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

Flood Hazard Mapping and Risk Evaluation using HEC- RAS Modelling and Geospatial Tools in Lower Karnali River of Nepal

A Dissertation Submitted to

SCHOOL OF ENVIRONMENTAL SCIENCE AND MANAGEMENT

Institute of Science and Technology

Pokhara University

Balkumari, Kathmandu, Nepal

Submitted By

Laxmi Chhinal

P.U. Registration No.: 2020-1-25-0014

February, 2023

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P.U. Exam Roll No.: 20250040

February, 2023

DECLARATION

I, hereby, declare that the work presented in this dissertation is genuine work done originally by me and has not been submitted anywhere for the award of any degree. All the sources of information have been specifically acknowledged with reference to the author(s) or institution(s).

………………….

Laxmi Chhinal

20th January 2023

LETTER OF RECOMMENDATION

This is to certify that **Ms. Laxmi Chhinal** has conducted this dissertation work entitled "**Flood Hazard Mapping and Risk Evaluation using HEC-RAS Modelling and Geospatial Tools in Lower Karnali River of Nepal**" as partial fulfillment of the requirement for M.Sc. in Environmental Science under my supervision and guidance. To my knowledge, this research has not been submitted for any other degree, anywhere else.

I, therefore, recommend the dissertation for acceptance and approval.

………………………

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Sudeep Thakuri, Ph.D.

Associate Professor

Tribhuvan University

CERTIFICATE

This is to certify that the thesis entitled "**Flood Hazard Mapping and Risk Evaluation using HEC-RAS Modelling and Geospatial Tools in Lower Karnali River of Nepal"** submitted by Laxmi Chhinal towards partial fulfilment of Degree of Master of in Environmental Science and Management is based in original research and study under the supervision of Assoc. Prof. Dr. Sudeep Thakuri. The thesis is part of full property of **School of Environmental Science and Management (SchEMS)** and thereof should not be used for the purpose of awarding any academic degree in any other institution.

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LETTER OF APPROVAL

This dissertation paper submitted by Miss Laxmi Chhinal entitled "**Flood Hazard Mapping and Risk Evaluation Using HEC-RAS Modelling and Geospatial Tool in Lower Karnali River**" has been accepted for the partial fulfillment of Master of Science in Environmental Management from Pokhara University.

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February 2023

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ABSTRACT

Flooding is one of the major natural hazards in Nepal, and most of the Terai region are flood prone areas. Among them Rajapur Municipality of Bardiya district is one of the highly flood risk areas. With the help of the HEC-RAS (Hydrologic Engineering Center's River Analysis System), this research gives thorough hazard mapping and risk assessments in the downstream zone of the Karnali River Basin which is Rajapur Municipality for various return-period floods. The Karnali River was assessed throughout a ~38 km section from Chisapani to Nepal-India border. To perform hydrodynamic simulations, a time series of monthly discharge records from the Chisapani gauging station was used. Flooding conditions representing, 5-, 10-, 50-, 100-, and 200-year return periods (YRPs) were determined using Gumbel's distribution with the highest daily average discharge of up 22,422 m^3/s in 200 YRP. The area vulnerable to flooding in the study was carried out by household survey using (VRA) framework in Wards - 1, 3, 4, and 7 of the Municipality and risk maps were established using ArcGIS and HEC-RAS model. Flooding in agricultural land poses a high risk to food security, which directly impacts on residents' livelihoods. Additionally, even after a five-year return period, the 2014 simulated flood (equal to a 100-YRP) had a significant impact on each ward and make them at high risk. In conclusion, this study can support in decision-making for better community settlement and the creation of flood control measures in Rajpur Municipality of the Bardiya district in the future.

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ACRONYMS

KRB	Karnali River Basin
YRP	Year Return Period
QGIS	Quantum Geographic Information
HEC-RAS	Hydrologic Engineering Centre’s River Analysis Sy
IPCC	Intergovernmental Panel on Climate Change
CC	Climate Change
DHM	Department of Hydrology and Meteorology
LULC	Land Use Land Cover
UTM	Universal Transverse Mercator
DEM	Digital Elevation Model
NAP	National Adaptation Plan
VRA	Vulnerability Risk Assessment

CHAPTER I: INTRODUCTION

1.1 Background

Flood, one of the striking water-induced hazards, is one of the serious disasters in Nepal that affect the human lives and huge amount of property. They are particularly prone to flood damage because of the strain from the growing population and squatter colonies of landless people living along the riverbank [1]. Climate change's effects are evident everywhere, including Nepal. Traditional and indigenous knowledge on climate and plant relationships has become less reliable as a result of changes in weather patterns that have made them less predictable, weather events that are typical of one season occurring in another, an increase in extreme events, and changes in the behavior of important crops [2]. Rainfall patterns have changed, summers are hotter, and winters are icier. In Nepal, the maximum air temperature increased by +0.045 °C more than the minimum temperature (+0.009 °C) on average between 1976 and 2015 [3]. The IPCC 6th assessment explains that the increase in global surface temperature is 1.09 (0.95 to 1.20) °C in 2011–2020 above 1850–1900. There is at least a greater than 50% likelihood that global warming will reach or exceed 1.5°C in the near-term, even for the very low greenhouse gas emissions scenario[4]. Flash floods and landslides have risen in frequency because of more frequent monsoon rain. Due to this, there are now many distinct sorts of disasters, with water-related disasters being the most common. Variations in solar energy, temperature, and precipitation are a result of climate change, which is a phenomenon caused by emissions of greenhouse gases from fuel burning, deforestation, urbanization, and industrialization [5]. The scientific community predicts that climate change will alter the world's hydrological cycle and increase the frequency of extreme weather events [6]. Increasing frequency of flooding, storms, and other climate-related disasters has a direct impact on the welfare of the poor and vulnerable, causing physical resources like shelter and infrastructure to be damaged. Such climate-related extremes influence ecosystems, disrupt food production systems and water supplies, wreak havoc on towns and infrastructure, increase morbidity and death rates, and have negative effects on human well-being. Climate-related risks and hazards affect people, settlements, various types of infrastructure, natural resources, and cultural places [7]. In the risk-hazard method, vulnerability is evaluated in terms of the losses or consequences that could follow from the occurrence of a specific external hazard on vulnerable persons and property [8].

Flooding events are common at the lower region (Terai) of Nepal in summer monsoon months (June-August). The intense rainfall causes flood as it gives rise to major rivers of Nepal. These floods generally rise slowly in the Southern Terai Plains. Inundation caused by overflowing of riverbanks causes extensive damages in the various regions of Terai. Due to the climate change, flood frequency has also changed so it is necessary to analyze the flood hazard and risk of flood in the vulnerable areas.

One of the most significant floods to have hit Nepal was in 1993. It left hundreds of people homeless, caused extensive property damage, and crop destruction on thousands of hectares of land. This flood had an impact on 45 districts across the nation. Other significant floods in Nepal include those in the Tinau River Basin in 1978 and the Koshi River in 1980. Additionally, the flood of 1987 in the Sunkoshi Basin inundated the central and eastern Terai [9]. Since barrages and embankments created in India interfere with natural drainage and cause water logging, many communities in the Terai region flood every year. About 27 border localities have been flooded as a result of the embankments built along the Bagmati, Karnali, and West Rapti Rivers near to the border, which have restricted river flow [10]. Nationwide, there are more than 6,000 rivers and rivulets. The Koshi, Narayani, Karnali, and Mahalaki are regarded as some of these rivers' principal rivers. They come from the Himalayas, flow through the Terai plains after descending from the slopes. These rivers rise during the monsoon, which is about from June to September, and harm the areas inside their flood plains. Flooding primarily causes severe damage in the districts of Baglung, Banke, Rautahat, Bardiya, and Sindhuli. The two types of floods in Nepal are as follows: both rivers and flash floods [9].

The Karnali River lies between the mountain ranges of Dhaulagiri and Nanda Devi, in the western part of Nepal. The basin extends from 28.2–30.4° N and 80.6–83.7° E, covering a total area of 45,269 km^2 [11] and yielding an average annual discharge of 1441 m^3/s. The Karnali River has experienced floods in 1963, 1983, 2008, 2013, and 2014, which resulted in multiple fatalities and extensive infrastructure damage. The 2014 flood was one of the worst in the Karnali River's history, even affecting relatively safe areas. On August 15, 2014, at around midnight, the water level crossed the danger level mark, and floodwaters inundated all the villages downstream, killing 220 people and severely affecting 120,000 more [12].

The floods have been modeled using HEC-RAS, which has also been used to pinpoint flood-prone locations. A graphical user interface (GUI), independent hydraulic analytic components, data storage and administration capabilities, visuals, and reporting tools are all included in the integrated software system known as HEC-RAS. It is intended for interactive use in a multiuser, multi-tasking network environment, and it can currently calculate 2D water surface profiles for steady, gradual, and variable flow in channels that are either natural or artificial [13].

Risk is sometimes expressed as the likelihood that dangerous events or trends will occur, multiplied by the consequences if these events or trends happen. The interaction of vulnerability, exposure, and hazard leads to risk. The assistance provided by all these evaluation components will help identify medium- and long-term adaption solutions. Sector-specific and founded on experience, including expert judgment, the proposed indicators for Nepal's VRA formulation process. The indicators primarily represent quantifiable components that aid in determining and classifying risks, exposure, sensitivity, and capacity for adaptation [7].

1.2 Statement of Problem

Rajapur is highly vulnerable area due to the heavy rainfall and long-term flood during the monsoon and pre-monsoon time. People of Rajapur specially people from Wards - 1, 3, 4, and 7 are facing the flooding and inundation problems from long time ago. Many studies have been done for the proper management of flood but still the problem is same, therefore this flood modelling in Rajapur in Wards - 1, 3, 4, and 7 may help in the further planning of river restoration to mitigate the loss and damage during flood.

1.3 Rationale of Study

All facets of managing floodplains can be informed at a reasonable cost by flood modelling.
The precision and accuracy of the flood modeling that forms the basis of flood mitigation assessments, land use planning restrictions, infrastructure design, and even flood insurance classifications all have a direct bearing on these issues. Another region that is particularly vulnerable to flooding is Rajapur. Two streams of the Karnali River, the biggest river in Nepal, encircle Rajapur [14]. Karnali may discharge 21,000 m^3/s during the monsoon season, which is roughly a hundred times greater than during the dry season [14]. The inhabitants of Rajapur face significant climate hazards since they are exposed to catastrophic flooding and are at danger of flooding in general. Every year, floods cause a significant amount of harm and loss to residents' lives and property.
The pre-monsoon rainfall also has been damaging many properties and crops as well as many lives of people in Rajapur. Therefore, it is mandatory to understand the flood risk, vulnerabilities, and adaptive capacities to develop appropriate coping and adaptation strategies.

Assessments of vulnerability carried out holistically, can provide an important guide to the planning process and to make decisions on resource allocation at various levels, and can help to raise public awareness of risks. The assessment of risk will provide a basis for envisioning future risk of flood due to climate change as well as identifying viable options to build resilience and adaptive capacity as well as the control of loss and damages. Hence this study includes hydrodynamic modelling and risk evaluation which is an efficient way to predict flood frequency and obtain flood information for emergency response planning and evaluation degree of risk posed to the local community.

1.4 Objective

The main objective of the study is flood hazard mapping and risk evaluation using HEC-RAS modelling and Geospatial tool. To address the main objective, the study will have the following specific objectives:

- To prepare the flood hazard maps of different return period of Lower Karnali River
- To evaluate the risk of community and infrastructure in the region.

1.5. Limitation of the study

The study covers only some specific areas of Rajapur Municipality of Bardiya district of the Karnali River Basin (KRB). The indicators of the study may vary and cannot comply with other studies, as they depend on the scale and community characteristics.

- The flood model was validated only for two points in river stretch of nearly 38 km. This can lead to some uncertainty in flood water depth and flood extend. More measured data for calibration and validation would help to reduce model uncertainty.
- Water infiltration into groundwater is ignored in hydrodynamic flood model. This will increase the surface runoff. Including infiltration parameter requires detail study of soil parameters which was out of scope of this research.
- Unavailability of LULC of 5 m resolution causes the difficulty to run the model in DEM of 5 m resolution.

CHAPTER II: LITERATURE REVIEW

2.1 Hazard

Hazard is defined as the potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources [4].

According to the USGS, the flood can be defined as “an overflow or inundation that comes from a river or another body of water and caused or threatens damage, any relatively high stream flow overtopping the natural or artificial banks in any reach of a stream. Flood is a period of high discharge of a heavy precipitation which is one of the major striking water induced disaster in the world [15].

2.2 Flood Risk

Flood risk is a complex interaction of hydrology and hydraulics of the flow with the potential of damage to the surrounding floodplains. The element of risk has both the spatial and the temporal domain and is also, function of the level of human intervention of the surrounding floodplains.

Flood risk assessment is a clear understanding of the causes of potential disaster. It is a combination of natural hazard of flood and vulnerability of the element at risk. Where element mean, people and their lives, properties, social connections [16].

Understanding, evaluating, and forecasting flood events and their effects have been ongoing goals throughout human history. Therefore, flood inundation models are created to accomplish this. The creation and use of flood inundation models, as well as related research, have become an international undertaking since flooding makes up a sizeable portion of all reported natural catastrophes that occur worldwide, and over the past 30 years, this proportion has been rising [17].

Evidence of climate change in Nepal points to rising temperatures and altered precipitation patterns. Extremely hot and cold days, consecutive wet and dry days, extreme weather variability, and climate-induced hazards such floods, landslides, crop inundation, drought, and hailstorms are the main hazards and climatic extreme events that have an impact on agriculture and food security [7].

There are multiple social, economic, cultural, and political repercussions of the climate events on agriculture. Droughts, landslides, and floods are all projected to continue to increase in frequency [18].

The intense rainfall causes flood as it gives rise to major rivers of Nepal [9]. One of the most significant floods to have hit Nepal was in 1993. It left hundreds of people homeless, caused extensive property damage, and crop destruction on thousands of hectares of land. This flood had an impact on 45 districts across the nation. Like the 1978 flood in the Tinaue Basin, the 1980 flood along the Koshi River was another significant flood in Nepal. Additionally, the flood of 1987 in the Sunkoshi Basin inundated the central and eastern Terai [9].

The rapid influence of human activities has led to an increase in the intensity of flood disasters. The subject of flood vulnerability is very important and has a wide range of dimensions. Since the extent of destructions vary over time and geography, assessing food vulnerability assumes greater important [19].

Extreme rainfall combined with urbanization is the main cause of floods in Nepal's urban areas. However, the problem of urban flooding was brought to attention when Kathmandu was inundated in 2002, resulting in a total of 27 fatalities. Most of the rivers were flooded, resulting in significant property loss. The narrowing of the river channel for the human habitation was the main contributor to the flooding [1].

Large destruction and heavy floods were observed at Banke-Bardiya districts (Western Terai) of Nepal on June 16, 2016 and August 13, 2017 [20].

The hydro-meteorological report of Kushum station (Rapti River) was obtained from DHM, which shows an average discharge as of 2870 m^3/s with a yearly minimum 1550 m^3/s to maximum 4860 m^3/s. At Chepang station (Babai River), mean discharge value was found as 1695 m^3/s with a yearly minimum 787 m^3/s to maximum 3870 m^3/s. Severe flooding damages were observed with the extreme rainfall on June 15–16, 2016 and August 12–13, 2017 over the study area [21].

Every year, the Terai region floods because of the barrage and embankment that India built. About 27 border localities have been flooded as a result of the embankments that have been built along the Bagmati, Karnali, and West Rapti Rivers close to the border [10].

The application goal of flood modeling typically necessitates contextual attention to the output variables of predictive importance and their time and space scales, the needed level of accuracy, and computing efficiency requirements. Applications may need to consider quick run times and real-time data assimilation for flood predictions. The precision of supercritical flow depiction that may be provided by a numerical model that simulates fluid dynamics is crucial for flood risk assessments in metropolitan settings. For dam building, flood damage assessment, or erosion studies, velocity should be properly simulated and reported, although maximum flood extent and water depth may be adequate for hazard mapping, environmental flow evaluation, and water resource planning. Due to all of these factors, end users must carefully choose a model that balances their needs [17].

Historically, Bardiya has experienced regular flooding because of the wide network of Karnali River branches in the area. Due to the frequent flooding in the Rajapur district of Bardiya, people have a terrible time getting by. They deal with the loss of life as well as their property, especially their arable land, every year [5].

To assess the flood risk in District 8 in Ho Chi Minh City, Vietnam, hydrological modeling tools based on geographic information systems and remote sensing techniques were combined. According to the author, District 8's whole area was subject to flooding due to precipitation in about 60% of cases, and tides also caused flooding in about 60% of cases. Flooding brought on the tides was far worse than flooding brought on by rain. The reasons of flood danger in this area are increasing urbanization, increasing impervious surface, and shrinking length areas [22].

