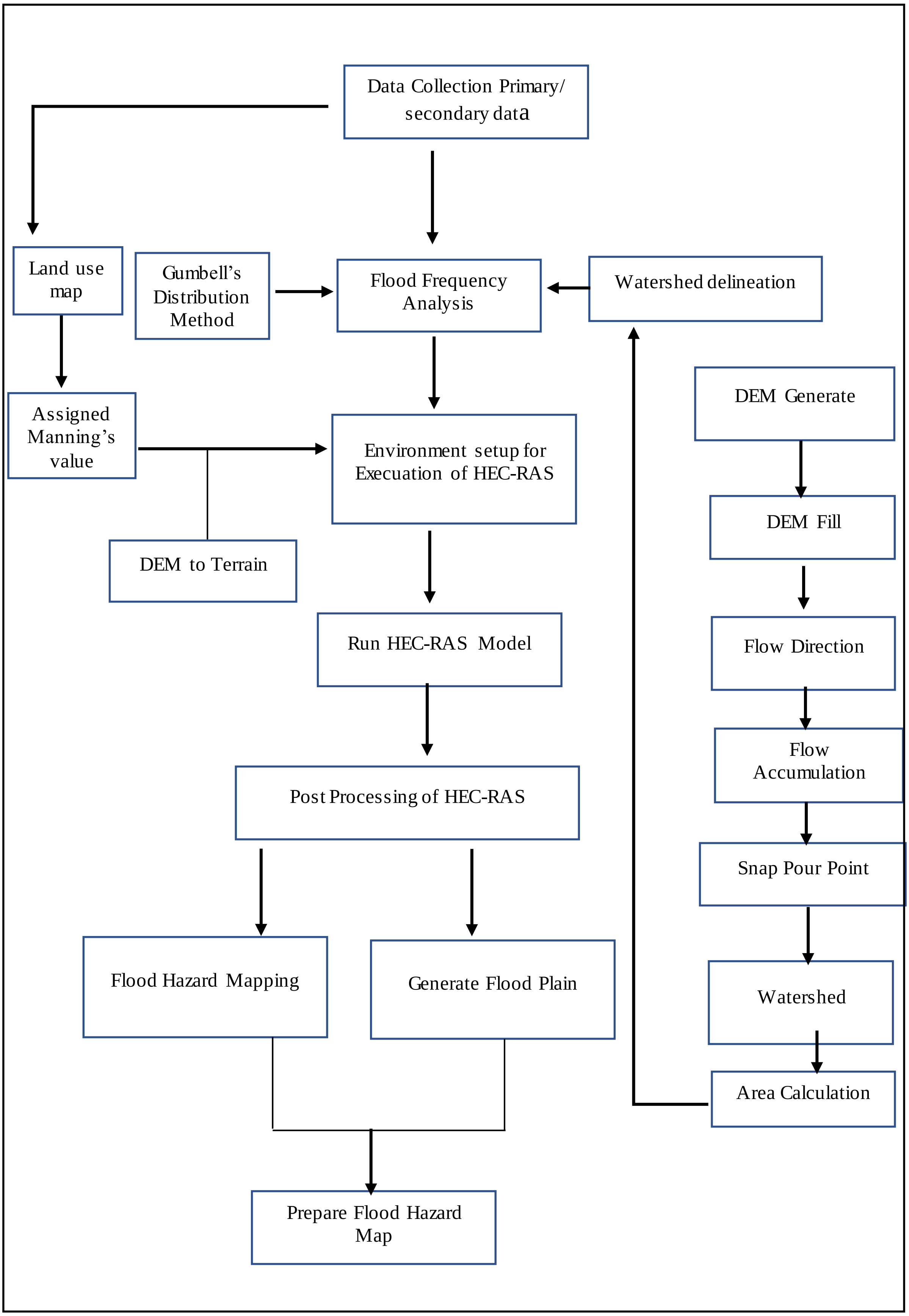


Figure 3.10: Flood Hazard Mapping

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Result

4.1: Hydrological Model Development:

A successful hydrological model of the Karnali River Basin (KRB) was developed using HEC-HMS Software. This Software is a semi-distributed conceptual hydrological model that is capable of simulating hydrological processes of a watershed to derive river discharge and water balance. A basin model, meteorological model, control parameters, and input data (time series data) make up the HEC-HMS model's configuration. A basin model is used to provide a physical representation of a watershed. Daily precipitation, discharge (for calibration and validation), are all included in the simulated runoff as production. The twenty-five sub-basin and twenty-two reaches are designed while considering different hydropower and hydrological stations in the basin shown in figure below.

Figure 4.1: Hydrological Model of Karnali River Basin

4.1.1: Model Calibration and Validation

Table 4.1: Performance Statistics Parameter

Model Elevation	**Calibration** **(19921995)**	**Validation** **(2009-2012)**
Coefficient of Determination (R^2)	0.9	0.9
Nash-Sutcliffe Efficiency (NSE)	0.192	0.238
Percent Bias (PBIAS)	24.93%	22.95%

