Assessing the Status and Effectiveness of Dykes in Lower Karnali River Basin, Rajapur Municipality, Bardiya, Nepal

1*Gaurav Neupane 1Ajay B. Mathema
1*School of Environmental Science and Management, Pokhara University, Nepal

Introduction

- Different flood control strategies have been practiced from ancient times such as “reforestation, and construction of leeves, dams, reservoirs and channels” to divert flood water.
- Dykes have had been being used for centuries in China and the Netherlands as flood defence to protect human lives and economically important areas from the rise of river and sea water (Silva, Dijkman and Loucks, 2004; Yu, 2010).
- The construction of 40 KMs embankment, was initiated in 2014 along the Karnali river basin in Rajapur, as “the only solution” to cope with the floods, but flooding is still a problem, with significant flooding in 2017, 2020, and 2021(Gladfelter, 2017; LDCRP, 2021).

Objectives

- To study the distribution and structure of dykes used in lower Karnali river basin, Rajapur.
- To study the status of dykes lower Karnali River basin, Rajapur.
- To compare the impacts of flood before and after the construction of dykes in lower Karnali river basin, Rajapur.

Materials and Method

Primary data collection

Coordinates of dykes where deteriorated were collected

Key Informant Interviews (village chiefs, senior citizens, members of local clubs and NGOs, as well as the administrative officer of Rajapur municipality)

Household surveys with gps location

Secondary data collection

Rajapur Municipality Publications

BIPAD portal

Karnali River Management Committee

Journals, articles & publications of various I/NGOs

River discharge data from DHM

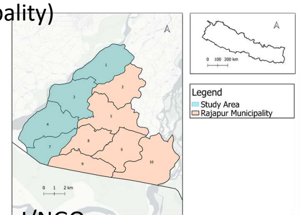


Fig: Map of the Study Area

Results and Discussion

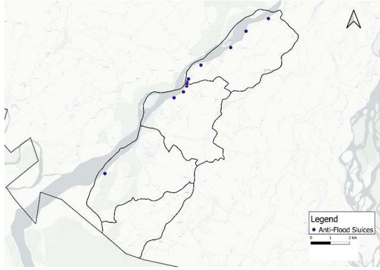


Fig: AFS in the study area

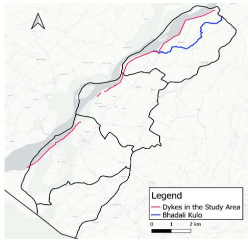


Fig: Dykes in the study area

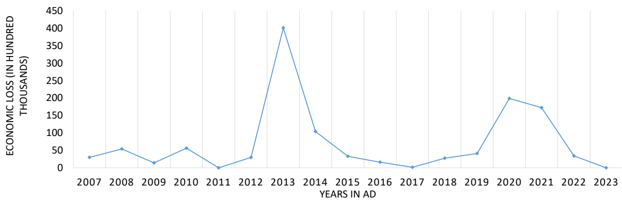
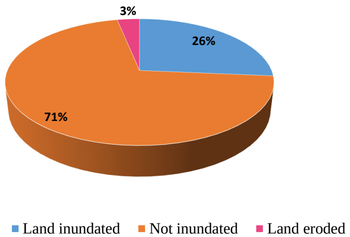
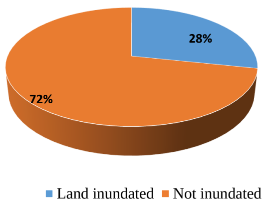


Fig: Economic loss of study area (2007-2023) (Source: BIPAD portal, LDCRP, KRMP)

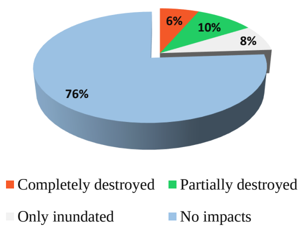
Impacts of flood on land (2007-2014)



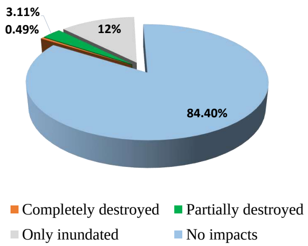
Impacts on land (2015-2023)