The research Published by [23] with main objective to integrate flood simulation model, remotely sensed data with topographic and socio-economic data in GIS environment for flood risk mapping in the flood plain of Kakani River in Nepal. Gumbel's method for flood frequency analysis, HEC-RAS etc, have been used to process the data. Data were collected through maps, aerial photographs, imagery DHM, field survey and discussions and from published and unpublished document. The author found that total 59.3 km^2 and 59.8 km^2 of the study area will be under flooding in a 25 YRP flood and 50 YRP flood respectively. Agriculture system is in more vulnerable position and according to level of hazard, high hazard area will be increased, and more settlement will be under the high hazard zone. The hazard prone area will be considerably increased from 25 YRP flood to 50 YRP floods. Vulnerability assessment regarding flooding and climate change depicted that people's livelihood are worsening each year.

CHAPTER III: MATERIALS AND METHODS

3.1 Study Area

Bardiya lies in Lumbini Province in midwestern Nepal. Bardiya District is in the Terai region of Bheri zone. The district covers an area of 2,025 km2 and according to the Central Bureau of Statistic CBS 2021, the total population of Bardiya is 61431 out of which 32265 are female and 29166 are male. Most of Bardiya is in the fertile Terai plains, covered with agricultural land and forest. The northernmost part of the district extends into the Churiya or Siwalik hills and Bardiya National parks, covers 968 km^2 (374 sq mi) occupies most of the northern half of the district. This park is the largest undisturbed wilderness in Nepal's Terai. The district is split into two distinct sections: the mainland of Bardiya and the Rajapur Delta. Rajapur Delta is 37 kilometers west of Gulariya and has historically been and area of frequent flooding due to extensive network branches from the Karnali River. Rajapur area within Bardiya District is known for being pre-dominantly settled by Tharu people. It is said that most of the Tharus in this area are first or second generation migrates from Dang district of Nepal. Most people living in this district are farmers. The district headquarter Gulariya lies on the Babai River, The Karnali one of Nepal's largest rivers, divided into multiple branches when it reaches the Terai. Bardiya has historically been and area of frequent flooding due to extensive network branches from the Karnali River. People of Rajapur are living difficult life due the frequent flooding due to the heavy and continuous rainfall during the monsoon and pre-monsoon time.

This study covers the area of upstream Chisapani to the downstream Ward no.1,3,4,7 of the Rajapur. These wards are attached to the river basin of Karnali River hence highly vulnerable for flood.

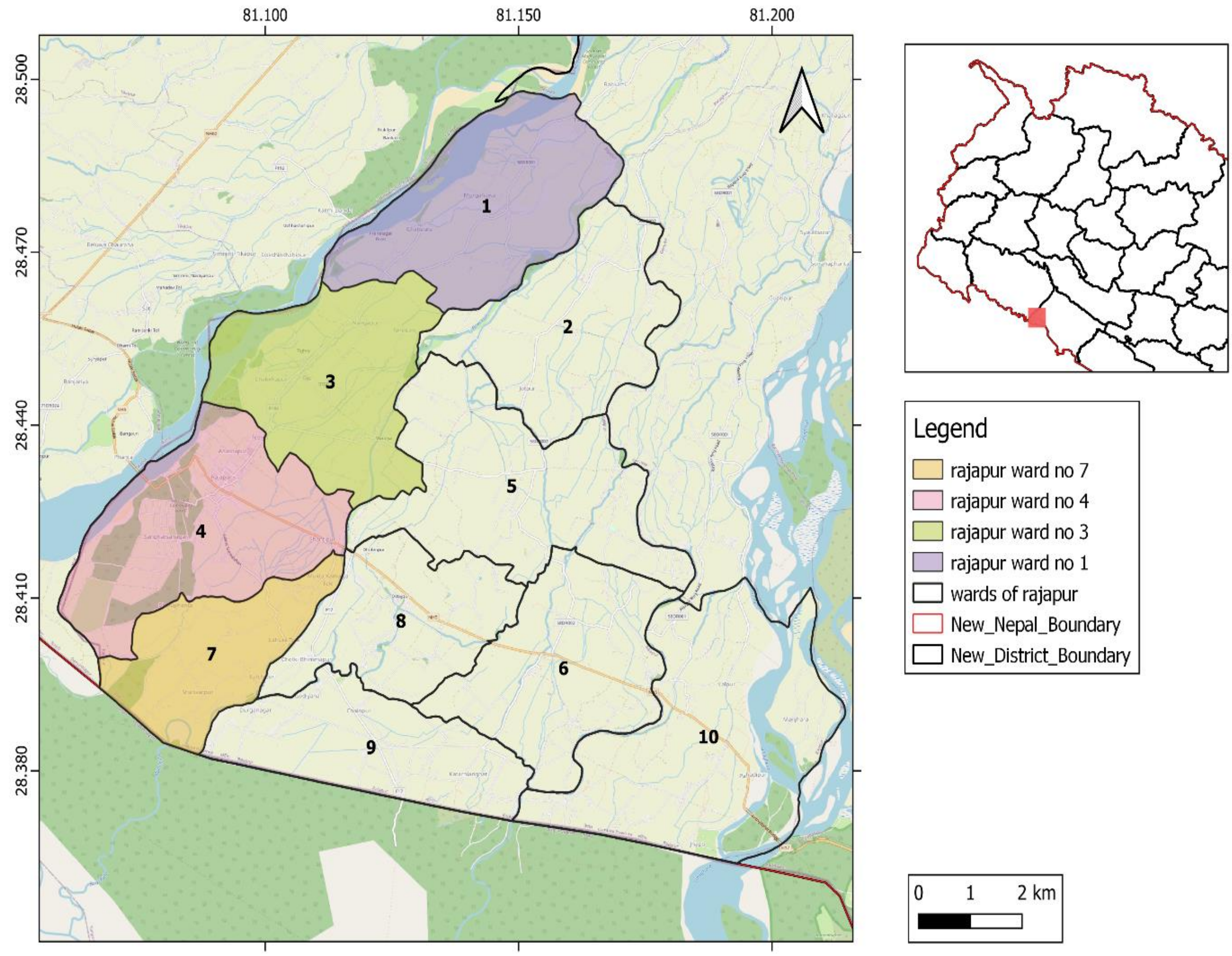

Figure 1: Map of Rajapur Municipality

3.1.1 Flood Event Trend

The figure shows the trend of flood events in Rajapur, Bardiya. In the period from 1992 to 2021, sixteen major flood events were observed, and the trend is increasing. However, minor flooding and inundation occur almost every year. The deadliest flood occurred in 2014 with a discharge rate of 17,900 m^3/s. Post-monsoon season floods occurred in 2009 and 2021, causing loss and damage in a variety of sectors, particularly paddy production.

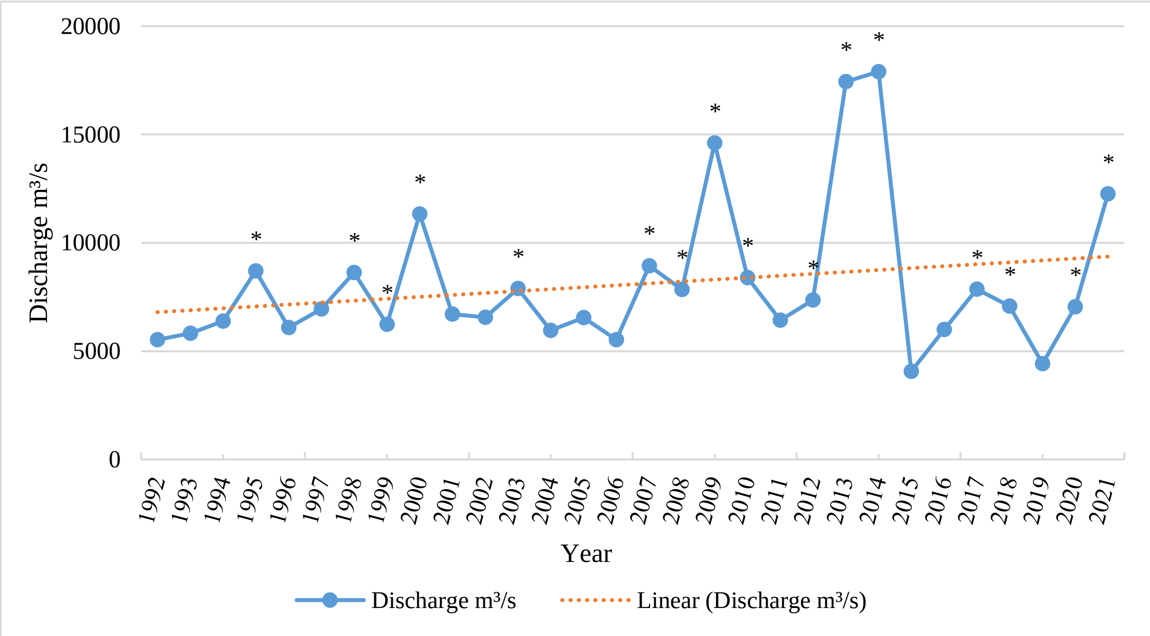

Figure 2: Flood event trend in Rajapur Municipality (*denotes the flood events in respective years).

3.2 Conceptual Framework of the Study

The conceptual framework explains about the working process of the thesis which describes about the objectives set with their appropriate methods which will be followed throughout the study period.

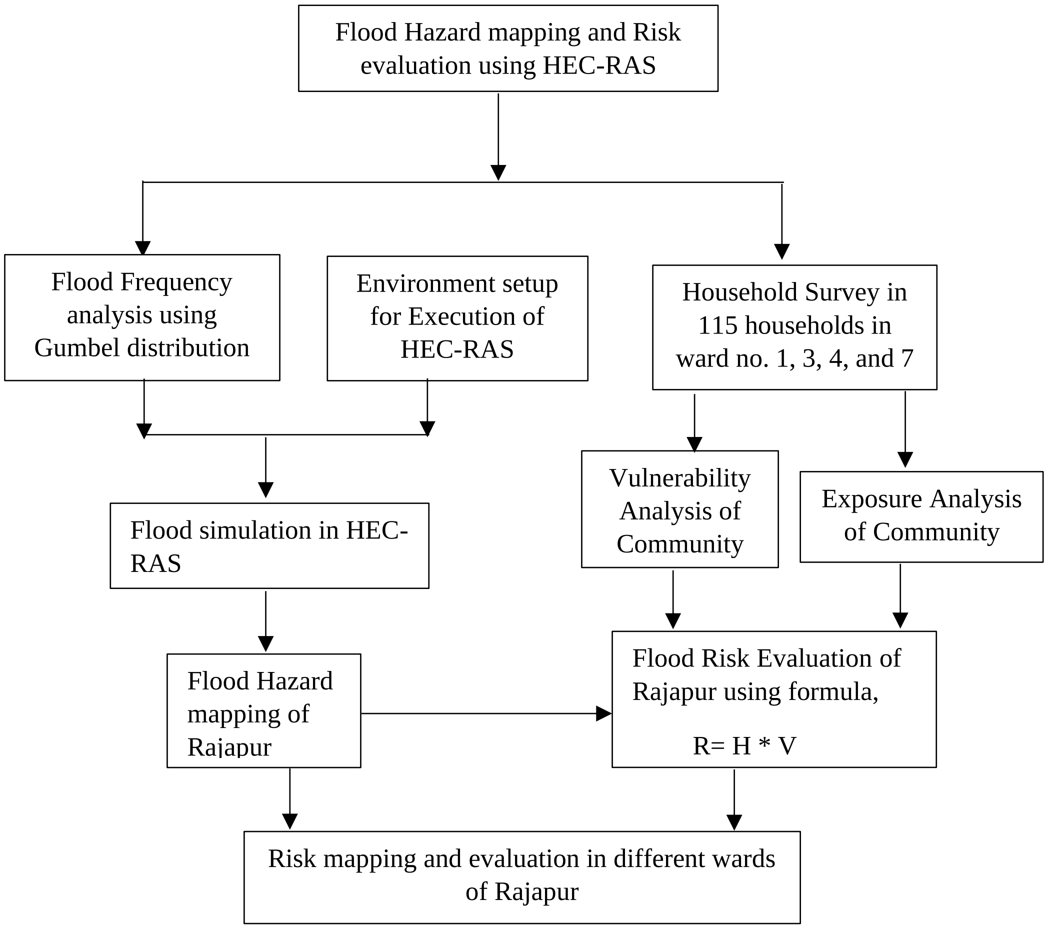

Figure 3: Conceptual Framework

3.3 Data collection

The mode of data collection throughout the project time periods is divided into primary and secondary. For the primary data collection, data of household survey, Key Informant Interview (KII), Focus Group Discussion (FGD), GPS Point, and discharge data of 30 years (1991-2021) from Department of Hydrology and Meteorology (DHM) was collected. Similarly, the secondary data is the DEM of 5 m resolution, some published literatures, river cross section and GPS coordinates of the project locations.

3.3.1 Primary Data Collection

Primary data collection was based on systematic and representative manner from household survey, KII, GPS point, FGD.

3.3.1.1 Household Survey

A representative sample of 110 households among 4,767 household on a random basis was surveyed in four (1, 3, 4, 7) wards of Rajapur Municipality. From Ward1, 26 household was taken and from the ward no.3, 25 household was taken similarly from the Ward. 4, 29 household and from Ward7, 17 household was taken. Both qualitative and quantitative information was collected with the help of the kobo toolbox. The household sample was determined by using the formula of sample size,

$$\text{Sample size, } n = \frac{\mathrm{NZ^2P(1-P)}}{\mathrm{Nd^2+Z^2P(1-P)}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ 1$$

3.3.1.2 Key Informant Interview

KII was done in each ward office (4 in total) by local government representatives and different organizations like Practical Action, CDS to document the changes in climate, adaptive practices, sensitivity, and exposure of the wards of respective municipalities.

3.3.1.3 Focus Group Discussion

FGD was done by gathering the local leaders called Barghar, member from local organizations like KMJS, from each ward and the information was collected about the flood effected people and loss and damages that the people are facing every year due to the flood and climate change.

3.3.2 Secondary Data Collection

In this study, discharge data of 30 years (1991- 2021) was collected from the Department of Hydrology and Meteorology (DHM) Chisapani. Discharge data was recorded in Chisapani gauge station. Also, the secondary data for flood mapping such as Digital Elevation Model (DEM) and used DEM was ALOS World 3D of 5m resolution. GIS-data – (from survey department) is the updated Municipal boundary, Road Network, River Network, building footprint. Similarly Land used map was obtained from International Centre for Integrated Mountain Development (ICIMOD) website. Number of Household information was obtained from the LDCR of Rajapur Municipality, the cross sections along the river channel created by HEC-RAS, and other required information were collected from different secondary source and published literatures.

3.4 Data Analysis and Interpretation Tools

In this study, both qualitative and quantitative data were used. Prepared data were analyzed with the help of MS Excel and MS Word. The results were presented in simple charts, tables, and bar diagrams. Besides, tools such as HEC-RAS, QGIS, ArcGIS, Google earth, Google satellite and open street maps were also used for flood modelling, creation of maps, charts, and tables.

3.5 Methods and Application procedure for Flood mapping

The specific data used for flood mapping are DEM, cross-section point of river, flow path, GPS point, Google satellite image etc.

3.5.1 Watershed Delineation and catchment Area Calculation

Watershed is the natural system where flows across or through from a common outlet way to any stream, river, or lake. For flood hazard mapping, it is important to delineate the watershed boundary for areas, symbolizing the main boundary with contributory river network of the main channel of the river. The general process of watershed area delineation in GIS environment is as follow:

DEM generation > Fill > Flow direction > Flow accumulation > Snap pout Point > Watershed and area calculation

3.5.2 Hydrological Analysis

Comparative maximum annual flood discharge for different return period (5, 10, 20, 50, 100, 200, 500, 1000 years) respectively was calculated using Gumbel's distribution method of lower Karnali River Basin. The daily average discharge data of 30 years (1991- 2021) was collected from the Chispani gauge station.

Gumbel's distribution is a statistical method often used for predicting extreme hydrological events such as floods [24].

The equation for Gumbel's distribution as well as to the procedure with a return period T is given as,

$$X_T = X + K.\sigma x \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where,

σx = Standard deviation of the Sample Size

K = Frequency Factor, which is expressed as, K = $Y_T - Y_n / S_n$

In which, Y_T = Reduced Variate, $Y_T = -[\text{Ln. Ln. } (T/T-1)]$

The values of Y_n and Sn are selected from Gumbel's Extreme Value Distribution considered depending on the sample size.