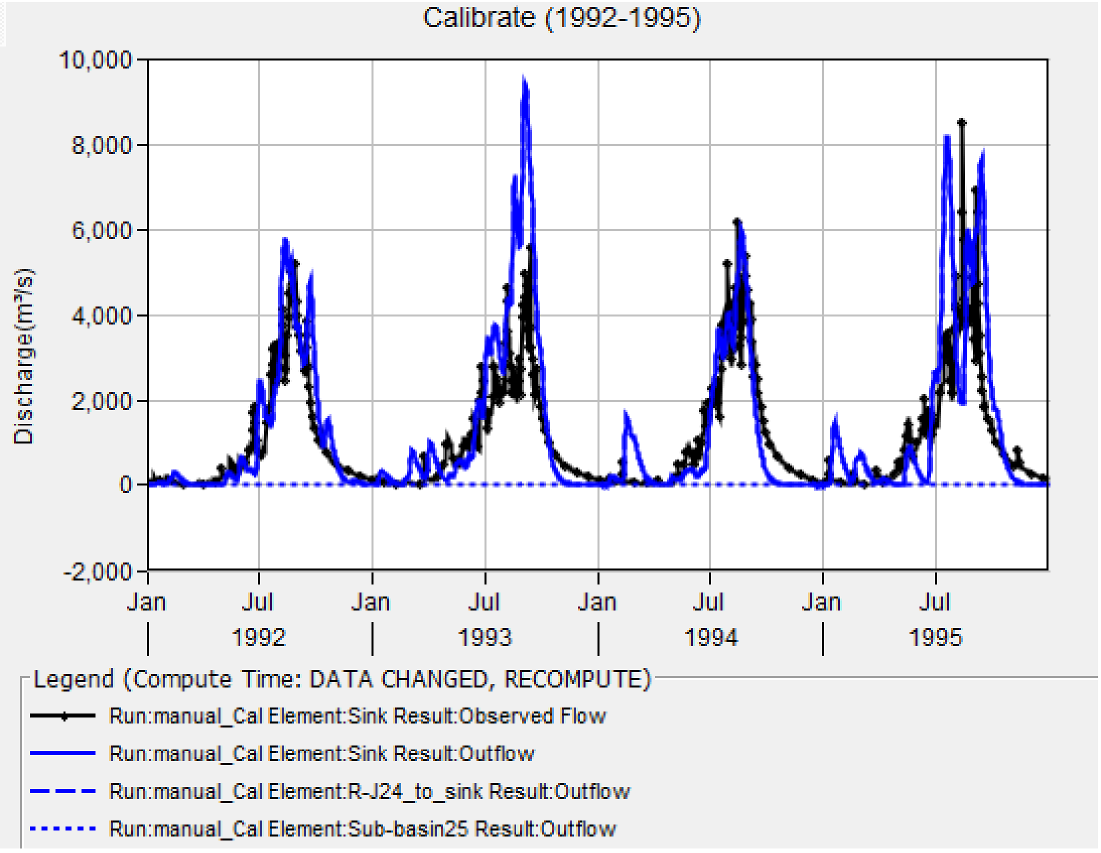


Figure 4.2: Calibrate Model (1992-1995)

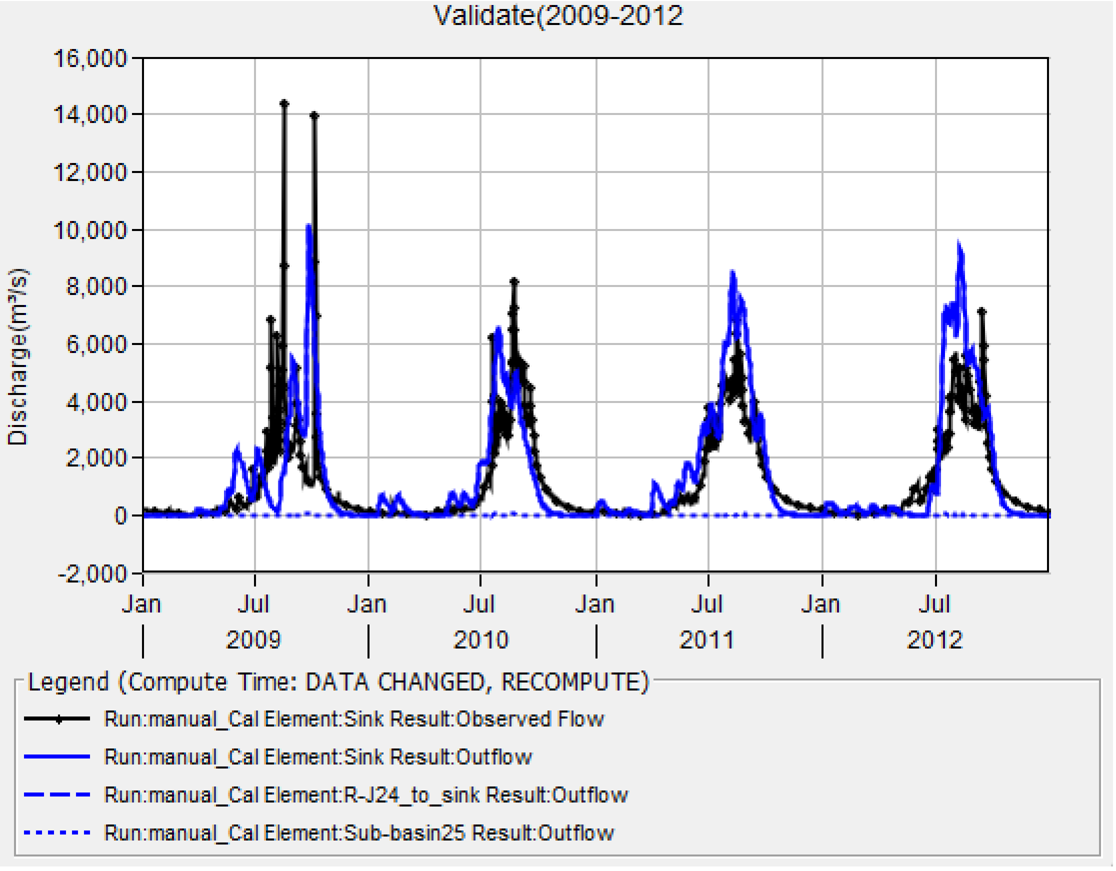


Figure 4.3: Validate Model (2009-2012)

4.2: Application of Climate Model Data

The climate model data can be utilized in time series data for future precipitation and temperature obtained from climate models. It can also be used in the development of a python script to process and analyze the climate model data. The time series data for future precipitation obtained from climate change used in the hydrological model are used to assess its impact on the water resources of the Karnali basin.