Impacts of flood on Houses (2007-2014)



Impacts of on Houses (2015-2023)



Challenges of dykes

1. Backflow of Bhadali Kulo

Fig: Meeting point of Bhadali Kulo and Karnali

2. Sediment deposit in Geruwa Khola

2005 2022

Fig: Flow of the Karnali River in 2005 and 2022

3. Budi Kulo

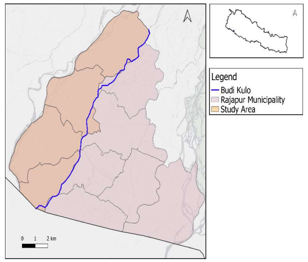


Fig: Budi Kulo

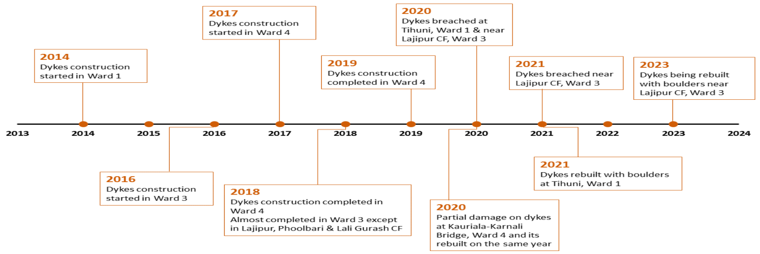


Fig: Timeline of dykes construction and breaching

Conclusion

Even though dykes are considered as the only flood prevention measure, it has breached at multiple locations, in multiple times in less than a decade.

References:

Silva, W., Dijkman, J.P.M. and Loucks, D.P. (2004) ‘Flood management options for The Netherlands’, *International Journal of River Basin Management*, 2(2), pp. 101–112. Available at: https://doi.org/10.1080/15715124.2004.9635225
Yu, C.W.F. (2010) ‘Indoor and Built Flooding and EcoBuild – Strategies for the Future : Dykes , Dams , SUDS and Floating Homes’, 44(0), pp. 595–598. Available at: https://doi.org/10.1177/1420326X10388063.
Gladfelter, S.R. (2017) Training Rivers, Training People: Interrogating the Making of Disasters and the Politics of Response in Nepal’s Lower Karnali River Basin.
LDCRP (2021) ‘Local Disaster and Climate Resilience Plan’.

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Assessing the Status and Effectiveness of dykes in Lower Karnali River Basin, Rajapur Municipality, Bardiya, Nepal

Gaurav Neupane

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Assessing the Status and Effectiveness of dykes in Lower Karnali River Basin, Rajapur Municipality, Bardiya, Nepal

Supervised by Associate Professor Ajay Bhakta Mathema

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

Gaurav Neupane

P.U. Registration No.: 2021-1-25-0006

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December 2023

DECLARATION

I, Gaurav Neupane, hereby declare that, the Project paper entitled, **Assessing the Status and Effectiveness of dykes in Lower Karnali River Basin, Rajapur Municipality, Bardiya, Nepal** is my original work and has not been submitted anywhere else for any academic award. All literature, data, or works done by others and cited within this report has been given due acknowledgment and listed in the reference section.

……………………………………

Gaurav Neupane

P.U. Registration No.: 2021-1-25-0006

December 2023

LETTER OF RECOMMENDATION

The thesis attached hereto entitled "Assessing the Status and Effectiveness of dykes in Lower Karnali River Basin, Rajapur Municipality, Bardiya, Nepal" was prepared and submitted by Gaurav Neupane in partial fulfillment of the requirement for the Degree of Master of Environmental Management under my supervision and is hereby accepted**.**

…………………………………

Supervisor

Ajay Bhakta Mathema

Associate Professor

School of Environmental Science and Management

CERTIFICATE

This is to certify that the thesis entitled "Assessing the Status and Effectiveness of dykes in Lower Karnali River Basin, Rajapur Municipality, Bardiya, Nepal" submitted by Gaurav Neupane 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.

……………………..