3.5.3 Selection of Model Tools

In this study, HEC-RAS version 6.2 was used to calculate water surface profiles and QGIS version 3.22.9 was used for the GIS data processing. These software tools HEC-RAS and QGIS were used in this research mainly because of the free availability of the systems and most used and recommended package for data processing.

3.5.4 Methodology flow chart for HEC-RAS mapping

The approach used for flood plain analysis and risk assessment using one dimensional model, HEC-Ras and QGIS is depicted in the flow chart below.

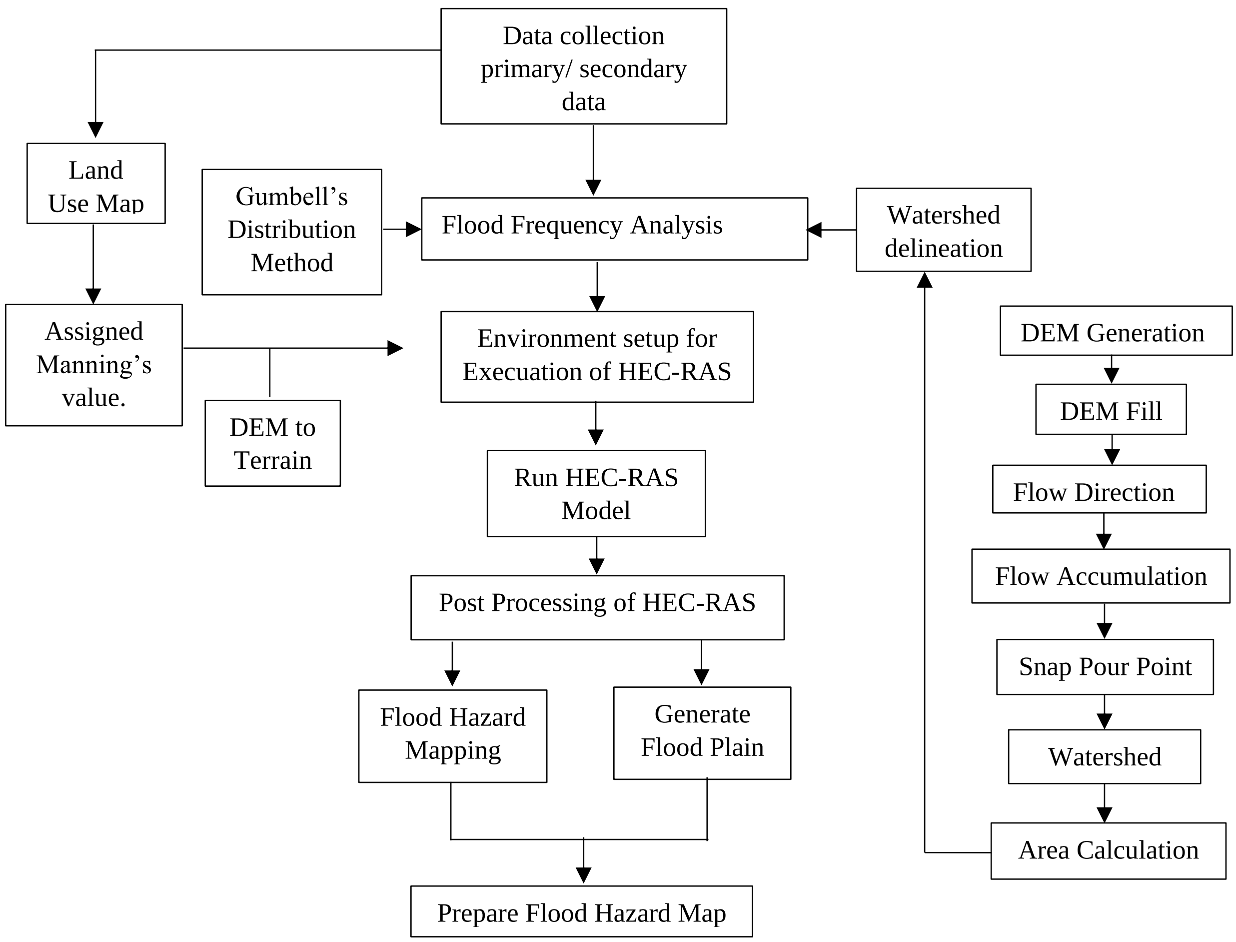

Figure 4: Flood hazard mapping

3.5.5 Land Use/Land Cover Map

The Land use/ Land Cover map was collected from ICIMOD Nepal website.

3.5.6 HEC-RAS Application

2D flood model HEC RAS was used for calculation of Two-dimensional water surface elevations/profiles for flood level prediction for different return periods. Streamlines is generated from the DEM using QGIS. This streamline is given as one of the inputs to the 2D model HEC RAS. Frequency analysis was carried out on the peak annual discharge data at the upstream from Chisapani Gauge station. The values obtained from Gumbell distribution was chosen as the hydraulic parameter for input to HEC RAS. The land use map was utilized for assigning Manning's roughness coefficient values to the model input. HEC-RAS hydraulic reference manual for different land use types within the study area. Geometric data editing was carried out in HEC RAS to fit the surveyed cross sections to the model. The frequency analysis of the 30 years discharges at the upstream and downstream gauge station.

Table 1: Manning Roughness Coefficients for Different Land use

LULC ID	Land cover	Manning's n value
1	Waterbodies	0.025
2	Forest	0.16
3	River bed	0.035
4	Built-up	0.15
5	Crop land	0.05
6	Grass land	0.05
7	Forest	0.16

3.5.6.1 Preprocessing of HEC-RAS

QGIS is used as pre-processing tool for the geographical data. Digital elevation model (DEM) of 5 m resolution is used. The DEM is filled, and river channels and catchment area are delineated. The necessary maps of Bardiya district, Rajapur Municipality and its wards are extracted as shapefiles using QGIS. The Land Use Land Cover (LULC) data of Nepal for year 2009 and 2014 is obtained from ICIMOD Regional Database System with resolution of 30 m resolution. The LULC data of the model area is clipped from the Nepal LULC data. All the extracted data in QGIS are exported to HEC RAS for flood simulation.

3.5.6.2 Postprocessing of HEC-RAS

Hazard maps and risk maps were prepared.

3.5.7 Model Calibration and Validation

The hydraulic simulations must include model calibration and validation. To confirm that the model would perform satisfactorily in future simulations, two separate stations were employed. The observed peak discharge and depth given in the Table 1 and Table 2 was obtained from the study done by [25].The model was calibrated using observed instantaneous peak discharge and water depth recorded at the Chisapani hydrological station and at Satighat observation station for 2009. The model was then validated with peak discharge and water depth at Chisapani hydrological station and Satighat observation station for 2014.

Table 2: Instantaneous Peak Discharge and Depth at Chisapani Hydrological Station [26].

Year	Peak Discharge (m^3/s)	Depth (m)
1983	21,700	15
2014	21,700	15.2
1975	16,000	13
2009	17,000	13.4

Table 3: Instantaneous peak discharge and water depth at Satighat discharge station [26].

Year	Peak Discharge (m^3/s)	Depth (m)
2009	17,000	2.3
2013	-	2.4
2014	21,700	2.6

The Hicks and Peacock equation [27], in Equation (3) below, was adopted to assess simulation performance based on the percentage difference between simulated and observed water levels during historical peak flood events in the downstream region of the Karnali River. A lower percentage error between the simulated (Swl) and observed (Owl) water level indicates a better performance of the model.

$$\%\ \text{error} = (Swl - Owl)/\ (Owl) * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (3)$$

Thus, the simulated 2014 flood water level, with a difference of only 1.3% between the observed (15.2 m) and simulated (15 m) water levels. A detailed comparison of the calibration and validation processes is illustrated in Figure 5 and Figure 6.

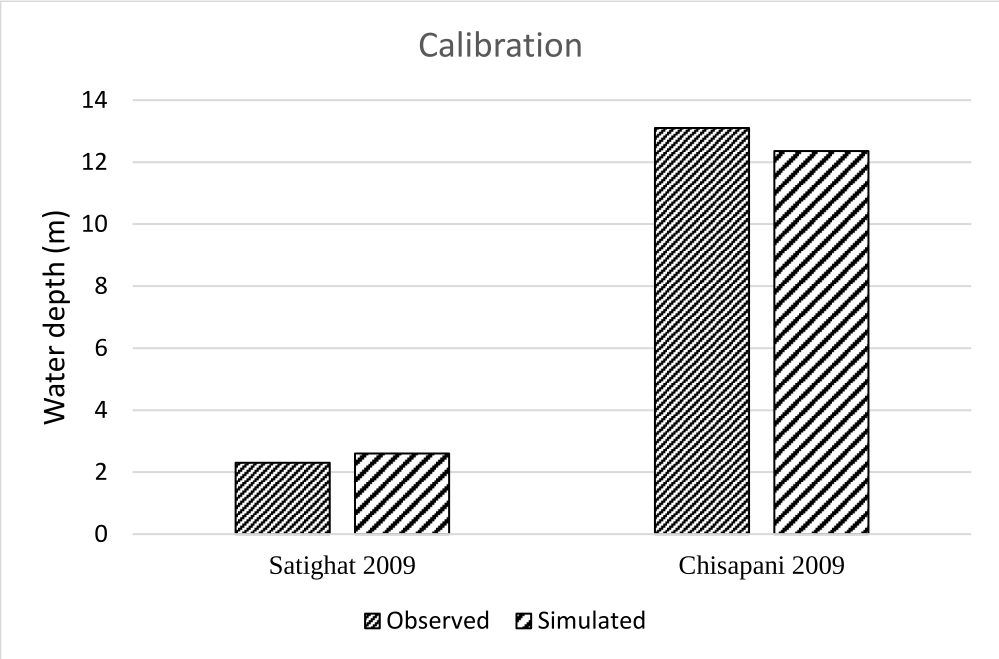

Figure 5: Comparison between observe and simulated water levels at Chisapani and field Observation site Satighat in river channel for flood events of 2009.

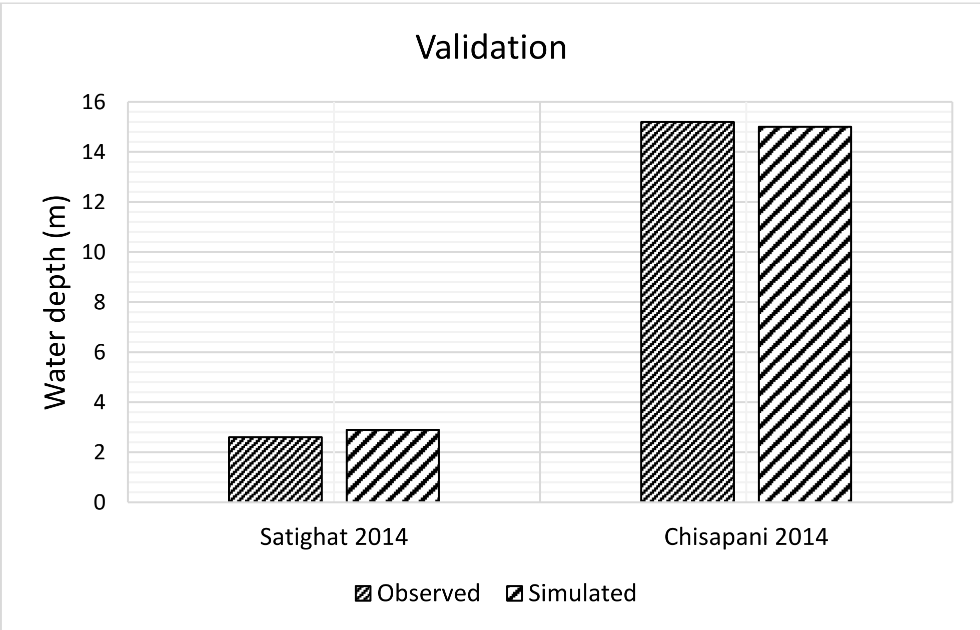

Figure 6: Comparison between observed and simulated water levels at Chisapani and field observation site Satighat in river channel for flood event of 2014.

3.5.8 Flood Risk Assessment

Risk is defined as the combination of the probability of an event and its negative consequences. The probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between natural or human-induced hazards and vulnerable conditions. The word "risk" has two distinctive connotations: in popular usage the emphasis is usually placed on the concept of chance or possibility, such as in "the risk of an accident"; whereas in technical settings the emphasis is usually placed on the consequences, in terms of "potential losses" for some cause, place and period. It can be noted that people do not necessarily share the same perceptions of the significance and underlying causes of different risks.

The risk assessment for climate change scenario applied in this study follows the research by [28] and is calculated by the product of Hazard assessment (H) and Vulnerability assessment (V) as shown below,

$$R = H * V$$

The results of hazard and analyses are combined for the flood risk assessment.

3.5.8.1 Flood Hazard Analysis

Flood hazard assessment involved the estimation of adverse effects of flooding in the study area. For that, the most important parameter of flood, such as flood depth, flood velocity was taken and overlaid by weight. The water depth and velocity were classified into five groups as per Likert Scale as shown in Table 4. After classification, the water depth is given 80 percent weightage and velocity is given 20 percent weightage and these two layers are overlaid by weightage to generate flood hazard index as map of the Rajapur Municipality. These parameters were simulated by using 2D hydrodynamic model (HEC-RAS). Daily average discharge in an upstream gauge was used as flow hydrograph in upstream boundary condition and normal depth (frictional slope) as downstream boundary condition. Here, flood hazard was mapped after reclassifying the flood depth and flood velocity into five classes as shown in Table 4. Therefore, effective land use planning and recommendations can be implemented in different wards of Rajapur municipalities with the help of soft measures used in this study.

Table 4: Classification of flood depth and velocity

Depth (m)	Classes	Velocity (m)
0-0.3	Very low	0-025
0.3-0.6	Low	0.25-0.5
0.6-0.9	Moderate	0.5-0.75
0.9-1.2	High	0.75-1
>1.2	Very high	>1

The flood depth classification shows that most of the inundated area of these wards has a water depth less than 1m.

3.5.8.2 Food Vulnerability Analysis

The IPCC (2007) definition of climate change vulnerability as a function of exposure, sensitivity, and adaptive capacity. Formula for vulnerability assessment applied is,

Vulnerability = Sensitivity * Exposure / Adaptive Capacity

For calculation of Vulnerability Household Survey was carried out in the Karnali River baseline area of Rajapur, Bardiya district specially in Wards - 1, 3, 4, and 7. For household survey VRA framework given by the NAP 2017 was applied where five appropriate indicators of sensitivity, Exposure and Adaptive Capacity was determined and applied for the questionnaire. The information out from the Household survey was categorized using Likert Scale ranging from 1-5 and the value was normalized using the formula.

$$X_{norm},i = X_i - X_{min} / X_{max} - X_{min} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

where,

X_i is data value to be transferred.

X_{min} is the lowest value of the indicator.

X_{max} is the highest value and

X_{norm},i is the normalized value

In this way, vulnerability of the community and people was obtained and analyzed in the excel.

3.5.8.3 Flood Risk Analysis

The flood risk analysis includes the combination of result of vulnerability, exposure, and hazard assessment. This is defined by the relationship between vulnerability classes, flood depth and exposure in any area. For this, the exported water depth and velocity raster file from HEC-RAS were imported in QGIS for risk mapping. The water depth and velocity were classified into five groups as per Likert Scale as shown in Table 4. After classification, the water depth is given 80 percent weightage and velocity is given 20 percent weightage and these two layers are overlaid by weightage to generate flood hazard index as map of the Rajapur Municipality. The hazard index is multiplied by the vulnerability index to ascertain flood risk index for Rajapur Municipality. Finally, flood risk maps for different return period were exported as images. From flood risk map, the risk area of each ward of Rajapur was calculated in QGIS.

CHAPTER IV: RESULTS AND DISCUSSION

4.1 Flood Frequency Analysis

Flood frequencies obtained using Gumbel's distribution for different YRPs are presented in Table 1 and Figure 4 using the log chart along with the recorded historical peak discharge for the different years. Of the three types of extreme value theory, the straight line of Type I was determined as being the most appropriate. The discharges predicted by Gumbel's distribution were 11076, 13321, 15472, 18256, 20343, and 22422, m^3 /s for the 5-, 10-, 20-, 50-, 100-, and 200-YRPs, respectively (Table 1; Figure 4)

Table 5: Flood frequency of different year period using Gumbel's Distribution method.