The time series data of 2022-2054 precipitation data is obtained from CORDEX Model.

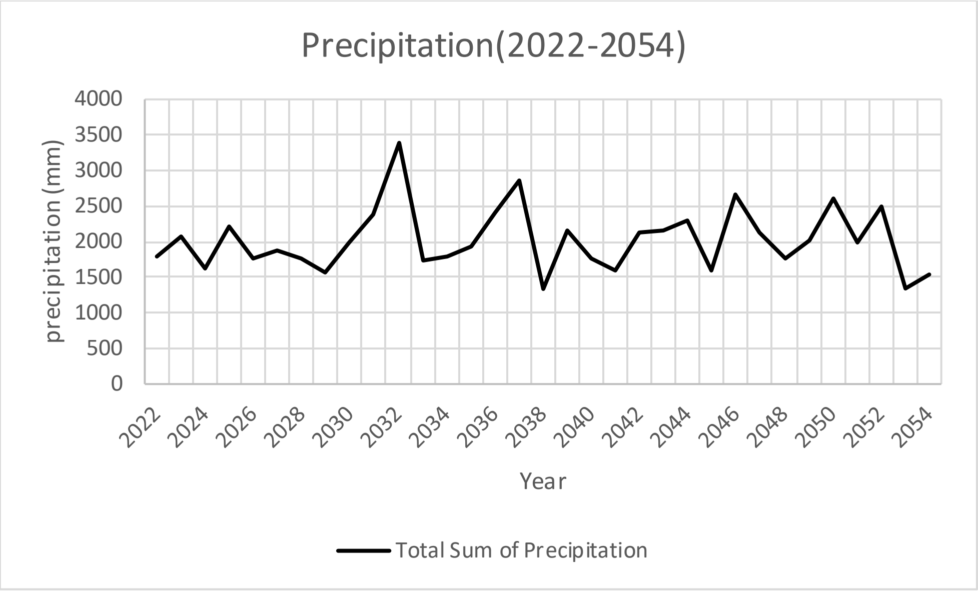


Figure 4.4: Estimated Future Precipitation Data obtained from CORDEX Model

The graph illustrates precipitation trends over several years. The highest precipitation will occur in 2032 with the annual precipitation of 3389.76mm and the lowest annual precipitation will be estimated in 2053 with 1347.43mm

4.3: Estimation of Future Discharge

The assessment involves predicting future discharge levels at the Chisapani bridge by using projected precipitation data from climate models. The analysis offers valuable insights into the possible alterations in river discharge that could occur in response to future climate scenarios (RCP 8.5). It aids in comprehending the hydrological consequences for the study area.

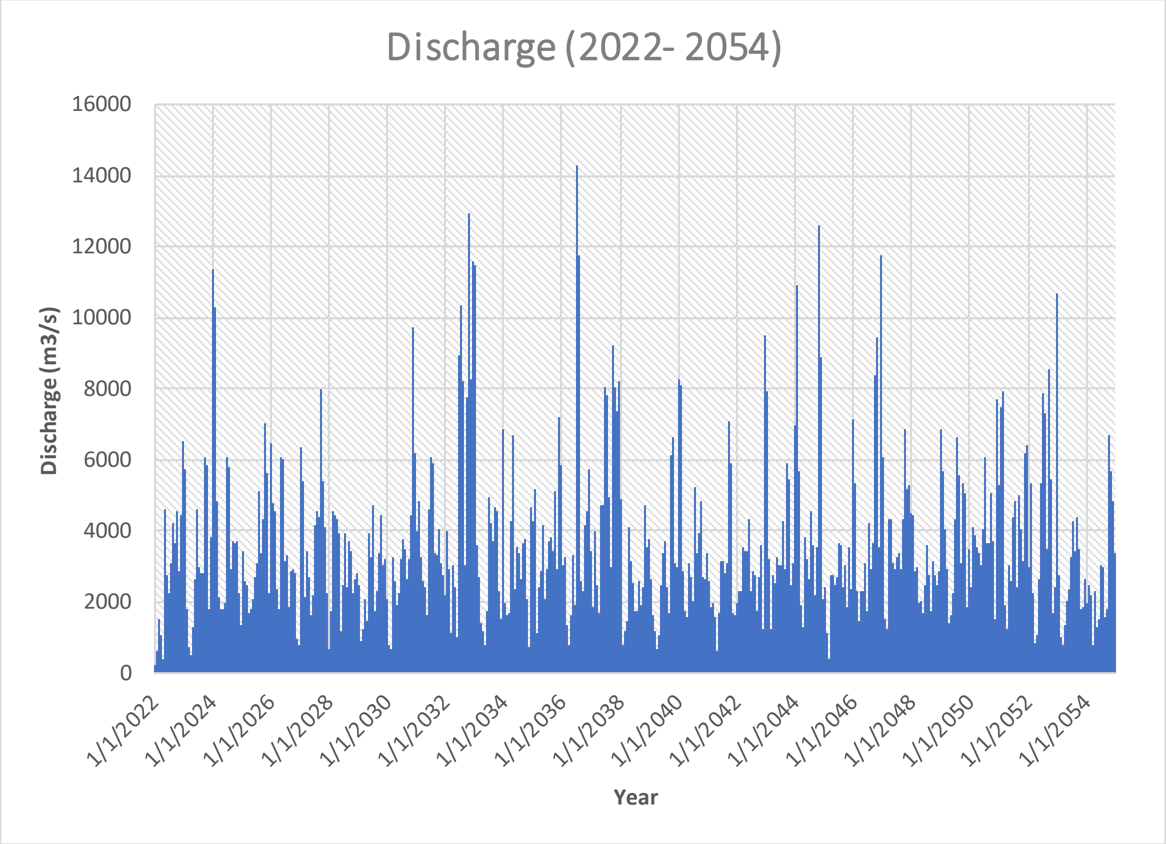


Figure 4.5: Estimated Discharge (2022-2054)

The graph illustrates the total discharge expected from the Karnali River Basin. The peak discharge, at 14286.2 m³/s, is projected to occur in the year 2036.