Associate Professor Ajay Bhakta Mathema

School of Environmental Science and Management

Date:

…………………………….

External Examiner

Date:

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Praveen Kumar Regmi

MSc. Program coordinator

School of Environmental Science and Management

Date:

LETTER OF APPROVAL

This dissertation paper submitted by Gaurav Neupane entitled “Assessing the Status and Effectiveness of dykes in Lower Karnali River Basin, Rajapur Municipality, Bardiya, Nepal” has been accepted for the partial fulfillment of Master of Science in Environmental Management from Pokhara University.

……………………………………..

Associate Professor Ajay Bhakta Mathema

Principal

School of Environmental Science and Management

December 2023

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December 2023

ACRONYMS

BIS – Bureau of Indian Standards

CIRIA – Construction Industry Research and Information Association

CWC – Central Water Commission

DWIDP – Department of Water Induced Disaster Prevention

EU – European Union

FEMA – Federal Emergency Management Agency

FGDs – Focus Group Discussions

GIS – Geographic Information Science

GPS – Global Positioning System

KIIs – Key Informant Interview

KRMP – Karnali River Management Project

LDCRP – Local Disaster and Climate Resilience Plan

MoHA – Ministry of Home Affairs

NDRRMA – National Disaster Risk Reduction and Management Authority

QGIS – Quantum Geographic Information

UNDRR – United Nations Office for Disaster Risk Reduction

USACE – United States Army Corps of Engineers

VDCs – Village Development Committees

WECS – Water and Energy Commission Secretariat

ABSTRACT

Different flood adaptation techniques have been employed in Rajapur to prevent and control flood, but flood is still a problem there. One of the adaptation measures is the construction of dykes along the Karnali River. This study examines the status as well as effectiveness of dykes in Lower Karnali River Basin, Rajapur. Firstly, the design of the dykes is compared with some guidelines and the coordinates of areas which are in need of maintenance are collected and mapped on QGIS. Similarly, the impacts before and after the construction of dykes are compared in this study. In less than a decade of construction of dykes, it has breached in multiple locations; flooding Rajapur on several occasions. In addition, the dykes is not continuous: resulting areas without dykes vulnerable to flooding. Moreover, the breakage of dykes as well as the run off coming from Geruwa Municipality might be responsible for flooding in Rajapur almost every year. The study also found that the poor drainage system for the accumulated water on the land ward side into the river causes water logging for a long time. Similarly, spurs were also deteriorating in multiple locations and sediment deposition was high between spurs. The erosion of agricultural land and complete destruction of houses was found to be significantly lower after the construction of dykes, although prevention of flooding has not been achieved. This study suggests for more research to identify and monitor weak points on the dykes using fluid dynamics principles and hydraulic engineering software.

Keywords: flood adaptation, dykes and flood adaptation, flood in Rajapur

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Flood is one of the most common natural hazards, which has disastrous impacts especially in poor countries. Floods pose threat to livelihoods of people and also influence the development globally [1]. Increase in population and economic assets in the regions prone to flooding will likely increase the exposure to flood by three fold by 2050 [2]. If the global temperature rises to 1.5 °C, loss of human lives from flooding will increase by 70-83% and the damage by the flood will increase by 160-240% in comparison to 1976-2005 [3].

The worldwide increase in floods are mostly due to "global warming, weather change and urbanization" [4]. Global warming has increased the rate of snow melt runoff, which directly influences flood [5]. Precipitation during monsoon along with early snowmelt results flooding in the Himalayas [6]. Flood risk is directly related to "land use and land cover change and expected annual damage" [7]. The croplands, pastures, wilderness and forests have been converted into impervious urban surfaces such as housing, commercial spaces, industries, highways and streets, which has reduced infiltration and increased surface runoff, resulting floods [8], [9].

About 23% of global population are directly affected by flood, most of whom live in South and South East Asia [1]. Floods damage crops, infrastructure, buildings and can kill people [10]. In the last two decades, floods accounted about 44% of all disaster event, which affected 1.6 billion people globally, while Asia had the highest impacts, experencing majority of all the flooding events affecting more than a billion people [11].