S.N.	Return Period (T) in years	Gumbel's value (Q) m^3/s	G_{max}	G_{min}
1.	5	11077.83	13121.65	9034.003
2.	10	13320.39	16139.28	10501.5
3.	20	15471.51	19062.14	11880.87
4.	50	18255.91	22863.64	13648.18
5.	100	20342.43	25719.36	14965.51
6.	200	22421.34	28568.14	16274.53

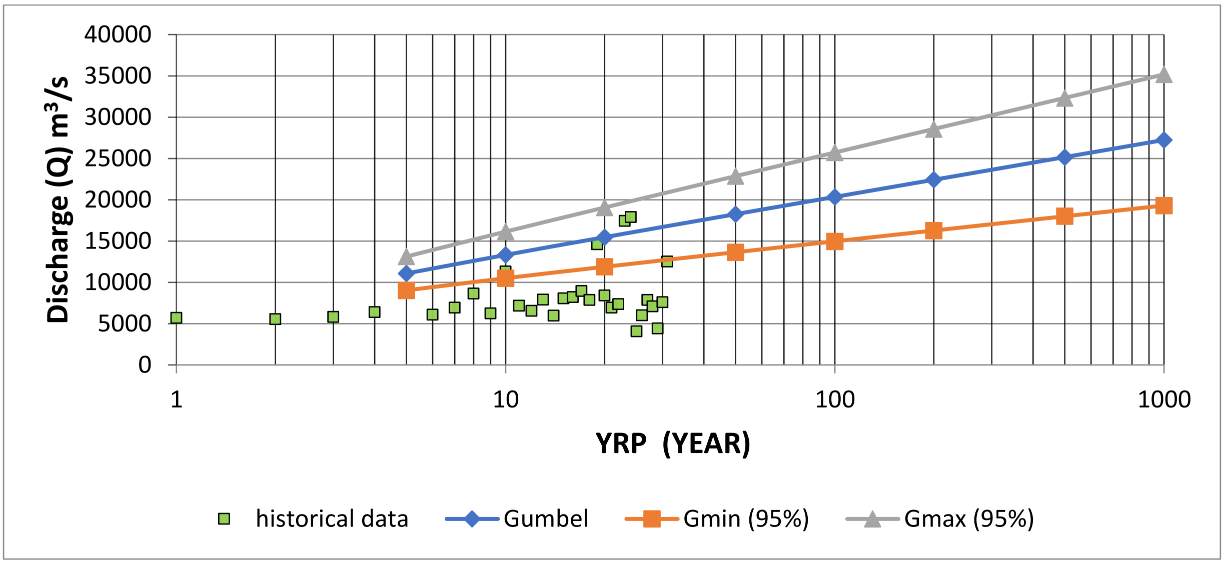

Figure 7: Frequency analysis of flood discharge at Chisapani gauge, showing the Gumbel's distribution and its 95% confidence limits of extreme values (calculated using the standard normal distribution). The year return period (YRP) is plotted on a logarithmic scale for clarity. Historically observed discharge is also given here for reference.

4.2 Watershed Delineation

The watershed boundary of the study area was delineated. Pour point was taken from the downstream end point of study area. The catchment area of Karnali River was calculated. The total area of Karnali catchment is about 44,000 km^2. The watershed delineated map is presented in (Figure 8).

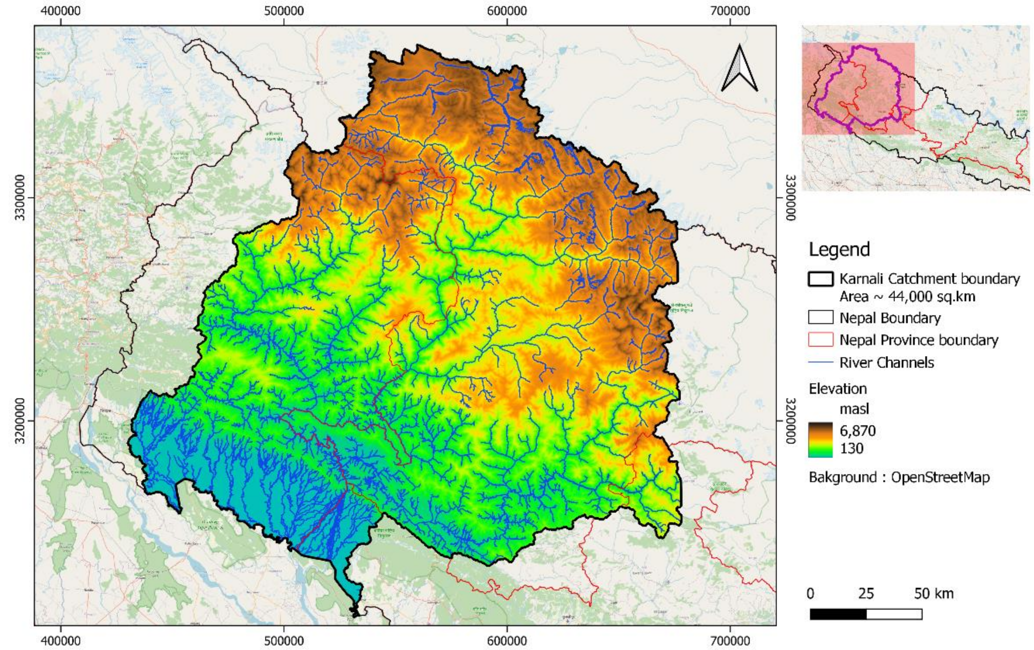

Figure 8: Karnali catchment boundary within Nepal.

4.3 Simulation of 2014 Flood Event

HEC-RAS version 6.3.1 was used for flood simulation. Initially, the clipped raster data such as DEM and LULC, and vector data such as Municipality and ward boundary are imported in HEC-RAS. The projection was set to UTM44N (EPSG: 32644) with SI unit as measurement system. The DEM was converted to Terrain in RAS-Mapper. LULC data is imported, and necessary Manning's n value was given for each class of land cover. Google Satellite Map and Open Street Map were used as per need as model background. After importing necessary data and assigning required values, the geometry of the model area was ascertained by drawing model perimeter. The model perimeter provides boundary to the model and mesh size of 10 m resolution was generated. Flow hydrograph was used as upstream boundary condition and normal depth was used as downstream boundary condition. Model calibration was done for peak discharge of 2009 and validation was done for peak discharge of 2014. The peak flood events were simulated for 36 hours with computational interval of 10s and output interval of 1 hour. After calibration and validation, the return flood events of the Karnali River were simulated. The flood depth and flood velocity of different return period were exported as raster file.

The DHM has established threshold water level gauge heights of 10 m and 10.8 m for warning and danger levels, corresponding to 201.64 and 202.44 m a.s.l., respectively [28; Table 4].

Table 6: Classification of threshold discharge (m^3/s) water level gauge height (m) and mean above sea leavel (m.a.s.l.) reference height categorized according to the warning and danger levels for flood forecasting in Karnali used by DHM, Nepal [29]

River name	Station	Runoff (m^3/s)	Threshold by DHM Water level (m)	Reference to MSL	Remarks
Karnali	Chisapani	8200	10.0	201.64	Warning level
		10,000	10.8	202.44	Danger level

4.4 Flood Hazard Analysis

Flood hazard assessment involved the estimation of adverse effects of flooding in the study area. For that, the most important parameters of flood, such as flood depth, flood duration, and inundation extent, were necessary. Such parameters were simulated by using a 2D hydrodynamic model (HEC-RAS) for both base-line and future CC scenarios [30].

In this study, the flood hazard maps were prepared and inundate area is calculated as shown in Table 5. The analysis of flood hazard mapping indicates that considerable increase in flood inundation with increasing discharge of flood was shown from 5 years to 1000 years return period respectively. From Table 5 and Table 6 we can understand that total hazard area is progressively increasing with the increasing return periods. The change is more visual before 100 years return period and less visual in subsequent return period after 100 years as shown in graph below. We can observe that among the four wards of Rajapur Municipality ward no. 1 is highly inundated even in 5 years return period with area 9.31 m^2 and in 1000 YRP is 11.5 m^2. Hence, almost 70% of total area of ward no. 1 in 5 YRP gets inundate following 86% in 200 YRP. Similarly, all the four wards get highly inundate and increases with the increase of discharge in every return period which is shown in Table 5 and Table 6.

The flood hazard mapping in this study shows the existing warning and danger levels corresponds well with the observation during the flooding season. The flood depth classification shows that most of the inundated area of these four wards has water depth of 1-10 m. Therefore, floods with depths of 1m can cause severe damage and are considered of high risk in the Rajapur area.

Table 7: Inundate area of each ward for different year return period.

Ward No.	5 YRP (km^2)	10 YRP (km^2)	20 YRP (km^2)	50 YRP (km^2)	100 YRP (km^2)	200 YRP (km^2)
1	9.31	10.05	10.56	10.93	11.17	11.37
3	7.65	8.35	8.84	9.27	9.56	9.78
4	8.05	8.90	9.42	9.81	10.09	10.41
7	4.56	5.19	5.64	5.96	6.133	6.27

Table 8: Percent of area that is inundated by flood in different year return period.

Ward No.	5 YRP %	10 YRP %	20 YRP %	50 YRP %	100 YRP %	200 YRP %
1	69.90	75.5	79.33	82.12	83.87	85.41
3	59.43	64.85	68.6%	71.96	74.18	75.92
4	55.40	61.26	64.86	67.5	69.44	71.66
7	54.95	62.55	67.90	71.9	73.9	75.65

The figure below shows the water depth of Rajapur Municipality in every YRP.

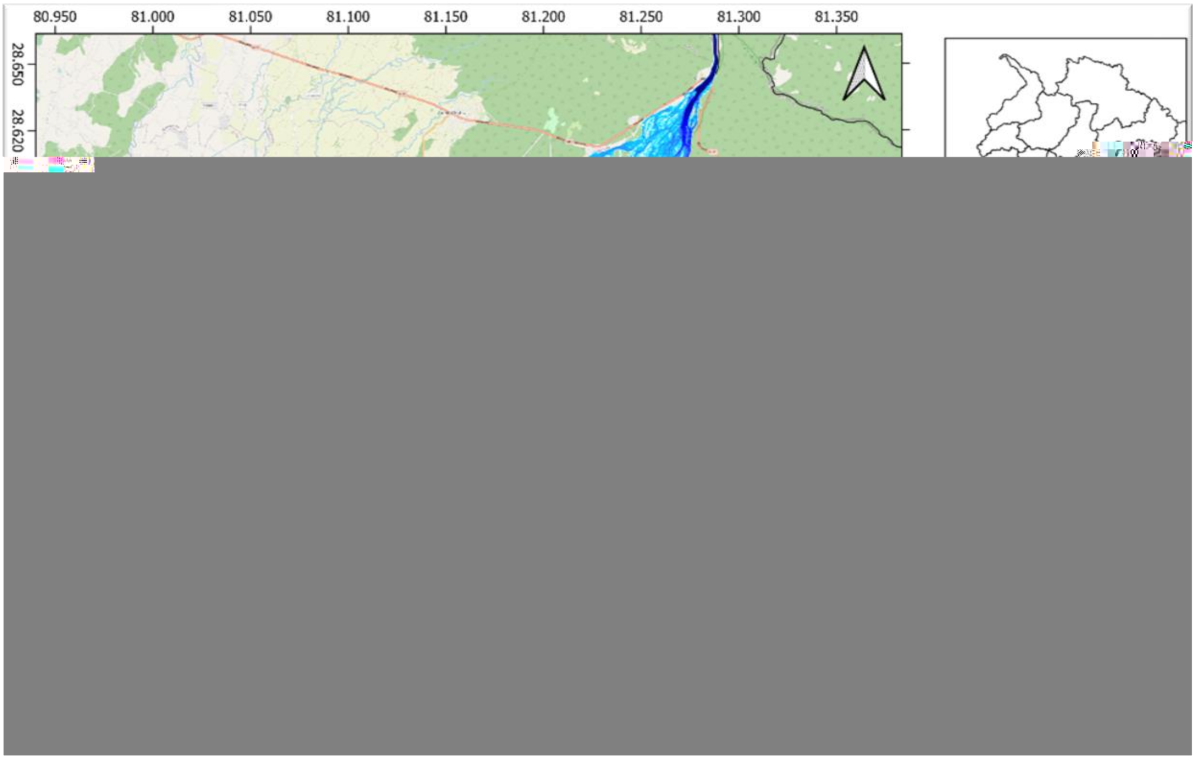

Figure 9: 5 YRP flood hazard map of Karnali River

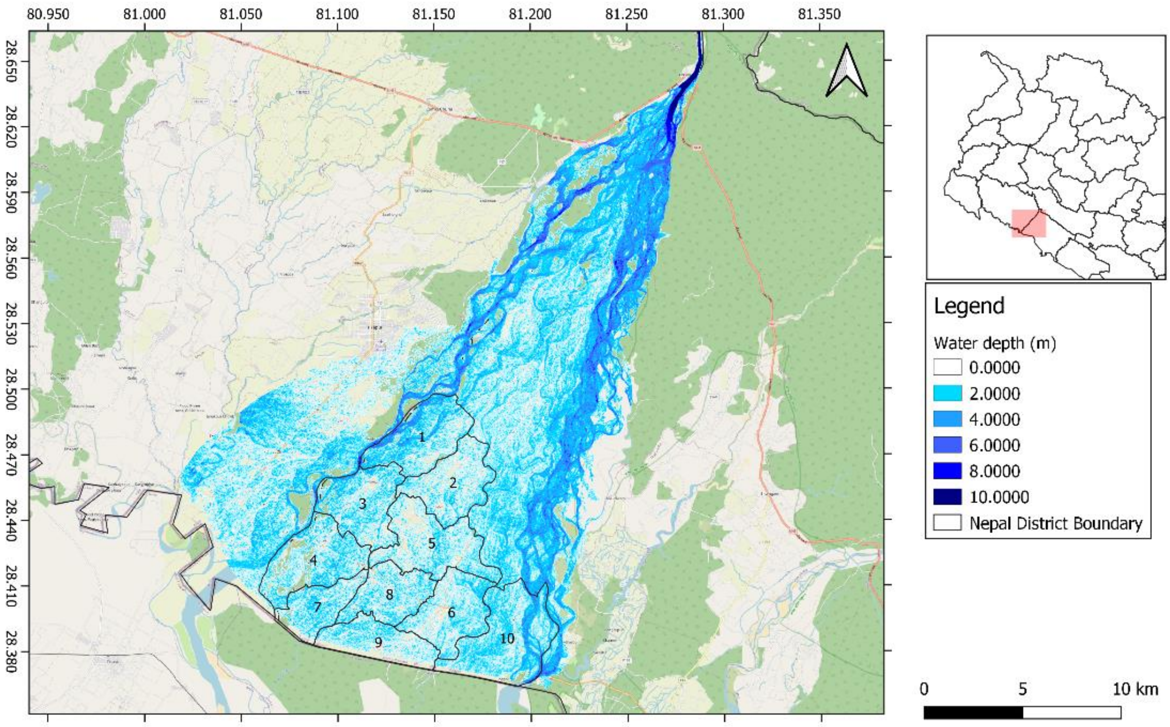

Figure 10: 10 YRP Flood Hazard map Of Karnali River

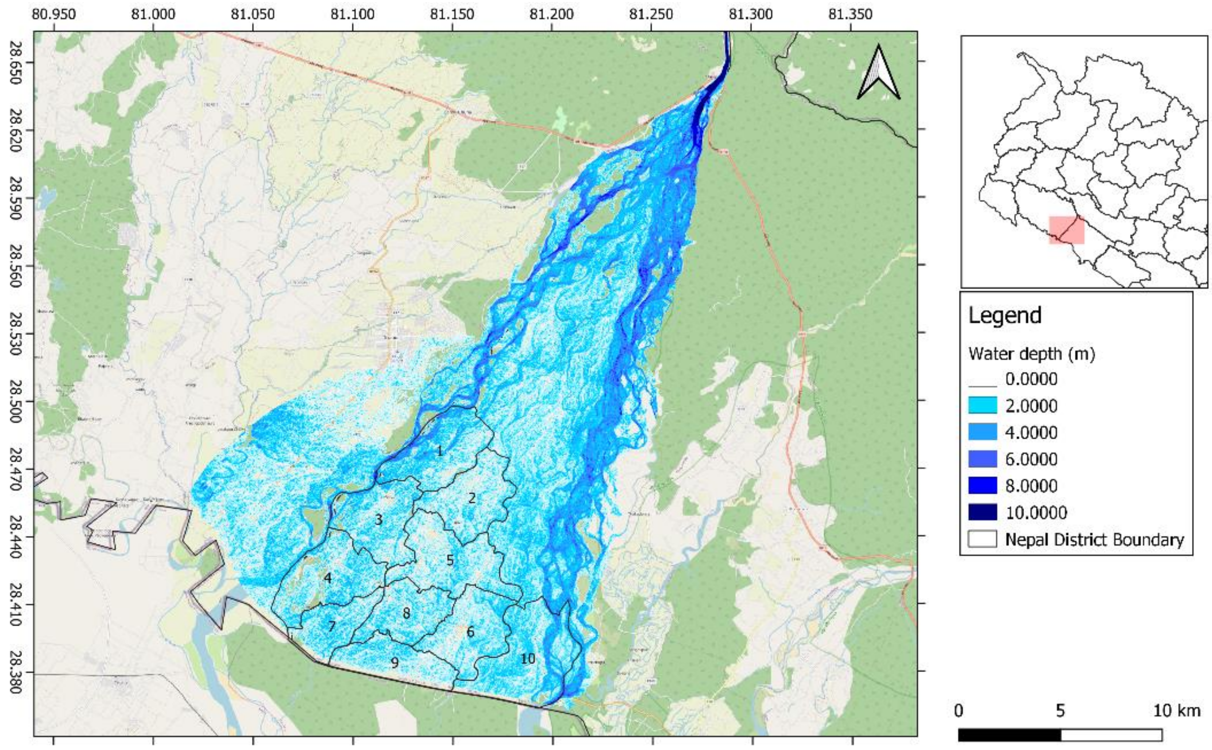

Figure 11: 20 YRP Flood Hazard map of Karnali River.