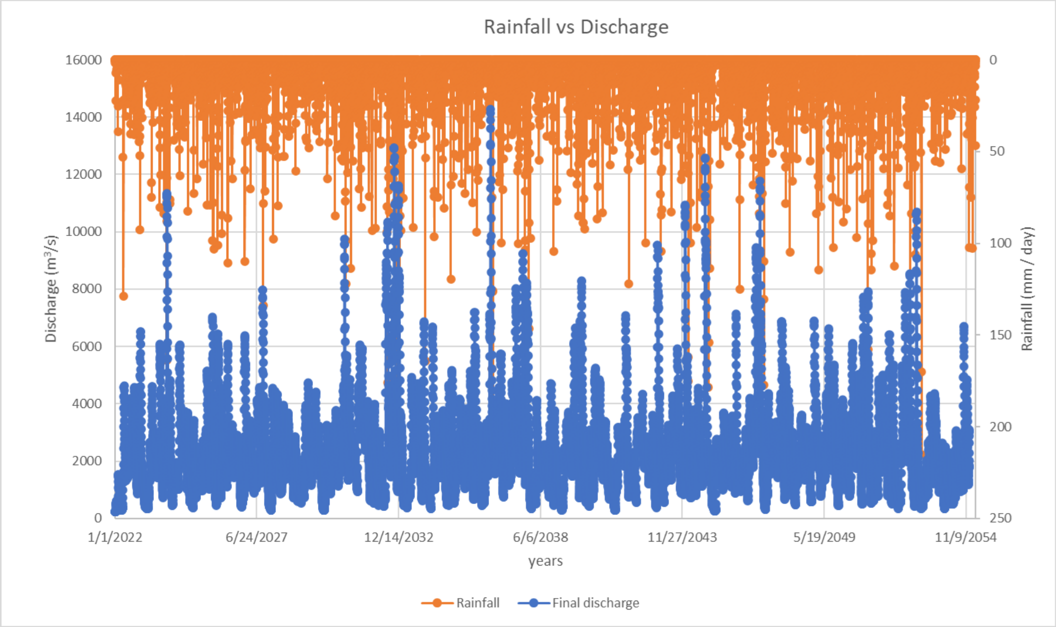


Figure 4.6: Combined Precipitation and Discharge (2022-2054)

44: Flood Inundation Mapping

The estimated future discharge the maps illustrate the potential extent and severity of flooding in the municipality. The flood inundation maps provide valuable information for disaster preparedness, land-use planning, and decision-making to mitigate flood-related risks.

The figure below shows the water depth of Rajapur Municipality in every year return period (5, 10, 25, 50, 100, 500, 100)