Different flood control strategies have been practiced from ancient times such as "reforestation, and construction of leeves, dams, reservoirs and channels" to divert flood water. One of the flood adaptation methods is dykes. Dykes have had been being used for centuries in China and the Netherlands as flood defence to protect human lives and economically important areas from the rise of river and sea water [12], [13]. A dyke is an embankment built to prevent flooding, stop the sea, or confine a river to a specific flow, usually only temporarily loaded due to flooding. Dykes are usually made of various natural materials such as soil and rock often supplemented with other materials, such as geosynthetics [14]. Geosynthetics are products made of synthetic or natural polymeric materials, which are used in contact with soil or rock and/or other geotechnical materials [15]. As climate change is increasing the levels and frequencies of floods, people tend to increase the height of the dykes and strengthen it to cope with the increasing water level. This might turn into a disaster if the dyke breaches, as flood levels in the rivers is increasing, so as the economy and population of low lying countries [16].

1.2 Problem Statement

Nepal ranks 20th in the list of flood prone countries in the world [17]. The study area, Rajapur, is very vulnerable to flooding in monsoon as well as in pre-monsoon season, especially the wards along the Karnali river basin i.e. wards 1, 3, 4, and 7. The Rajapur area was flooded significantly in 2009, 2013, and 2014. The flood of 2014 in Karnali river killed 222 people and affected 120,000 people, as well as destroyed infrastructures and properties of people and displaced many of them [18]. Climate change is increasing the frequency of river floods as well as drought [19]. Water Induced Disaster Prevention Division (WIDP), a governmental agency constructed few dykes and spurs along the Karnali river, but lacked resources to scale up their work [20]. The construction of 40 KMs embankment, was initiated in 2014 along the Karnali river basin in Rajapur, as "the only solution" to cope with the floods, but flooding is still a problem, with significant flooding in 2017, 2020, and 2021[21], [22].

1.3 Research Questions

- Where are dykes located along the Karnali River in Rajapur?
- What are the construction materials of dykes in Rajapur?
- What is the dimension of the dyke?
- What were the impacts from flood before and after the construction of dykes?
- What is the condition of dykes after the flood of 2023?

1.4 Objectives

1.4.1 General Objective

- To assess the status and effectiveness of dykes in Lower Karnali River basin in Rajapur, Bardiya.

1.4.2 Specific Objectives

- To study the design of dykes used in lower Karnali river basin, Rajapur.
- To study the status of dykes lower Karnali River basin, Rajapur.
- To compare the impacts of flood before and after the construction of dykes in lower Karnali river basin, Rajapur.

1.5 Rationale of the study

Rajapur has several flood adaptation strategies to protect human lives, assets, cattle as well as agricultural crops. Dykes have been created along the Karnali River to channel its flow. These structure help to reduce the impacts of flood water by preventing it from entering human settlements. Although, many strategies are adapted as a means to control and prevent floods, no studies have been done to assess whether they are performing effectively or not. This study will try to compare the impacts before and after the construction of dykes, and help to find whether the dykes are able to reduce the impacts or not.

1.6 Limitations

- This research includes the wards along the Karnali river of Rajapur municipality but not that of Geruwa Rural Municipality, the adjacent Municipality with similar geography and adaptation measure.
- This study does not include the principles of fluid dynamics.
- This research focuses on past and present flood scenario but does not include future flood scenario, including climate change scenario.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of Floods

Flood risk particularly more prevalent in South Asia and Pacific region with 668 million people (28% of its total population) exposed to flood. Rentschler and his colleague found that between 9–20% of the regional populations of Sub-Saharan Africa, Europe and Central Asia, Middle East and North Africa, Latin America and the Caribbean, and the United States and Canada are exposed to high flood risk [1]. On average, 163 flood events occur each year globally, and are the most common disaster in the world. River flooding causes damage of € 7.8 billion/year and more than 170,000 people are exposed to river flooding in the European Union (EU) [23]. China is the most affected country due to flood, which affected 900 million people in last two decades [11]. About 1.81 billion people live in the locations that are vulnerable to floods [1]. Not all people in a community are affected equally due to flood, some may suffer "direct damage" to their property, while some may not suffer from such damage [24]. The global average of damaged caused by flood is about € 110 billion per year [3].