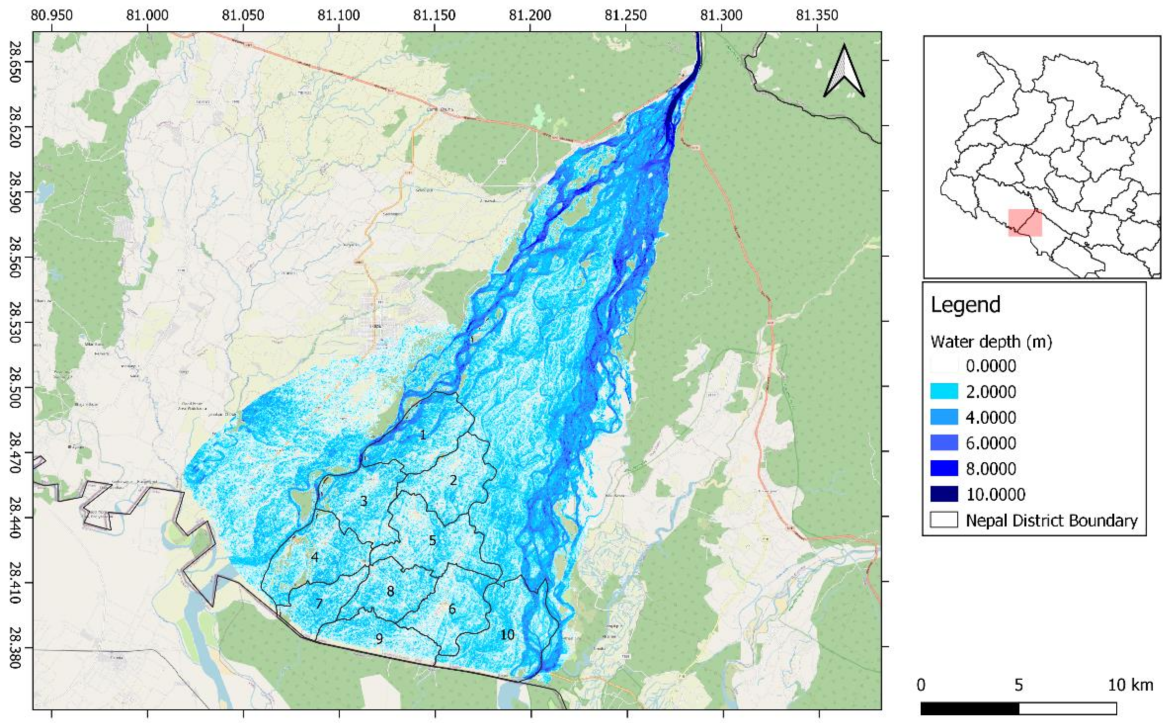

Figure 12: 50 YRP Flood Hazard map of Karnali River

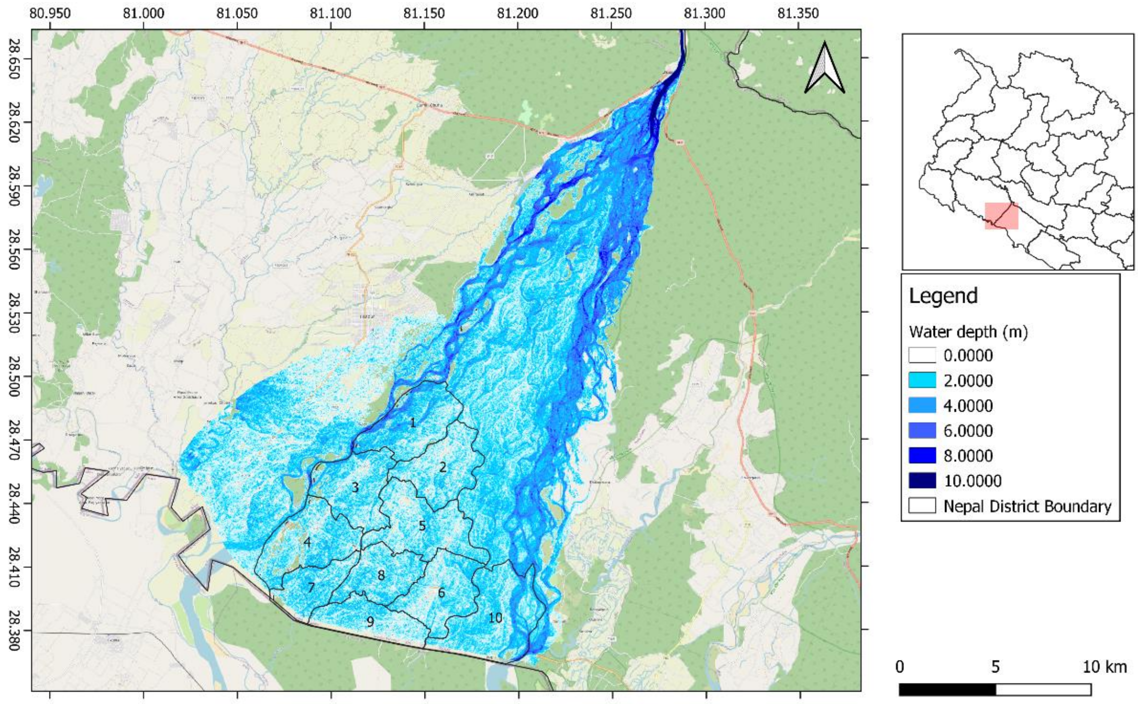

Figure 13: 100 YRP Flood Hazar map of Karnali River.

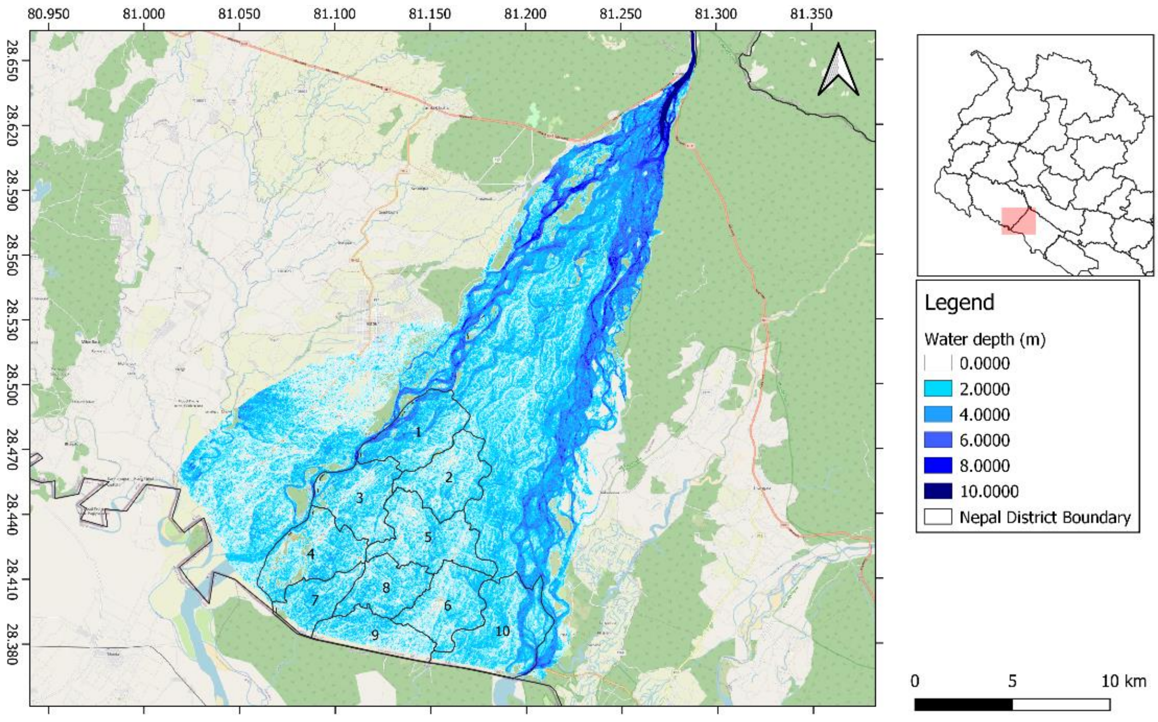

Figure 14: 200 YRP Flood Hazard map of Karnali River

4.5 Flood Vulnerability Analysis

Vulnerability is not only about sensitivity and exposure but also about the adaptive capacity of the people. Despite having more exposure and sensitivity to the change in climate, some wards were found to be comparatively less vulnerable because of the adaptation strategies and capacities of the area enhanced by the local government and private organizations.

Among the 10 wards of Rajapur Municipality, this study includes only four wards which are wards- 1, 3, 4 and 7. In which Wards- 1, 3 and 4 are highly vulnerable and Ward 7 is comparatively less vulnerable than Wards- 1, 3 and 4 as shown in the Table 7 and Figure 15.

Table 9: Vulnerability of different wards of Rajapur.

Ward no.	Vulnerability
1	0.9802
3	0.762
4	0.77
7	0.63

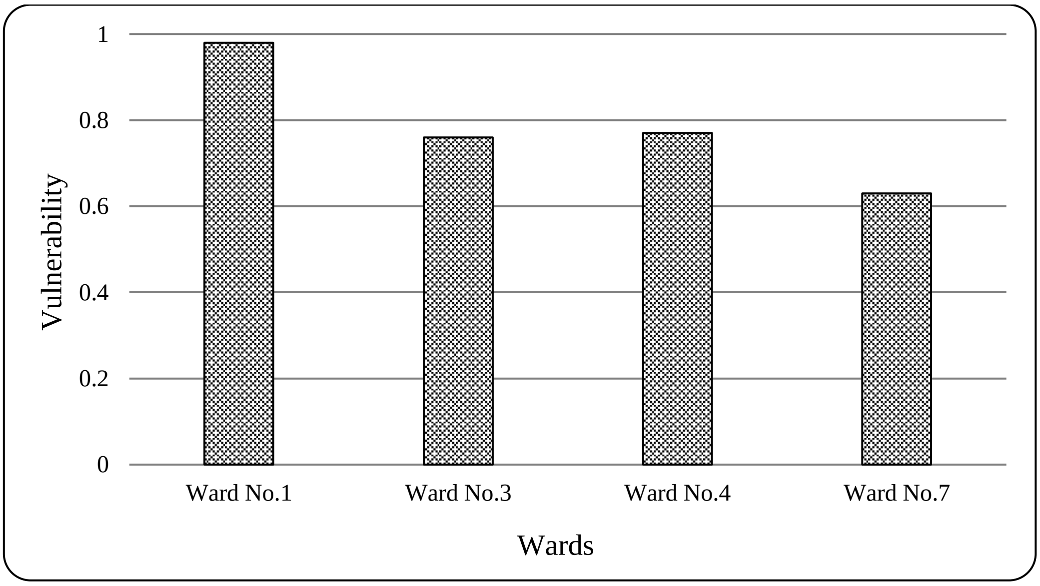

Figure 15: Vulnerability level of different ward of Rajapur Municipality

From the field observation and maps of Rajapur, we found that Ward 1 lies in between the Karnali River and the Budikulo (branch of the Karnali River) which causes excessive flow of water from both side during the flooding. So, it is obvious that Ward 1 is highly vulnerable than other 3 wards. Similarly, each ward lacks the well-built nature of houses and systematic way of settlement. People of these wards have built their house at the distance of 6 m also from the river which leads directly expose to the river. The value of exposure and sensitivity is found to be more than the adaptive capacity of community and people, which directly makes them vulnerable. Settlements are linear, agriculture land area exposed to the river that may swift away the crops by flood during the flood of 2m depth also, which is common in Rajapur area while the highest depth is found 10m from hazard mapping of this study as well as other report of published every year for Rajapur Municipality. Hence, field observation justifies the vulnerability value of these wards shown in Table 7 and Figure 15.

4.6 Flood Risk Analysis

The flood risk analysis includes the combination of the results of the Hazard and Vulnerability. For this, the exported water depth and velocity raster file from HEC-RAS were imported in QGIS for risk mapping. The water depth and velocity were classified into five groups as per Likert Scale as shown in Table 8.

Settlements in the Rajapur Municipality are at high risk due to flood and inundation of late. The area is at high risk as the river starts eroding the Ward 1 Tigra area of Rajapur Municipality. The water level in the river rises continuously and pushes the area in high risk of inundation. From this study we came to know that water level reaches up to 10 meter which is considered as high risk to community and infrastructure. In this study, all wards of study area are at high risk even in 5 YRP of flood. By calculating the area of risk of Ward-1, 3, 4, and 7, ward no. 1 is at very high risk about 3.45 km^2 in 5 YRP and 7.53 km^2 in 100 YRP of total area 13.32 km^2 of ward no. 1. As shown in Table 8. Similarly, total the risk area of ward no. 3, 4, and 7 of different YRP have been calculated and found that most of area of these ward are at high risk as shown in Table 9, 10, and 11. And percentage of risk in different YRP of Ward- 1, 3,4 and 7 are shown in Figure 16, 17, 18, and 19.

Typically, the potential vulnerability of a territory's vital infrastructure in a dangerous situation is used to evaluate the possible impact of a disaster. The functioning of the governing body and the region depend on the potential influence on these crucial facilities. Therefore, with the aid of the soft measures employed in this study, efficient land-use planning and its recommendations can be implemented in the Rajapur Municipality. The most recent early warning technologies, as well as door-to-door awareness programs in riverfront settlements and surrounding villages, are all crucial goals that can help in decreasing the loss of life and property due to floods [31].

Table 10: Risk area of Ward 1 of different YRP categorized in five class using Likert Scale.

Risk class	5 YRP (km^2)	10 YRP (km^2)	20 YRP (km^2)	50 YRP (km^2)	100 YRP (km^2)	200 YRP (km^2)
Very low	0.76	0.73	0.003	0.282	0.46	0.44
Low	0.89	0.88	0.38	0.895	0.8	0.73
Moderate	1.11	1.02	0.99	1.12	0.99	0.93
High	3.12	3.13	3.95	1.44	2.71	2.62
Very high	3.45	4.32	3.99	7.22	6.25	6.66

Table 11: Risk area of Ward 3 of different YRP categorized in 5 class using Likert Scale.

Risk class	5 YRP (km^2)	10 YRP (km^2)	20 YRP (km^2)	50 YRP (km^2)	100 YRP (km^2)	200 YRP (km^2)
Very low	0.87	0.79	0.051	0.43	0.67	0.63
Low	1.03	1.05	0.592	0.995	0.991	0.983
Moderate	1.142	1.19	1.209	1.35	1.102	1.04
High	3.064	3.13	3.84	1.78	3.12	3.08
Very high	1.56	2.23	1.98	4.73	3.69	4.06

The total area of ward no. 3 is 12.89 km^2 in which 3.064 km^2 is at high risk and 1.56 at very high risk, similarly only 0.87 km^2 is at low risk even in 5 YRP. From the Table 9, we can observe that Ward 3 is at high risk following the continuity of increasing risk area up to 200YRP.

Table 12: Risk area of ward no. 4 of different YRP categorized in 5 class using Likert Scale.

Risk class	5 YRP (km^2)	10 YRP (km^2)	20 YRP (km^2)	50 YRP (km^2)	100 YRP (km^2)	200 YRP (km^2)
Very low	1.141	1.12	0.17	0.59	0.75	0.79
Low	1.14	1.24	0.75	1.12	1.08	1.038
Moderate	1.43	1.42	1.51	1.7	1.56	1.4
High	3.18	3.44	4.15	2.16	3.73	3.9
Very high	1.18	1.72	1.5	4.27	3.004	3.34

Table 10 explains about the area of risk in ward no. 4. The total area of ward no. is 14.53 km^2 of which 3.18 km^2 is at high risk, 1.18 km^2 at very high risk and only 1.14 km^2 at low risk in 5 YRP. Hence it seems to be ward no. 4 is at high risk.