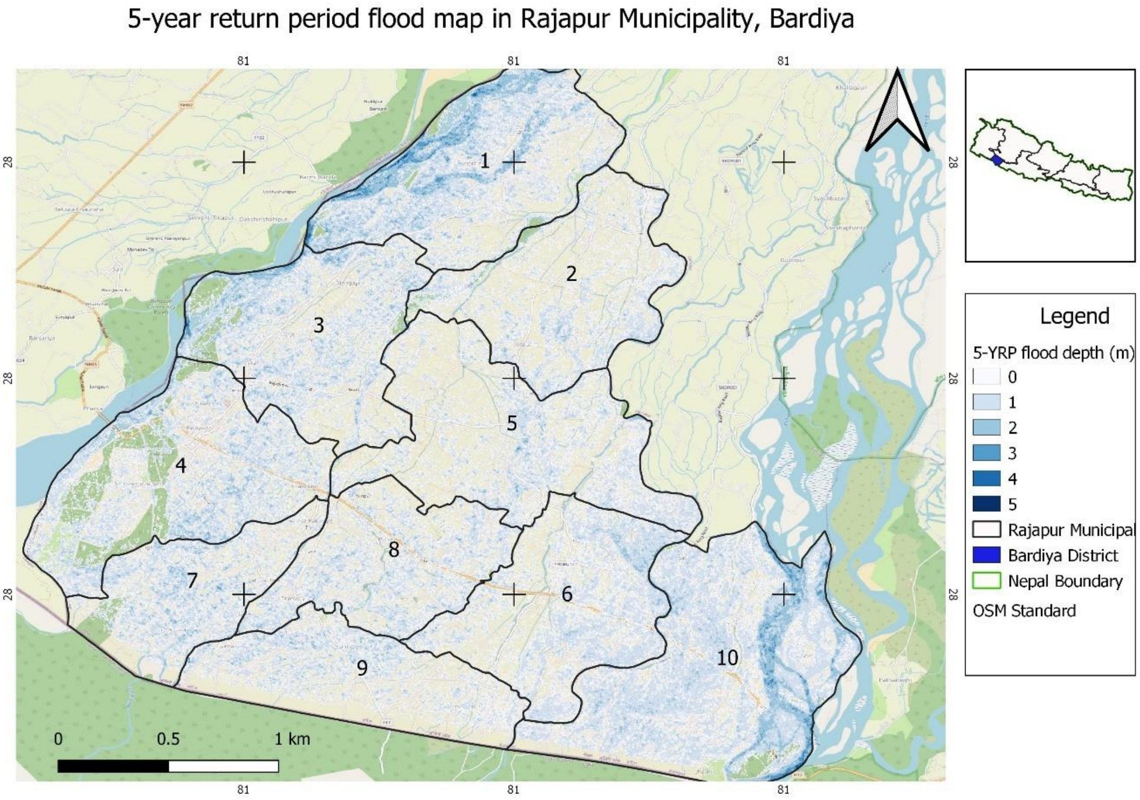


Figure 4.7: 5YRP flood hazard map

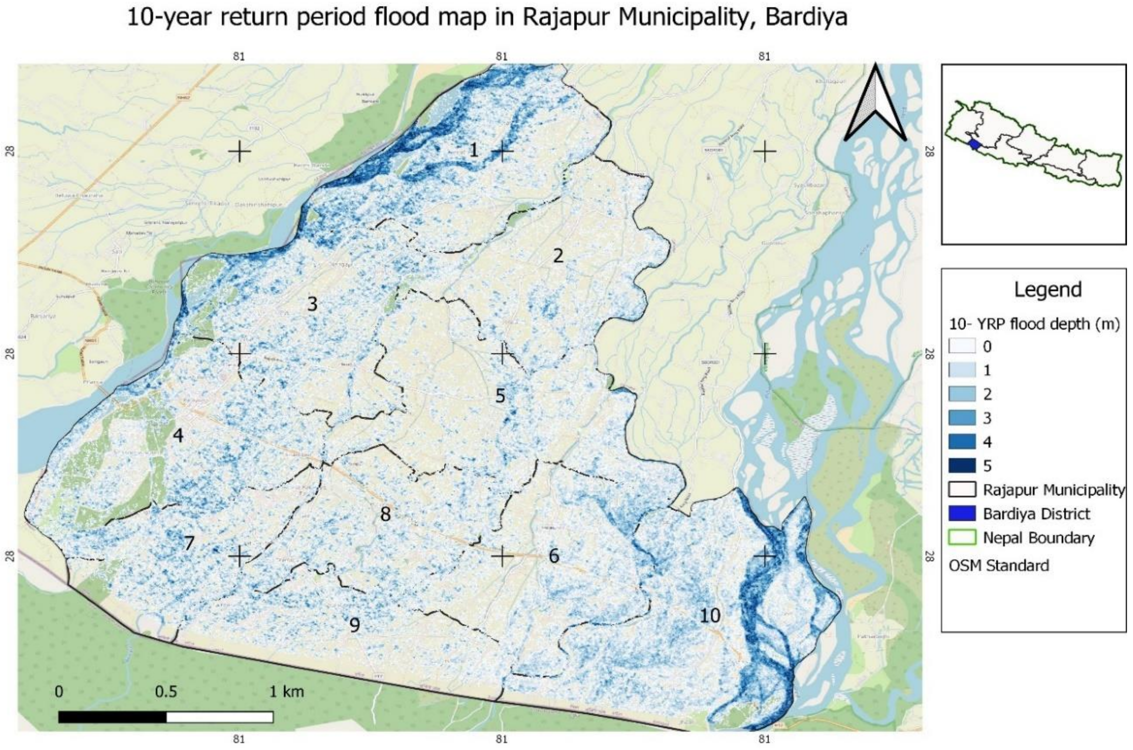


Figure 4.8: 10 YRP flood hazard map

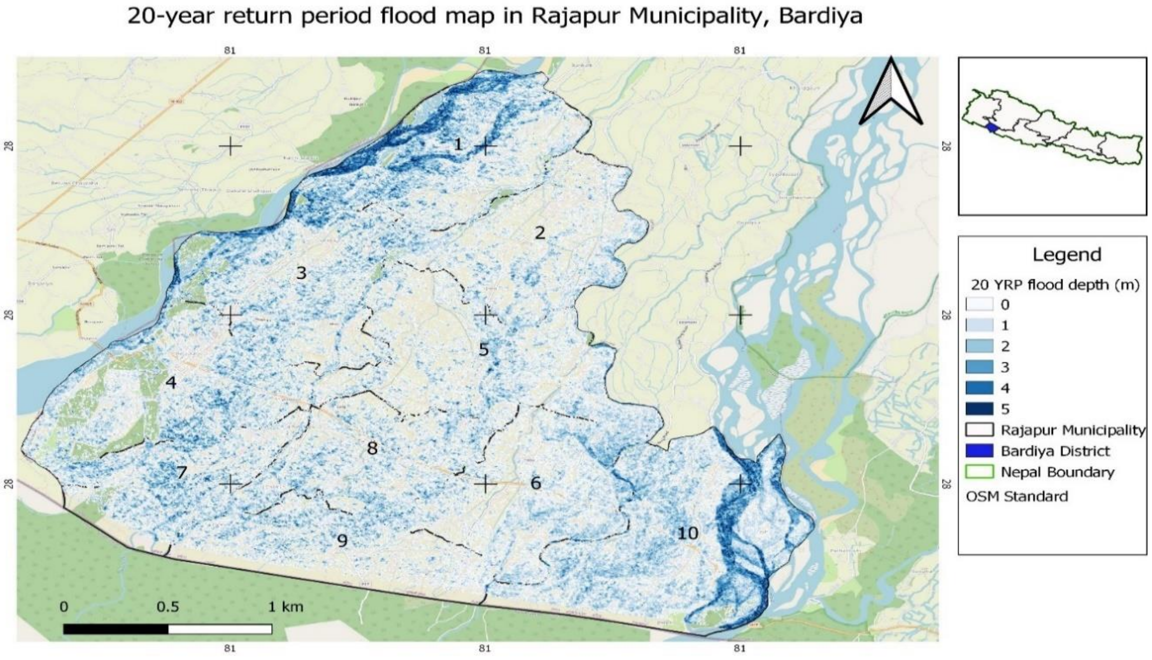


Figure 4.9:20 YRP flood hazard map

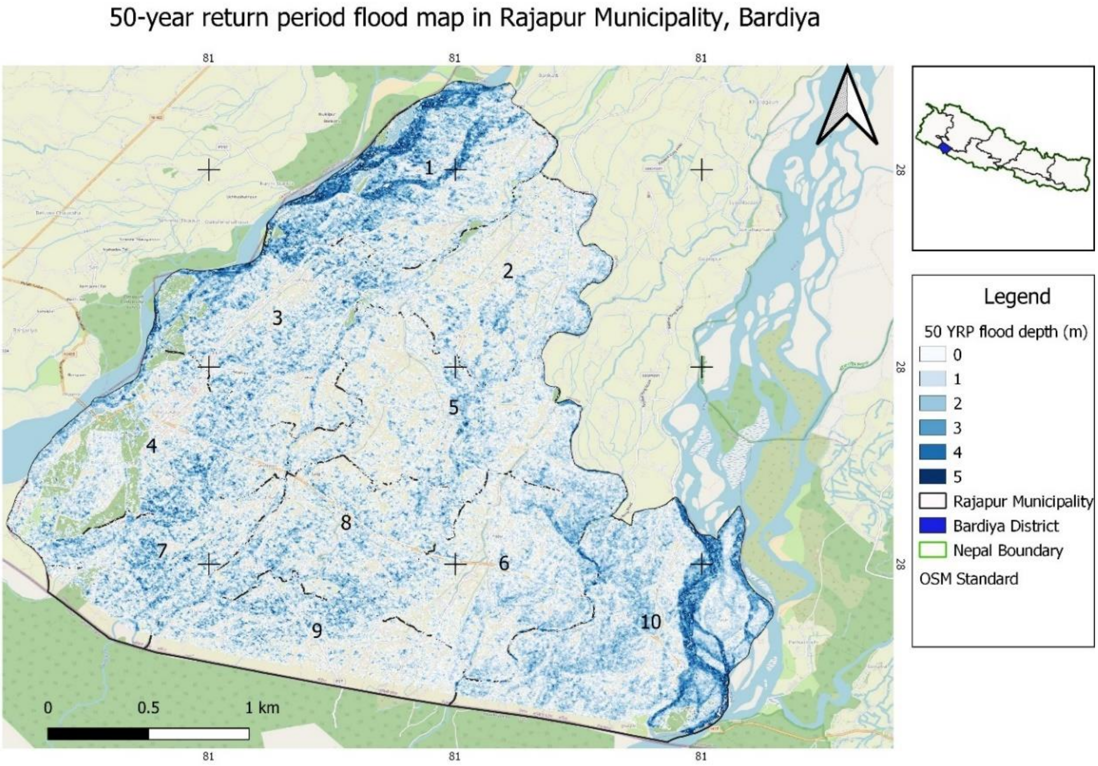


Figure4.10: 50 YRP flood hazard map

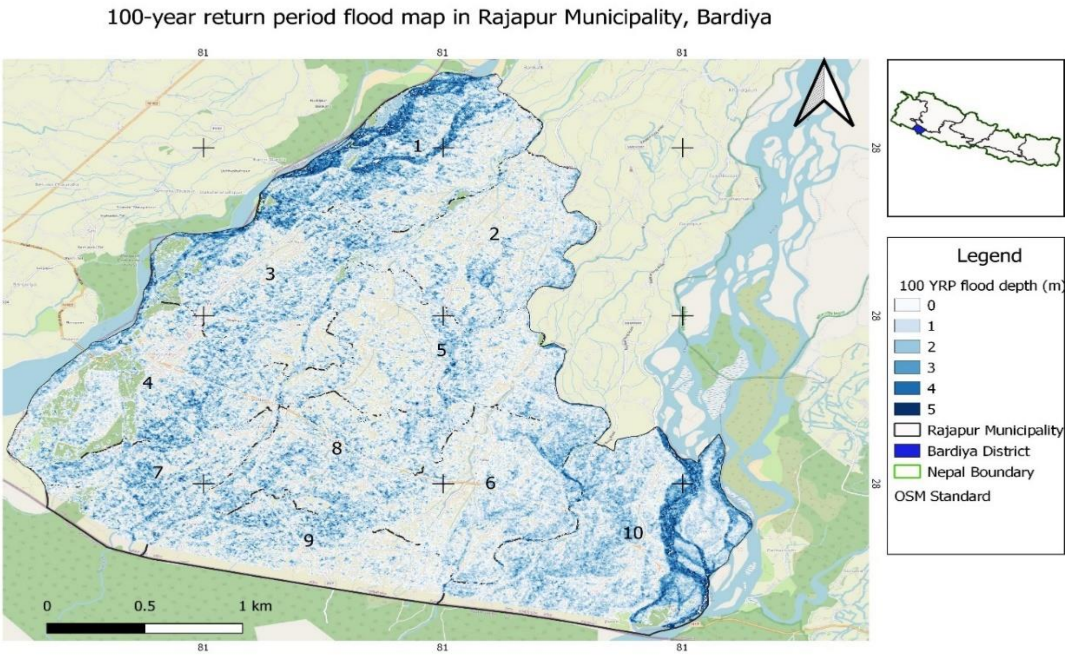


Figure 4.11: 100 YRP flood hazard map

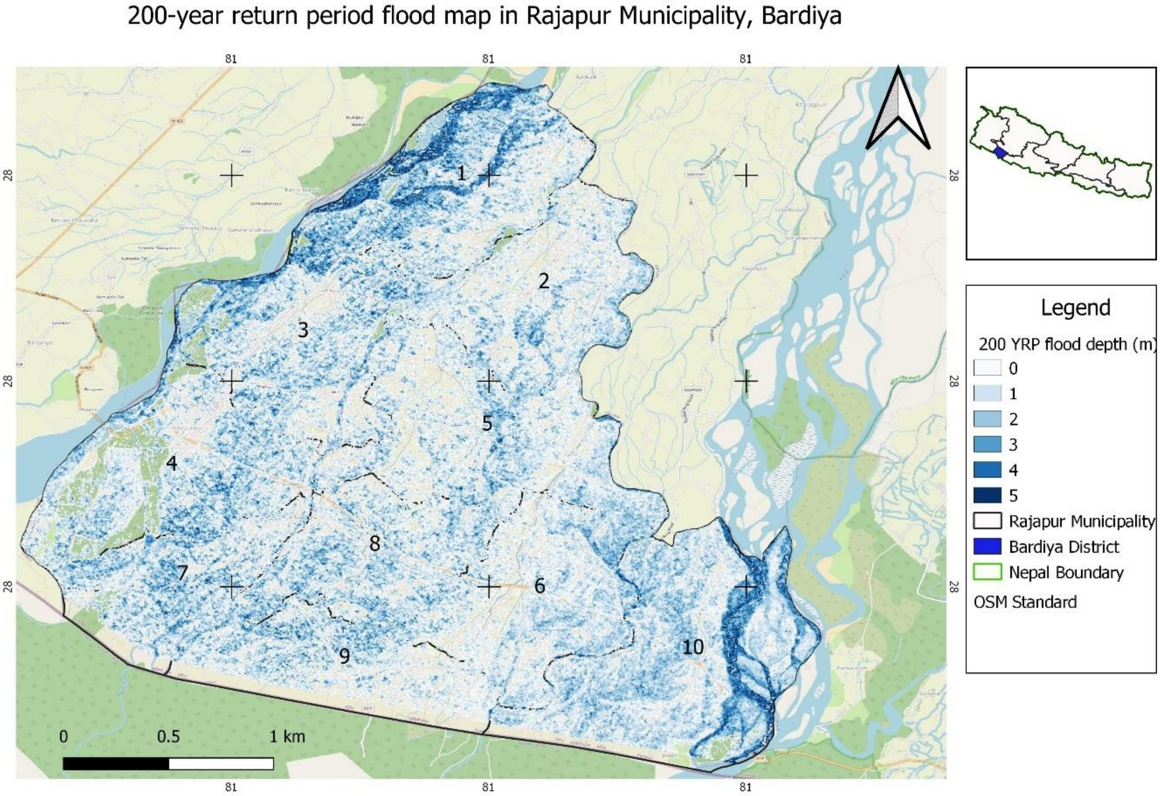


Figure 4.12: 200 YRP flood hazard map

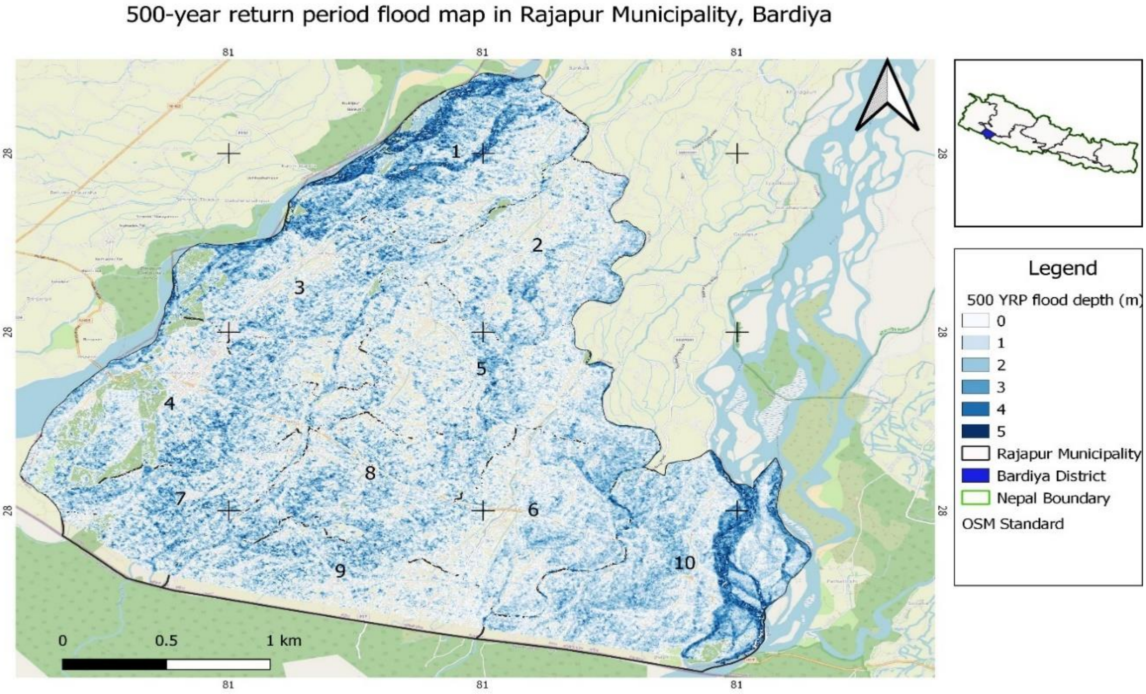


Figure 4.13: 500 YRP flood hazard map

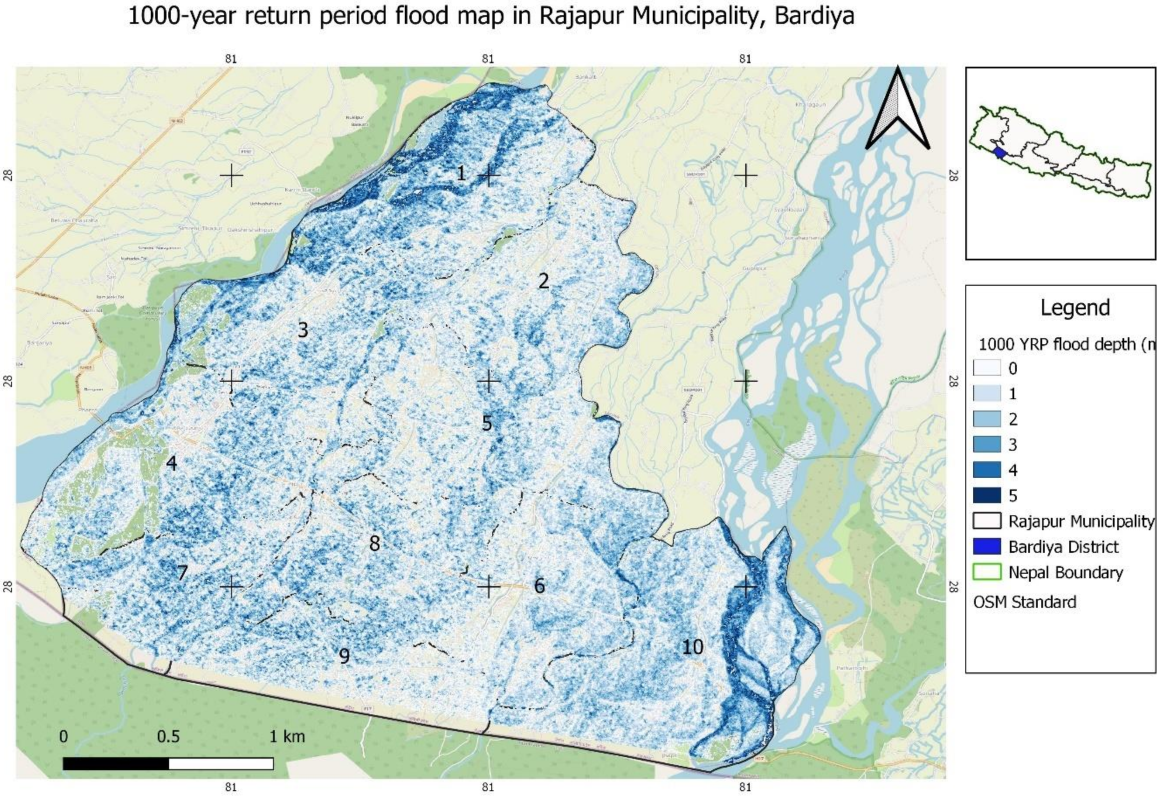

1000-year return period flood map in Rajapur Municipality, Bardiya

Figure 4.14: 1000 YRP flood hazard map

4.2 Discussion

Hydrological models driven by climate simulations predict an overall increase of river discharge over KRB. Future projection shows that the annual precipitation amount will increase compared to the baseline so does the river discharge [35]. The melting of snow and ice on Tamor River Basin, however, adds to an increase in river flows from December to March [69]. The primary river basins depicted indicate a steady increase in average temperatures and rainfall at a rate of 0.6 ºC and 65 millimeters per decade, respectively. This phenomenon has resulted in escalated melting of glaciers, leading to floods and extended periods of drought. By the year 2050, it is projected that around 60 million people