Flood usually occurs due to heavy rainfall, snowmelt, dam failures, rising of groundwater and land subsidence [25]. Rainfall along with the snowmelt increases the risk of flood [6]. Anthropogenic activities of construction of dams, irrigation and other developmental activities such as construction of roads, buildings etc. near river basin can reduce drainage channel and affect the free flow of water, which can also cause flood [26]. Impervious surfaces reduce infiltration and increase frequency and intensity of downstream runoff, which also influences flood [27].

2.2 Floods in Nepal

Nepal has more than 6000 rivers and streams [28]. Major rivers of Nepal usually flood in monsoon, as more than 80% of Nepal's rainfall falls in four months of monsoon season, which causes severe damages in Terai region. Nepal's rugged topography, haphazard land use, melting of snow, outburst of the glacier lake, and concentrated monsoon rain are a few key causes of water-induced disaster [29], [30]. Flood hazard in Nepal is due to improper land use plan, unplanned distribution of human settlement, and deforestation in upstream watershed [31], [32]. The natural flow of rivers has also been disturbed due to the barrages and embankments built by India at Nepal-India border, which has led to flooding in the Terai region of Nepal [33]. Nepal had have suffered from several floods, and many of which have resulted in significant loss of life as well as the economy. Flooding and inundation are major issues in Terai, which changes river course and causes bank erosion and erosion in river meanders due to the suspended load carried by the river [34]. In 2018/19, 418 flood incidents occurred in Nepal, which killed 183 people and affected 16,196 families, with the estimated loss of NRs. 60,944,400 [35].

In 2014, 21 Village Development Committees (VDCs), 2 Municipalities, were affected by the flood in Bardiya district, which completely damaged 3,859 houses and partially damaged 13,517 houses affecting 93,030 people. It also killed 31 people and 15 were disappeared. The estimated cost of this disaster was about NRs. 3 arba 75 crore [22]. Flood is the major disaster in Rajapur municipality too. This region saw floods in 1995, 1998, 1999, 2000, 2003, 2007, 2008, 2009, 2012, 2013, 2014, 2017, 2020, and 2021 [18], [22].

2.3 Dykes as a flood adaptation measure

Dykes have been in use to prevent flood since ancient time. Chinese used dykes in the Yellow river to raise the river banks [12]. Dykes are used to protect economically important part of the Netherlands from flooding [13]. They are also useful to reduce the impacts of flood on our society [36].

Traditionally, emergency dykes were constructed from materials that are locally available. This consisted mainly of sediment and vegetation residues, and these structures would be different in different areas due to difference in construction materials. Soil, more preferably coarse soil are used to fill textile bags, cement bags, tubes and mattress [37].

Embankment/levee is a manmade bank, which is built along banks of a river to protect adjacent land from inundation by flood. This structure is also called ‘embankment’, ‘stop-bank’, ‘bund’ or ‘dyke’ [38]. Dykes and levees perform same purpose and are often used interchangeably, with one difference. Dykes are flood barriers and without its presence, a particular area of land would be under water all the time, while levees are flood control method used to protect the land from the flood water which other-wise will be below ground [39]. The term dyke is commonly used in Britain, while the term levee is more preferable in the United States [40]. Levees are the embankment which are built along the river bank in order to prevent flooding [41]. They are built by using compacted soil or concrete, and are designed to contain and redirect flood water. Levees raise the banks of the river channel and help protect nearby land from inundation during high water events.

Dykes usually have spurs/groynes. Spurs/groynes are structures constructed transverse to the river flow and extend from the bank into the river. Spurs can be permeable or non-permeable, as well as submerged or non-submerged. These structures protect the riverbank on which they are located and deflect the main current according to their orientations. The orientation of both permeable and impermeable spurs should be kept at 90 degrees to the main flow direction for general purpose [37]. Spurs can be made from several locally available materials. Timber, bamboo, boulders/gabion filled boulders etc. are some of the common practices of building spurs [42].