Table 13: Risk area of ward no. 7 of different YRP categorized in 5 class of using Likert Scale.

Risk class	5 YRP (km^2)	10 YRP (km^2)	20 YRP (km^2)	50 YRP (km^2)	100 YRP (km^2)	200 YRP (km^2)
Very low	0.56	0.6	0.01	0.3	0.37	0.32
Low	0.69	0.61	0.17	0.71	0.7	0.6
Moderate	0.92	0.85	0.81	0.78	0.7	0.7
High	1.8	2.11	2.71	1.04	2.04	1.94
Very high	0.62	1.038	0.88	3.15	2.4	2.75

The total area of Ward 7 is 8.30 km^2 in which 1.80 km^2 is at high risk, 0.62 km^2 at very high risk and 0.69 km^2 at low risk in 5 YRP. It seems that ward no. 7 is comparatively at low risk than Ward 1, 3 and 4.

The given following graph shows a comparison between the wards for different return period

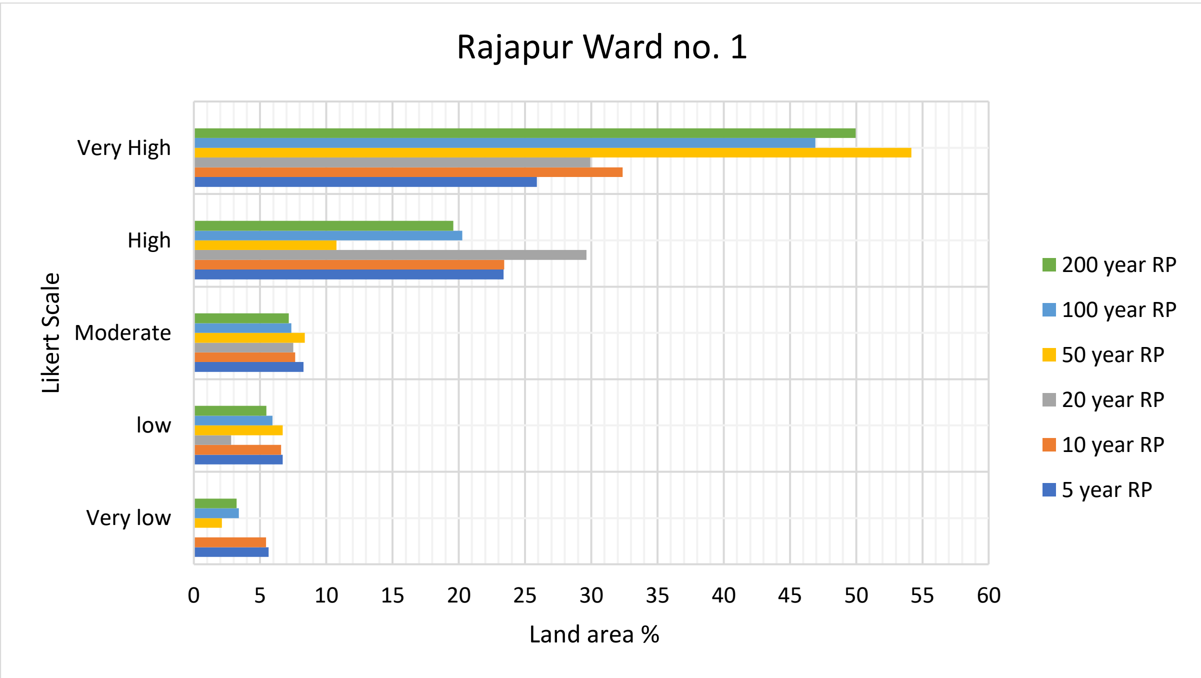

Figure 16: Percentage of Flood Risk area of Ward no. 1

From above Figure 6, 23.38% of Ward 1 is at high risk, 25.9% at very high risk and 6.71% at low risk. This shows that Ward 1 is very high risk even in 5 YRP of flood.

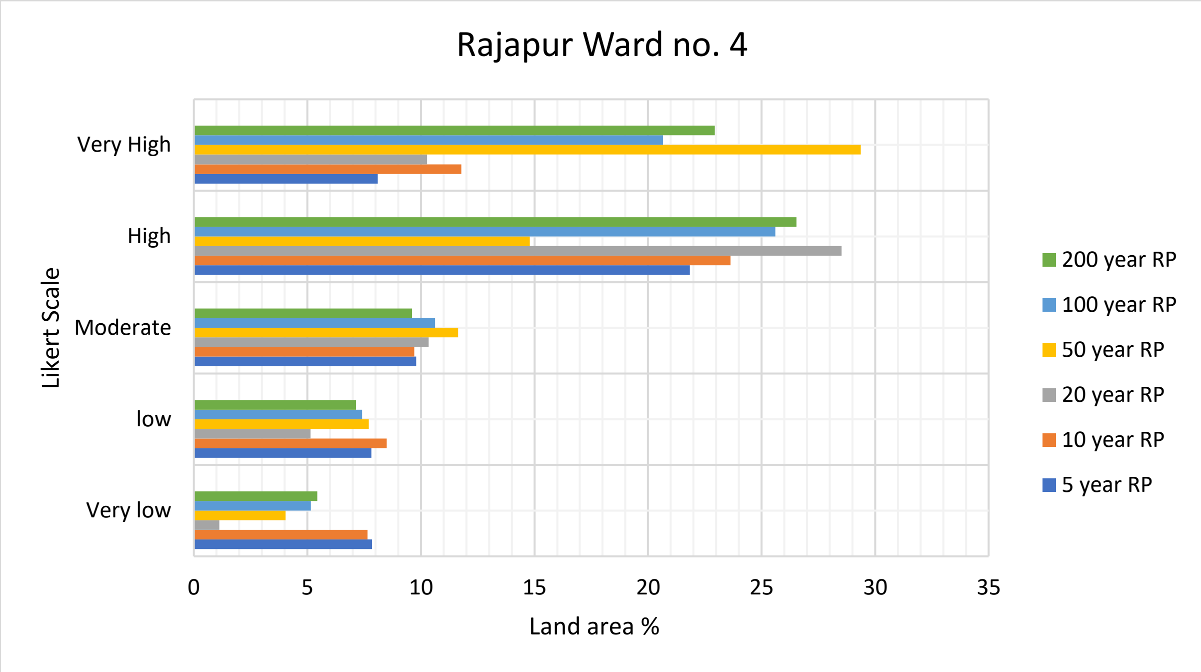

Figure 17: Percentage of Flood Risk area of Ward no. 4 of Rajapur Municipality.

Figure 17 shows that 21.84 % area of Ward 4 is at high, 8.1% is very high risk and 7.84% is low risk in 5 YRP of flood. So, we can say that Ward 4 is at high risk.

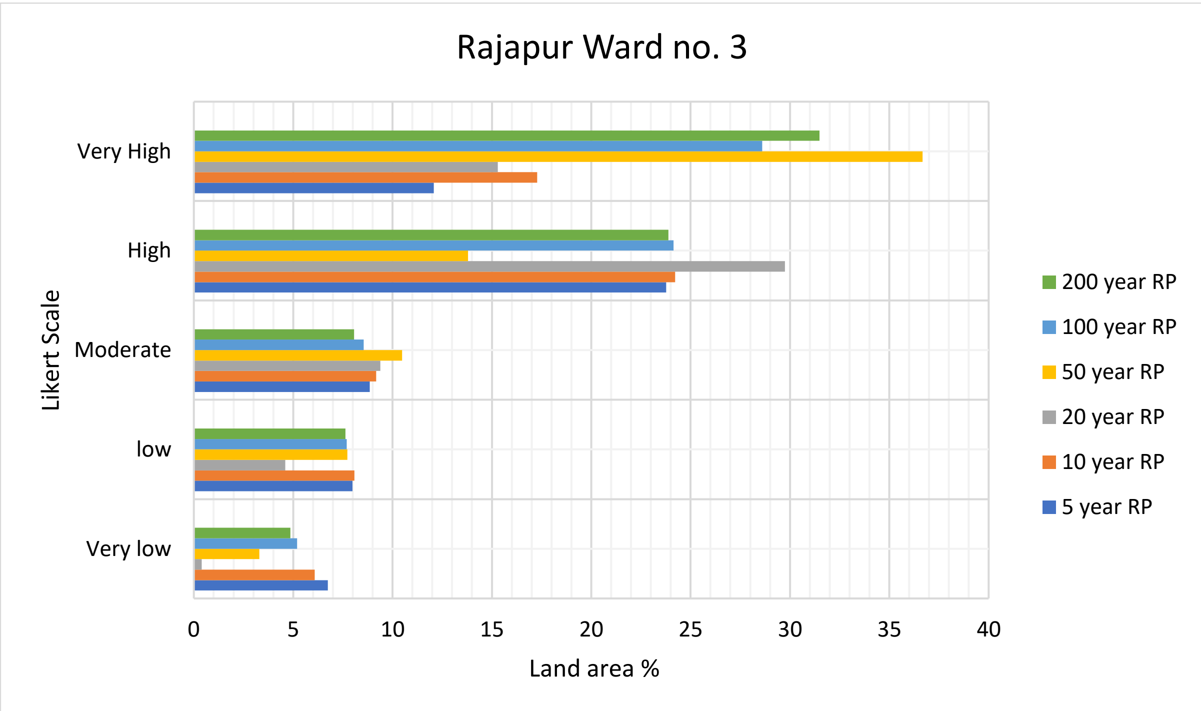

Figure 18: Percentage of flood risk area of Ward no. 3 of Rajapur Municipality.

About 24 % area of Ward 3 is at high risk, 12.1% is very high risk and 7.99% is low risk even in 5 YRP flood. This implies that Ward 3 is also at high risk as explain in Figure 18 comparing the percentage of risk area in every YRP of flood mention in study.

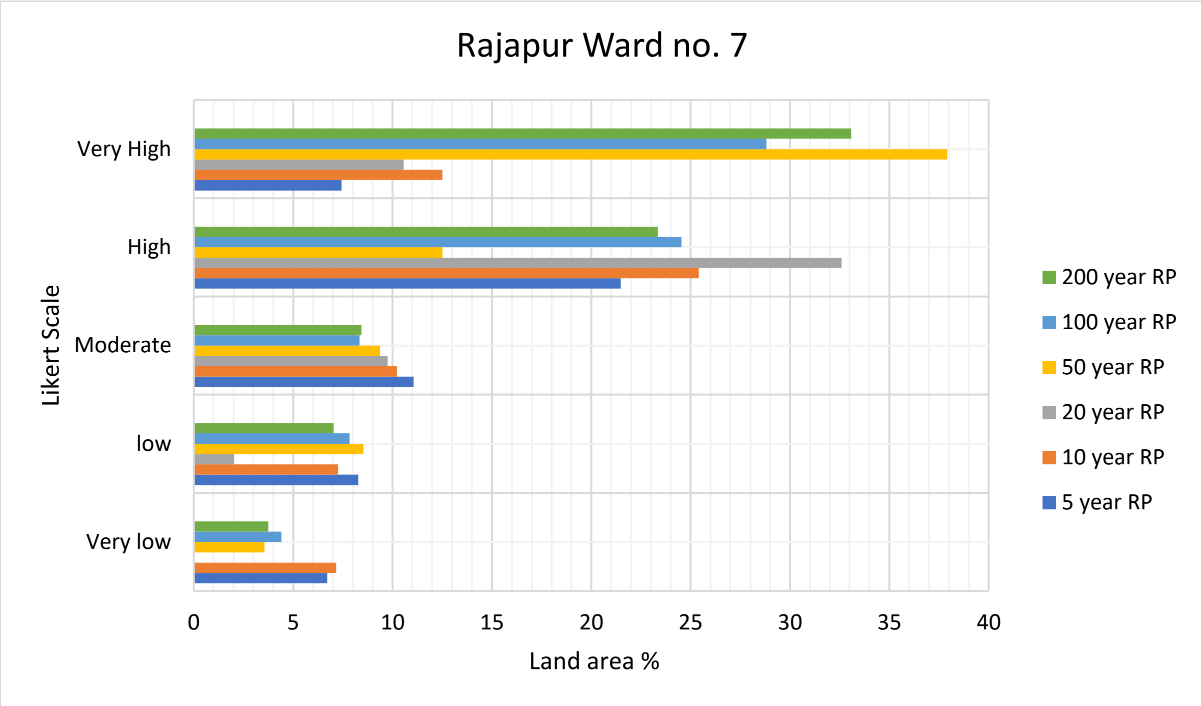

Figure 19: Percentage of flood risk area of Ward no. 7 of Rajapur Municipality

Figure 19 shows that 21.5% of Ward 7 is at high risk, 7.5% is at very high risk and 8.3% at low risk in5 YRP of flood. Hence, we can say that Ward 7 is at high risk following Ward 3 and 4 comparing the different YRP flood.

Figures 22-27 below shows the risk area in different YRP of flood in Rajapur Municipality.

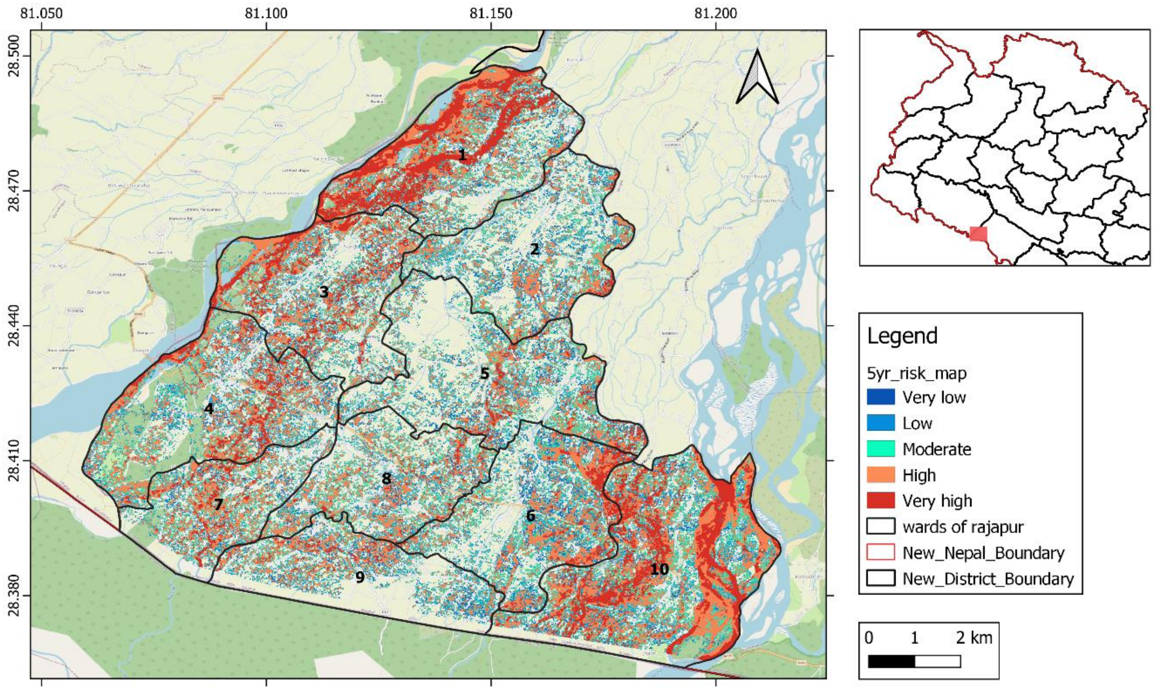

Figure 20: 5 YRP risk map of Rajapur Municipality

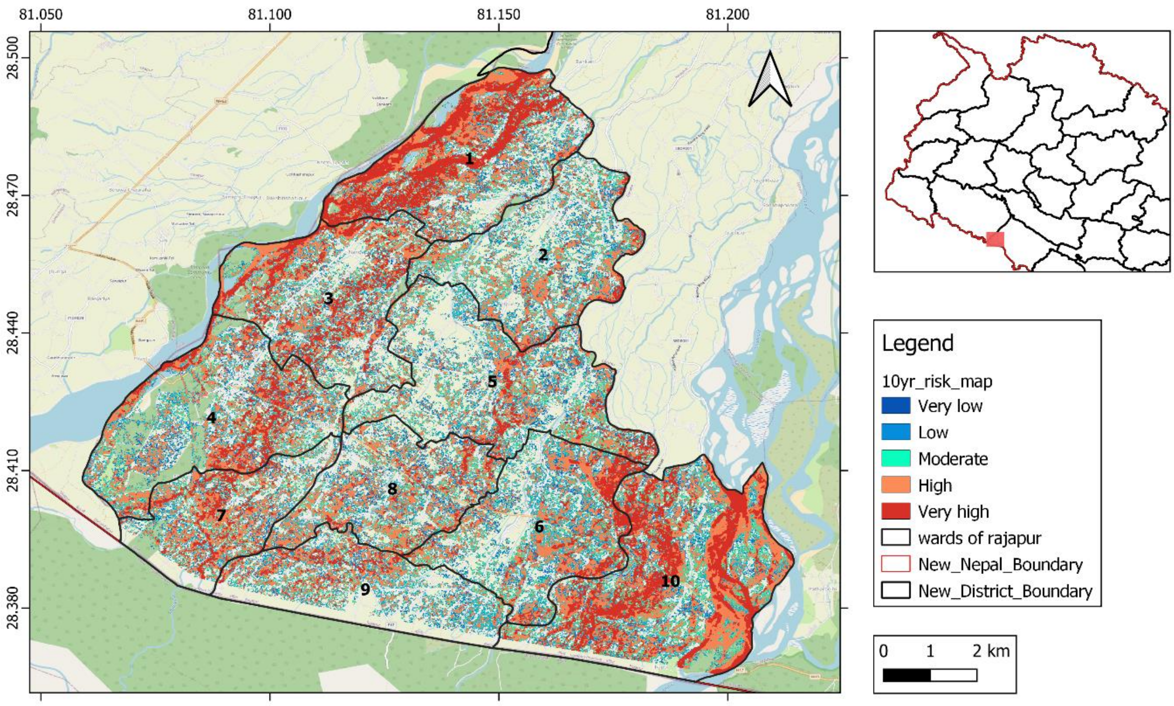

Figure 21: 10 YRP risk map of Rajapur Municipality.