may face water scarcity in the eastern and central Himalayas. Notably, the Langtang basin experienced a significant decline in glacier coverage, with a reduction of 26% between 1977 and 2009, as documented by [68] The use of appropriate hydrological models with real-time satellite rainfall estimates can help mitigate flood damage, provide support to contingency planning, and provide warning to people threatened by floods [51]. HEC-RAS model can estimate the water level and flood-affected areas for major hydrological events with a high degree of precision while requiring only a little amount of input data. This Model is a helpful too in the construction of safety and management during extreme flooding disasters [73]. In various return periods, maps reveal that wards 1, 3, 4, 7, 9, and 10, situated along the Karnali and Geruwa Rivers, experience significant inundation. According to Chinnal 2023 shows that the community of Rajapur Municipality's Wards 1, 3, 4, and 7 can become submerged even in a typical flood of 1 m, according to the spatial flooding scenario that was simulated, presenting a hazard to the population.

Overall, these results contribute to a better understanding of the hydrological dynamics, future water availability, and flood risk assessment in the Karnali basin, specifically focusing on the Rajapur municipality.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this study, a highly calibrated and verified HEC-HMS hydrological model was created for the Karnali River Basin in Western Nepal. Future precipitation projections were incorporated into the HEC-HMS model, which had been carefully calibrated and validated, to simulate discharge. This discharge data was then used as input for the HEC-RAS model to generate a flood inundation map for Rajapur Municipality in Bardiya District. The study demonstrates a strong correlation between HEC-HMS and HEC-RAS, indicating their reliability in assessing flood risks and accurately forecasting future floods in the study area. The findings recommend regular maintenance of the riverbed, including the removal of sediment transported from the basin's valleys, as well as clearing bushes, herbs, and weeds that often accumulate along the river's bottom and banks. This maintenance is crucial for ensuring maximum water flow capacity during periods of increased river flow, especially during the wet seasons.

Furthermore, the study suggests the construction of dirt barriers along the riverbanks to prevent water from Inundating agricultural land and residential structures. It is also advised not to reside near the riverbed and encourage land development in higher, flood-safe areas. These measures underscore the importance of utilizing projected data for flood analysis and provide the necessary background for the development of an emergency response strategy for flood management. The analysis of the results reveals that villages located closer to the river's mouth experience more significant flood impacts compared to villages further downstream. This highlights the importance of flood mitigation efforts and emergency preparedness in vulnerable areas.

5.2 Recommendation

- Improving data collection efforts is essential for providing comprehensive and accurate input parameters to climate models, thereby increasing the precision of flood predictions.

- Integrating local knowledge and expertise into the modeling process can enhance the prediction reliability, benefitting from the community's valuable input.

- Employing various modeling methods including multiple climate models with varying assumptions, helps quantify uncertainties and provides a range of potential flood scenarios, enabling decision-makers to better understand and plan.

- Recognizing the limitations and uncertainties in flood prediction models, adopting flexible flood management strategies, resilient infrastructure, and community-based initiatives is essential for effective preparedness and response.

- Involving local communities, government agencies, and relevant stakeholders in the flood prediction and planning process ensures local knowledge, priorities, and concerns are considered, leading to more effective flood mitigation strategies and decision-making.

CHAPTER 6

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