According to Bureau of Indian Standards, embankment can be classified into two categories, i.e. Homogenous embankments and zoned embankments. Homogenous embankments are practically uniform throughout their construction, meanwhile zoned embankments consist of an inner or impervious section which is often supported by two or more outer sections of relatively pervious materials [38].

Source: Bureau of Indian Standards (2000)

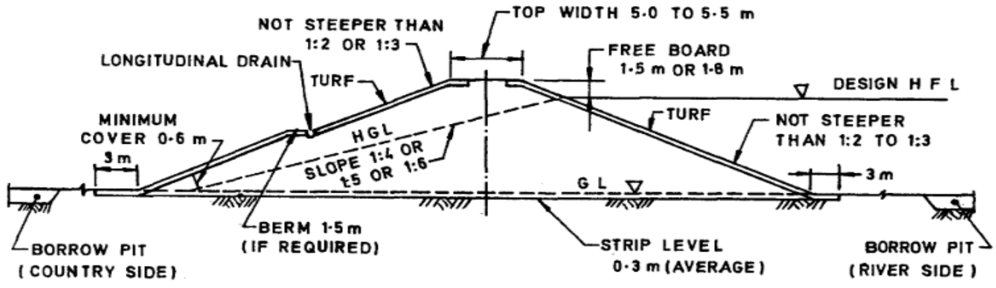


Figure 1: Cross section of homogenous embankment

Source: Bureau of Indian Standards (2000)

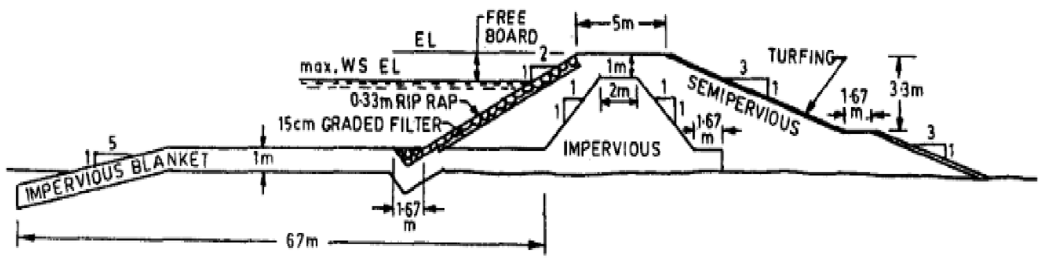


Figure 2: Cross section of zoned embankment

Source: Bureau of Indian Standards (2000)