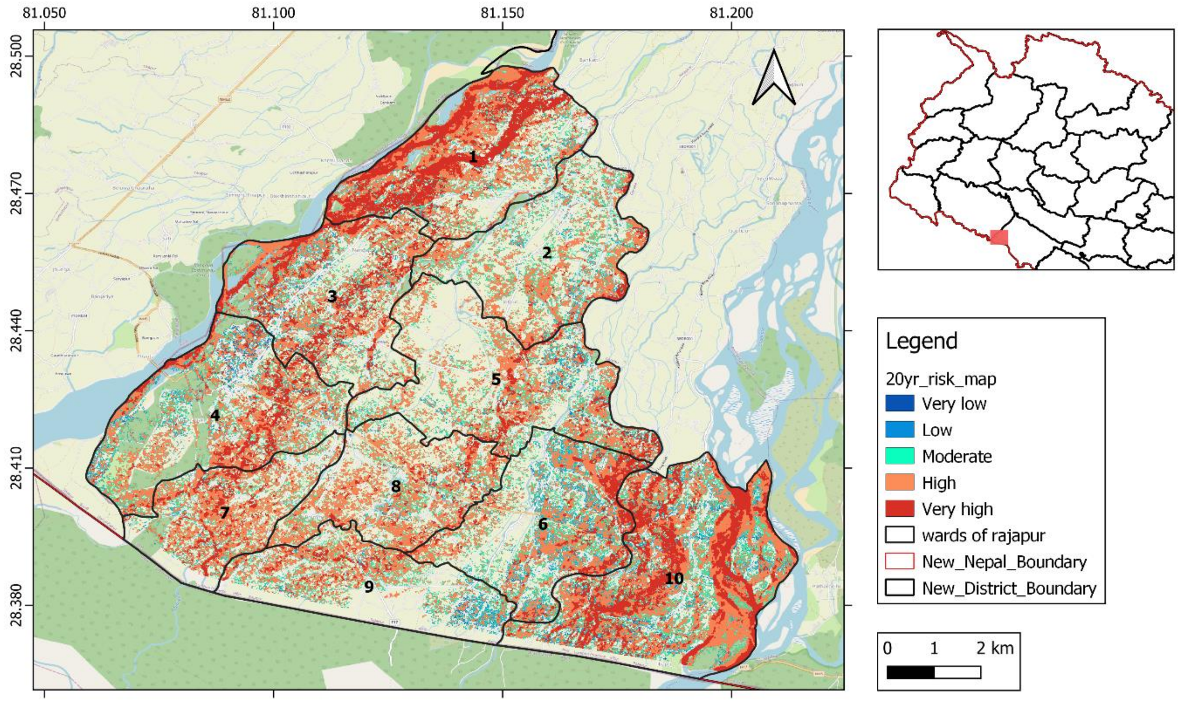

Figure 22: 20 YRP risk map of Rajapur Municipality.

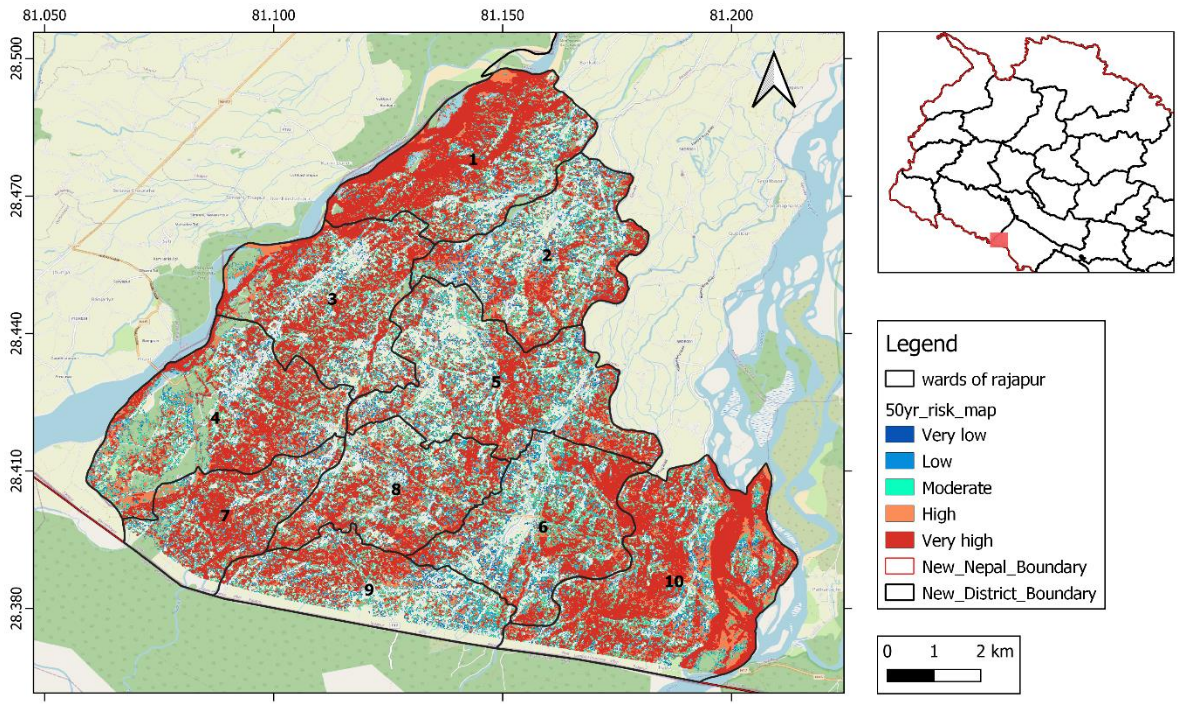

Figure 23: 50 YRP risk map of Rajapur Municipality.

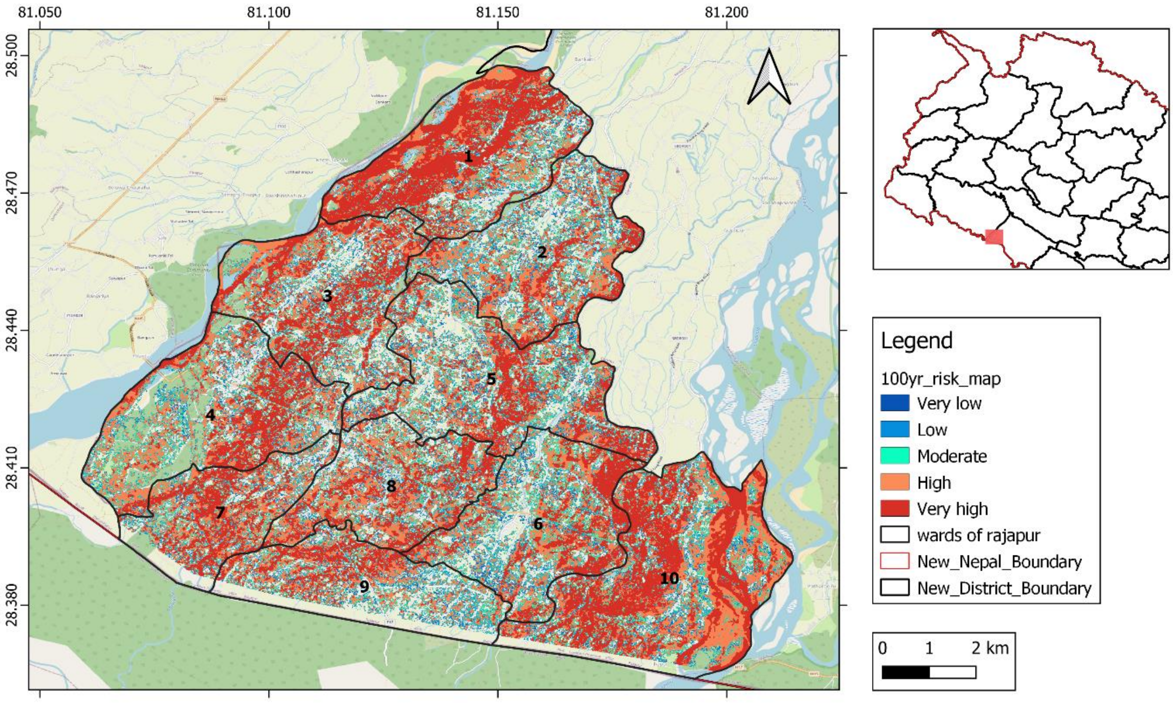

Figure 24: 100 YRP risk map of Rajapur Municipality.

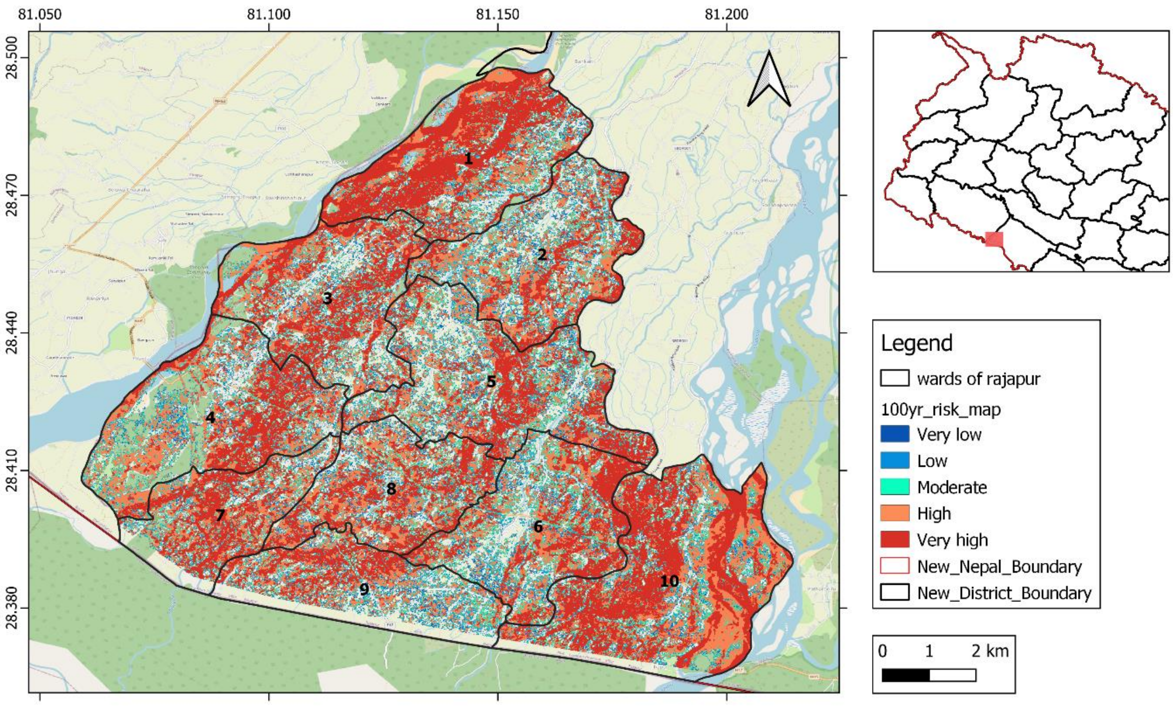

Figure 25: 200 YRP risk map of Rajapur Municipality.

4.2 Discussion

Disasters such as floods and landslides are very common in southern parts of the Nepal bordering India. These affect the life of people and causes enormous damage to physical properties, land crops and life of people. Therefore, it is mandatory to identify probable future floods and their inundation extent and risk area with available tools.

In this study, Type I Gumbel distribution method was used to determine the flood frequency. After calibration and validation Figure 4 and 5 of the mode, further simulation was carried out to observe probable scenarios of flood in the Rajapur Municipality. Due to high variability in the velocity of the river from Chisapani to Rajapur Municipality greater overflow of the river occurs along the lower reach than along the upper reach, causing an extensive inundation of the region around Wards- 1, 3, 4 and 7. Based on the flood frequency analysis, inundation areas were determined and compared under different YRP floods. The scenario depicted that Ward 1 of Rajapur Municipality is greatly affected by flooding and is at very high risk. 3.45 km^2 is at very high risk and 3.12 km^2 in high risk of total land area 13.32 km^2 even in 5YRP and destroyed settlements as well as crops land during excessive flooding whereas ward no. 3, 4 and 7 are high risk comparing the area of hazard and risk in different YRP. Similar kind of work in Karnali river by[25] show the downstream of Karnali River Basin is highly affected by the flood during the monsoon season. With an estimated peak discharge of up to 29,910 m3 /s and the flood depths up to 23 m in the 1000-YRP, the area vulnerable to flooding in the study domain extends into regions on both the east and west banks of the Karnali River.

A recent study analyzing two decades of maximum instantaneous discharge of the Karnali River showed very high discharges during the summer monsoon season, reaching 21,700 m^3/s, thus presenting a serious threat to the KRB [12] Following these study, we conducted the risk assessment and hazard mapping in the Rajapur Municipality with 2D HEC-RAS model with the DEM of 5 m resolution.

Thus, we could evaluate the capacity of the HEC-RAS model in generating water surface profiles and elevations. This will help in the further planning of river restoration to mitigate the loss and damage during flooding. Overall, the simulated water surface profile in the HEC-RAS model showed good performance in the Rajapur Municipality. Similarly, in this study the flood depth and velocity obtained after simulation helps in mapping flood hazard. Most of the flooded area is within or shallower than the depth class 2–10 m, as evident in Figure 20 to Figure 27.

Therefore, floods with depths of 1 m can cause severe damage and are considered of high risk in the Rajapur area.

The study of the Balkhu River in Nepal done by [15] to assess the hazard level in illegal squatter settlements along the riverbank and suggested their relocation. They also discussed the details of a plan implemented by the local government whereby construction activities were restricted by regulations requiring a 20m distance between development and the riverbank. A similar approach can be very fruitful in the downstream region of the KRB, which will help in reducing the future impact of flooding. Although a flood projection and water level threshold was established by the DHM in the KRB [29] (Table 4), uncertainty remains regarding the timing of flooding, as it is sometimes caused by anomalous flooding event.

The vulnerability assessment was conducted by identifying the major indicators using the VRA framework given by Government of Nepal and 115 household was taken for the sample size in which Ward 1 is highly vulnerable and Ward 3 and 4 is equally vulnerable to each other, but Ward1 seems less vulnerable than the ward 1, 3, and 4, respectively as shown in Figure 7. Similarly, the risk assessment in this study, shows that all these wards used for study area are at risk zone. Almost

Typically, the potential vulnerability of a territory's vital infrastructure in a dangerous situation is used to evaluate the possible impact of a disaster. The functioning of the governing body and the region depend on the potential influence on these crucial facilities. Therefore, with the aid of the soft measures employed in this study, efficient land-use planning and its recommendations can be implemented in the Rajapur Municipality of the Bardiya district. In Rajapur Municipality, there is an urgent need for the greatest number of flood forecasting units, the most advanced early warning technologies, and door-to-door awareness programs. These are all significant goals that can aid in lowering the loss of life and property due to floods.

CHAPTER V: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this study, we offered a methodical way to determining the frequency of flooding and the risk that it poses in the future based on the extent of hazard map in Rajapur Municipality, specifically in wards 1, 3, 4 and 7, respectively. The study's goals included the hazard mapping and assessment of flood risks in the lower Rajapur Municipality (Wards - 1, 3, 4 and 7) of Bardiya district. A QGIS and HEC-RAS model were used to create the YRP hazard maps. Several conclusions were drawn by looking at the Karnali River's historical hydrological occurrences and its current state. In the Rajapur Municipality, flooding is a common natural disaster that poses a socioeconomic risk and results in significant loss of life as well as damage to agricultural land, food production, private property, and public property. Therefore, it is essential to lessen the effects of flooding in Rajapur Municipality. The level of flood risk in the Rajapur Municipality for different return periods demonstrates that the overall risk in Rajapur rises as the YRP rises. Flooding caused by high discharge of the results from high intensity rains across the basin. Hydraulic models carried out for various YRPs reveal that when the YRP rises, an ever-increasing area of agricultural land will be submerged, endangering the food security of Rajapur Municipality. With the aid of the spatial flooding scenario that was simulated in this study, the community of Rajapur Municipality's Wards- 1, 3, 4, and 7 can get inundate even in a normal flood of 1m and cause danger situation to community.

Regarding the approach, HEC-RAS delivers very effective future risk maps and flood inundation maps of Rajapur Municipality (Wards- 1, 3, 4 and 7). The household survey was used to examine the community's Vulnerability due to climate change after generalizing hazard maps. The household survey provides appropriate information about the community's adaptability, sensitivity, and exposure done for the vulnerability assessment. Comprehensive risk mapping is provided by the community and individual's vulnerability assessment and hazard mapping. This study has classified the flood depths in different levels in several areas and has evaluated the risk area of the Wards-1, 3, 4, and 7, and found that Ward 1 is very high-risk area, highly vulnerable and most of its area are inundate during the flood. Similarly, Ward 3 and 4 are high risk area having similar type of vulnerability and hazard area in different year return period of flood, but Ward 7 is less risk area in comparison to other three wards. Therefore, this study can provide appropriate information which can be used to create a better and more suitable resettlement community and to prevent future floods.

5.2 Recommendation

HEC-RAS is a powerful tool which simulates complex river systems and predicts the impacts of various management and development activities on the flow of water in rivers and streams. The output of HEC-RAS could provide a basic for decision-making in areas such as river and floodplain management, design of bridges and culverts, generation of hydropower, and other relevant fields.

- The accuracy of HEC-RAS results depends on the quality of the input data. It is important to gather and prepare accurate data on topography, hydrology, and hydraulic properties of the river system being modeled.
- HEC-RAS models should be calibrated and validated against observed data, such as flow measurements and water surface elevation, to ensure the model is accurate and reliable.
- It is important to understand the limitations of the model and to interpret its result with caution.
- HEC-RAS requires significant computational resources, particularly for large and complex model, which can make it challenging to run on personal computers or low-powered servers.
- The risk map and hazard map created in this study of Rajapur Municipality can be used for the proper settlements of community and other infrastructure in that area.
- The government and local people can get knowledge about the situation of danger from this study.
- This research includes only four (1, 3, 4, and 7) wards of Rajapur Municipality among 10 wards, hence other wards of Rajapur should also be considered for hazard mapping and risk evaluation.

6. REFERENCES

[1] S. Dangol and A. Bormudoi, “Flood Hazard Mapping and Vulnerability Analysis of Bishnumati River, Nepal,” *J. Geoinformatics, Nepal*, vol. 14, no. October, pp. 20–24, 2017, doi: 10.3126/njg.v14i0.16969.

[2] J. Felkner, K. Tazhibayeva, and R. Townsend, “Impact of climate change on rice production in Thailand,” *Am. Econ. Rev.*, vol. 99, no. 2, pp. 205–210, 2009, doi: 10.1257/aer.99.2.205.

[3] S. Khanal, S. Thakuri, M. Dhakal, and L. M. Wagle, *Proceeding of Research Seminar on Climate Change*, no. March. 2019. [Online]. Available: www.cen.org.np

[4] H. Hans-O. Pörtner , Debra C. Roberts, *Climate Change 2022 - Impacts, Adaptation and Vulnerability - Summary for Policymakers*. 2022.

[5] R. Dhungel, “Use of indigenous knowledge in strategies for disaster risk reduction for flood disaster: the study of Tharu community of Bardiya district of Nepal,” 2011, [Online]. Available: http://123.49.46.157/handle/10361/1819%5Cnhttp://123.49.46.157/bitstream/handle/10361/1819/rachhita dhungel.pdf?sequence=1

[6] H. Hisdal, K. Stahl, L. M. Tallaksen, and S. Demuth, “Have streamflow droughts in Europe become more severe or frequent?,” *Int. J. Climatol.*, vol. 21, no. 3, pp. 317–333, 2001, doi: 10.1002/joc.619.

[7] greengrowthknowledge.org, “Vulnerability and Risk Assessment Framework and Indicators,” 2017, [Online]. Available: http://www.greengrowthknowledge.org/sites/default/files/downloads/policy-database/NEPAL%29 Vulnerability and Risk Assessment Framework and Indicators for National Adaptation Plan %28NAP%29 Formulation Process in Nepal.pdf

[8] N. Niamey, “Reviewing of Climate Vulnerability Assessment Methodologies,” no. December, p. 23, 2015, doi: 10.13140/RG.2.2.20817.07524.

[9] B. K. Pradhan, *Disaster preparedness for natural hazards: current status in Nepal*. International Centre for Integrated Mountain Development (ICIMOD), 2007.

[10] N. Dangol, “Flood Modeling Assessment: A Case of Bishnumati River,” *J. Geoinformatics, Nepal*, vol. 20, no. 1, pp. 31–37, 2020, doi: 10.3126/njg.v20i1.39474.

[11] K. R. Khatiwada, J. Panthi, M. L. Shrestha, and S. Nepal, “Hydro-climatic variability in the Karnali River Basin of Nepal Himalaya,” *Climate*, vol. 4, no. 2, pp. 1–14, 2016, doi: 10.3390/cli4020017.

[12] S. Venkateswaran, Kanmani ; Macclune, Karen ; Dixit, Kanchan Mani; Yadav, Shobha Kumari ; Maharjan, Rajani; Dugar, “Risk Nexus Urgent case for recovery: what we can learn from the August 2014 Karnali River floods in Nepal,” no. August, p. 44, 2015.

[13] G. W. Brunner, “HEC-RAS, River Analysis System Hydraulic ReferenceManual, Version 4.1. US Army Corps of Engineers-Hydrologic Engineering Center-HEC, Davis, CA,” 2016.

[14] S. E. Howarth and N. K. Lal, “Irrigation and participation: rehabilitation of the Rajapur project in Nepal,” *Irrig. Drain. Syst.*, vol. 16, no. 2, pp. 111–138, 2002.

[15] S. Dangol, “Use of Geo-Informatics in Flood Hazard Mapping: A Case of Balkhu River,” *J. Geoinformatics, Nepal*, vol. 13, pp. 52–57, 2017, doi: 10.3126/njg.v13i0.16937.

[16] R. Awal, “Application of Steady and Unsteady Flow Model and GIS for Floodplain Analysis and Risk Mapping: A Case Study of Lakhandei River, Nepal.,” 2003.

[17] J. Teng, A. J. Jakeman, J. Vaze, B. F. W. Croke, D. Dutta, and S. Kim, “Flood inundation modelling: A review of methods, recent advances and uncertainty analysis,” *Environ. Model. Softw.*, vol. 90, pp. 201–216, 2017, doi: 10.1016/j.envsoft.2017.01.006.

[18] MoFE, “Vulnerability and Risk Assessment and Identifying Adaptation Options in the Forest, Biodiversity and Watershed Management in Nepal,” p. 124, 2021, [Online]. Available: https://www.mofe.gov.np/downloadsdetail/3/2018/98853603/

[19] S. Rehman, M. Sahana, H. Hong, and H. Sajjad, “A systematic review on approaches and methods used for flood vulnerability assessment : framework for future,” *Nat. Hazards*, no. 0123456789, 2019, doi: 10.1007/s11069-018-03567-z.

[20] T. B. Chhetri, Y. P. Dhital, Y. Tandong, L. P. Devkota, and B. Dawadi, “Observations of heavy rainfall and extreme flood events over Banke-Bardiya districts of Nepal in 2016–2017,” *Prog. Disaster Sci.*, vol. 6, p. 100074, 2020, doi: 10.1016/j.pdisas.2020.100074.

[21] DHM, “GOVERNMENT OF NEPAL MINISTRY OF SCIENCE, TECHNOLOGY AND ENVIRONMENT DEPARTMENT OF HYDROLOGY AND METEOROLOGY Study of Climate and climatic variation over Nepal,” no. June, 2015.

[22] A. T. N. Dang and L. Kumar, “Application of remote sensing and GIS-based hydrological modelling for flood risk analysis: a case study of District 8, Ho Chi Minh

city, Vietnam," *Geomatics, Nat. Hazards Risk*, vol. 8, no. 2, pp. 1792–1811, 2017, doi: 10.1080/19475705.2017.1388853.

[23] S. Karki, A. Shrestha, M. Bhattarai, and S. Thapa, "GIS Based Flood Hazard Mapping and Vulnerability Assessment of People due to Climate Change: A case study from Kankai watershed, East Nepal," *Underst. Clim. Chang. Impact Nepal*, no. January 2011, pp. 95–107, 2011, doi: 10.13140/2.1.4444.4962.

[24] ZELENHASIC E, "Theoretical Probability Distributions for Flood Peaks," *Colo State Univ (Fort Collins), Hydrol Pap 42*, no. November, 1970.

[25] D. Aryal, L. Wang, T. R. Adhikari, J. Zhou, and X. Li, "A Model-Based Flood Hazard Mapping on the Southern Slope of Himalaya".

[26] D. Aryal *et al.*, "A model-based flood hazard mapping on the southern slope of Himalaya," *Water (Switzerland)*, vol. 12, no. 2, 2020, doi: 10.3390/w12020540.

[27] F. E. Hicks and T. Peacock, "Suitability of HEC-RAS for Flood Forecasting," *Can. Water Resour. J.*, vol. 30, no. 2, pp. 159–174, 2005, doi: 10.4296/cwrj3002159.

[28] Q. Zhou, P. S. Mikkelsen, K. Halsnæs, and K. Arnbjerg-Nielsen, "Framework for economic pluvial flood risk assessment considering climate change effects and adaptation benefits," *J. Hydrol.*, vol. 414–415, pp. 539–549, 2012, doi: 10.1016/j.jhydrol.2011.11.031.

[29] D. K. Gautam and K. Dulal, "Determination of Threshold Runoff for Flood Warning in Nepalese Rivers," *J. Integr. Disaster Risk Manag.*, vol. 3, no. 1, pp. 125–136, 2013, doi: 10.5595/idrim.2013.0061.

[30] M. S. A. Chyon, S. Biswas, M. S. Mondal, B. Roy, and A. Rahman, "Integrated assessment of flood risk in Arial Khan floodplain of Bangladesh under changing climate and socioeconomic conditions," *J. Flood Risk Manag.*, no. November, pp. 1–21, 2023, doi: 10.1111/jfr3.12876.

[31] F. Modeling, R. Sensing, and S. Images, "Application of Remote Sensing and Gis for Flood Risk Analysis : a Case Study At Kalu- Ganga River , Sri Lanka," *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.*, vol. XXXVIII, no. 8, pp. 110–115, 2010.

Appendix 1: Check Lists for KII and Focus Group Discussion

Check list for KII

Key informants:

Name:

Address:

Occupations:

Age:

1. How often do you experience the flood events in this area?
2. In which month do you experience most of the flood events?
3. Do you think that the flood is natural periodic events, or it is triggered by climate factors like high intense or unpredictable rain?
4. What do you know about flood events in the area over the time till now? (Maybe from the past 30-50 years)
5. How many infrastructures have been affected by the flood in this year?
6. What method do people adopt to prevent from flood before and after flood in this area?
7. What types of people have been affected mostly by the flood in this area?
8. Is there any early warning system in this area?
9. What do people of this area know about the climate change and its effect?
10. In your prior experience what would be the best option to prevent from flood?

Appendix 2: Check list for Kobo tool for Household survey.

Sensitivity

1. Types of flood tolerance crops
   a. 80-100%..........................(1)
   b. 60-80%............................(2)
   c. 40-60%..............................(3)
   d. 20-40% …………………(4)
   e. 0-20 %…………………..(5)
2. Population distributions
   a. Men/women
   b. Children
   c. Disable
   d. Pregnant
   e. Old age people above 75 years

3. Nature of House
    a. Cement + Brick + Roof top
    b. Cement +brick +Roof
    c. Mud + Brick + Roof
    d. Mud+ wood + Roof
    e. Mud + straw + Roof
4. Main occupation
    a. Agriculture
    b. Horticulture
    c. Shopkeeper
    d. Laboure
    e. Foreign employment
5. Types of settlement
    a. Isolated
    b. Dispersed
    c. Nucleated
    d. Linear
    e. Integrated

Exposure

1. Distance from River flowline
    a. 200-300m
    b. 150-200m
    c. 100-150m
    d. 50-100m
    e. 1-50m
2. No. of people involve in agriculture.
    a. 0-2
    b. 2-4
    c. 4-6
    d. 6-8
    e. 8-10
3. Land used type near your house.
    a. Forest
    b. Industrial
    c. Residential
    d. Barren
    e. Agriculture
4. No. of children below 11 years
    a. 0-2
    b. 2-4
    c. 4-6
    d. 6-4
    e. 4-5
5. Exposure agriculture land area (Katha)
    a. 1-5
    b. 5-10

c. 10-15
d. 15-20
e. 20- 30

Adaptive Capacity

1. No. of literate people
   a. 1-3
   b. 3-5
   c. 5-7
   d. 7-10
   e. 10-12
2. Types of embankments
   a. Modern earth fill
   b. Traditional earth fill
   c. Modern stone fill
   d. Traditional earth fill
   e. Wood + rope
3. Early warning system
   a. Yes ………..(5)
   b. No ………..(1)
4. No. of Trained person
   a. 0-2
   b. 2-5
   c. 5-7
   d. 7-10
   e. 10-12
5. No. of cattles
   a. 0-2
   b. 2-5
   c. 5-7
   d. 7-10
   e. 10-12

Appendix 3: Flood Hazard Area with successive return period

a. Flood Hazard Area of wads of Rajapur

Ward No.	5 YRP	10 YRP	20 YRP	50 YRP	100 YRP	200 YRP	500 YRP	1000 YRP
1	9.31	10.05	10.56	10.93	11.17	11.37	11.60	11.75
2	5.54	6.58	7.37	8.18	8.65	9.03	9.46	9.71
3	7.65	8.35	8.84	9.27	9.56	9.78	10.05	10.23
4	8.05	8.90	9.42	9.81	10.09	10.41	10.79	10.97
5	6.67	8.18	9.35	10.31	10.93	11.42	11.99	12.53
6	7.35	8.03	8.60	9.05	9.38	9.62	9.92	10.15
7	4.56	5.19	5.64	5.96	6.133	6.27	6.44	6.55
8	5.29	6.29	6.93	7.38	7.72	8.01	8.29	8.45
9	4.15	4.90	5.42	5.83	6.12	6.41	6.65	6.79
10	14.44	14.85	15.31	15.67	15.89	16.07	16.25	16.36

b. Percentage of hazard area of different ward s of Rajapur

Ward No.	5 YRP %	10 YRP %	20 YRP %	50 YRP %	100 YRP %	200 YRP %	500 YRP %	1000 YRP %
1	69.90	75.5	79.33	82.12	83.87	85.41	87.14	88.27
2	46.40	55.04	61.38	68.44	72.34	75.56	79.1	81.2
3	59.43	64.85	68.6%	71.96	74.18	75.92	78.02	79.41
4	55.40	61.26	64.86	67.5	69.44	71.66	74.25	75.44
5	44.27	54.28	62.02	68.41	72.48	75.79	79.56	83.15
6	59.95	65.51	70.10	73.85	76.5	78.5	80.9	82.8
7	54.95	62.55	67.90	71.9	73.9	75.65	77.6	78.97
8	54.7	64.24	70.71	75.1	78.83	81.8	84.7	86.35
9	40.94	48.41	51.87	57.5	60.4	63.3	65.68	67.06
10	76.6	78.12	81.26	83.17	84.36	85.27	86.26	86.84

Appendix 4: Photo Plate

1. **Type of House**




2. **People showing the depth of flood this year**


4. Type of embankment




5. Land used type


6. Key Informant Interview

7. Focus Group Discussion