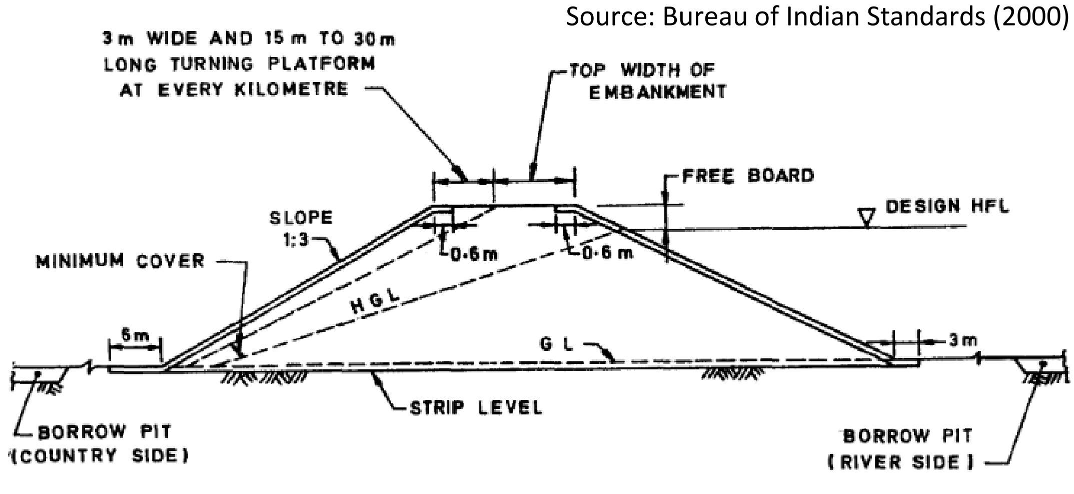


Figure 3: Typical cross section of an embankment

These structures are sustainable means of flood defenses, but they can become ineffective over the years, and can breach within few minutes, if they are exposed to high levels of flood water [43]. Building embankments in one location with insufficient "knowledge of the dynamics of river" can affect the other location [20]. During extreme floods, the dykes or embankment can breach releasing the flood water, which can have high destructive power [44]. Grasses, shrubs and smaller plants help to stabilize dyke slopes, but the deep rooted trees might weaken these structures over time through seepage [45]. Some of the reasons for earthen embankment failure are overtopping, foundation and structural defects, and piping [46].

The flood of 2014 was the most disastrous flood in the history of Karnali river, which reached even in the safe areas [47]. So, construction of 40 KMs of embankment along the Karnali River was initiated in 2014. In Rajapur, dykes are seen as the most effective measure to cope with the impacts of flood [21].

2.4 Building materials of dykes

2.4.1 Gabions/gabion mattresses

The gabions are rectangular boxes made of square or hexagonal double twist steel wire mesh filled with the small size boulders, while gabion mattresses are smaller in size than gabions normally between 0.15m to 0.50m thick. For the rivers with velocities 4m/s or more, there is hardly an alternative comparable to gabions [48]. Stones used for filling the gabion boxes or mattresses, and they should be clean, hard, sound, and angular rock fragments. The bed/foundation of the gabion structure should always be excavated and should be hard, flat and even [37].

2.4.2 Concrete blocks

Cement Concrete blocks are sometimes used in place of boulders for construction of bank revetment or slope protection of the embankment in those places where this is economical. The concrete blocks may be precast or can be casted in the site; however, precast blocks are mostly used and preferred too. These blocks may be cubical, cuboidal or in the shape of a tetrahedron. Concrete blocks may be loose non-interlocking or interlocking blocks [37].

2.4.3 Clay

Clay have been used to make dykes for several centuries [49]. The inner core layer is composed of sand which ensure that the water that enter can drain away. Outer layer is impermeable usually composed of clay, but it is sometimes supplemented by asphalt. The outer layer protects the sand core, while the inner layer provide support to the outer layer. It should also have drainage channel which helps to drain the water away, if the water enters, thus ensuring that the structure is not weakened by water saturation [50]. The use of finely graded soil and the soil with high organic matter is not preferable [51].

2.4.4 Sandbags

Sand bags are made from various materials, but the most common one is woven polypropylene. Sand is the used to fill and shape these sandbags. Silt and clay in bags will form a good dyke, but working with those materials is quite difficult. These bags are half filled with sand and are tied near the top. If it is tied, it permits the sand to move easily in the bag and creates a good dike. Overfilled bags and bags tied too low leave gaps in the dike, which allows water to seep through [52].

2.4.5 Riverbed materials

Riverbed materials such as soil, sand, and boulders are widely used in flood management works. Coarse soil free of organic matter are preferable, while angular and regular boulders are best [42].

2.4.6 Geo-synthetics

Geo-synthetics are synthetic materials, which are strong flexible sheets woven or non-woven, permeable, watertight membranes etc. and are used “to improve soil quality and performance in different applications like lining, drainage, filtration, separation, reinforcement and protection". Products like geo-mattress, geo-textile bags/tubes, geo-membrane, and geo-grid are used for specific application in flood management works. Geo-mattress are woven/non-woven polymers used for slope protection. Geo-textile bags are filled with sand and dredged materials are of 1-3m in diameter. Similarly, geo-membranes are thin sheets of polymeric materials the primary function of which is always containment as a liquid or moisture barrier or both. The use of geo- membrane is rapidly increasing for "soil stabilization, landfills, lagoons, lining, pavement, dams and spillways etc." A deformed/non deformed geo-grid can also be used for reinforcement by friction mechanism. Geo-grids are polymeric materials formed by intersecting ribs joined at junctions. [42].

2.5 Guidelines for dykes' construction

2.5.1 Location

Dykes are built on low-lying areas and are constructed parallel to the river bank to protect the areas behind dykes [53]. These structures should be kept at an appropriate distance from the riverbank to prevent potential erosion and land subsidence and should not be on the valuable land, historical or religious sites and on weak foundation. The construction of dykes should be at least 20m from the river bank [37], [54].

2.5.2 Height

The height of dykes is an important factor, as the dykes must be high enough to contain anticipated flood levels and prevent overtopping. Dykes are typically built 1-2 meters higher than the expected peak flood level to provide an adequate safety margin [55]. The specific height depends on historical flood data and hydrological modeling to predict potential future maximum flood heights [56].

2.5.3 Slope

If the height of the levee is less than or equal to 4.5m, then the slope should be 2:1(Horizontal distance to Vertical rise) on both the river side and the land side. If the height of the levee is greater than 4.5m or less than or equal to 6m, the slope should be 3:1 on both the river and land side [37]. The embankments/levees in countryside is usually in 3:1 ratio at every kilometer [38].

2.5.4 Width and Top Width

The top width of the embankment should be constructed for the dual-purpose i.e., for local road as well as for flood control. The road on the flood control structure is also called patrol road, which is useful for "inspection, maintenance and flood-fighting operations" [51]. In such case, the top width should be at least 5 m or a width adequate for the type of vehicular-traffic designed to use the embankment [37], [38]. The U.S. Army Corps of Engineers recommends building a dyke with a width at the base that is three times the dyke's height. Turning platforms should be available at every 1 km of the length of the embankment [42].

2.5.5 Drainage/sluices

Dykes should have drainage channels which help to drain the water away, if the water enters, thus ensuring that the structure is not weakened by water saturation [50]. Ditches can also constructed which can be used for irrigation and rearing fast growing fishes [57].

2.5.6 Cover and armor

Coir geotextiles are used for the protection of embankment in combination with grass. Coir is the fiber that surrounds the base shell of the coconut fruit [58]. Vetiver grass plantation on the slopes of embankments also helps to protect the slopes from erosion and run off [59]. The outer layer is sometimes supplemented by asphalt [50].

2.5.7 Free Board

The top of the embankment should be fixed so that there is no risk of overtopping [38]. The minimum free board of 1.5 m over the design High Flood Level is designed to carry the discharge up to 3000 m^3/s, while for a discharge higher than this has a minimum free board of 1.8 m.

2.5.8 Borrow pits

Generally borrow areas are made on the river side of the embankments and are located at a minimum distance of 25 m from the toe of the embankment for height less or equal to 6m, and 50m for height greater than 6m [37]. It is constructed in order to avoid the development of flow parallel to the embankment [60].

Table 1: Recommended distance and depth of borrow pits from Embankment toe

Distance of borrow pits (m) from toe	Maximum depth of borrow pits(m)	
	Riverside	Land side
25 to 50	1	0.6
50 to 75	1.5	0.6
75 to 100	2	0.6

Source: Handbook for flood protection, anti-erosion and river raining works, CWC (2012).

2.5.9 Turnings platforms

Turning platforms are required at every 1 km is a requirement [42].

2.5.10 Return Period

The return period of at least 25 years should be considered for constructing embankments in rural areas and 100 years for townships [38].

CHAPTER 3

METHODOLOGY

3.1 Study Area

Rajapur Municipality lies in Lumbini Province of Nepal, and covers an area of 127.08 sq. km. The Karnali River bifurcates at Chisapani and give rise to Geruwa Khola in the east of Rajapur, while Karnali River in the west. The altitude of this municipality lies within 142m-154m from sea level. The easting and northing coordinates of this area lies from 81°03’25.63”E to 81°12’52”E and 28°21’25.16”N to 28°29’43”N respectively [22]. According to the office of Rajapur Municipality, its total population is 69,873 out of whom, 34,561 are female and 35,352 are male. The Rajapur Municipality has 10 wards, out of which wards along the Karnali River i.e. 1, 3, 4, and 7 were selected as study area. There are 12,707 households in Rajapur municipality, and the study area has 5,077 households.

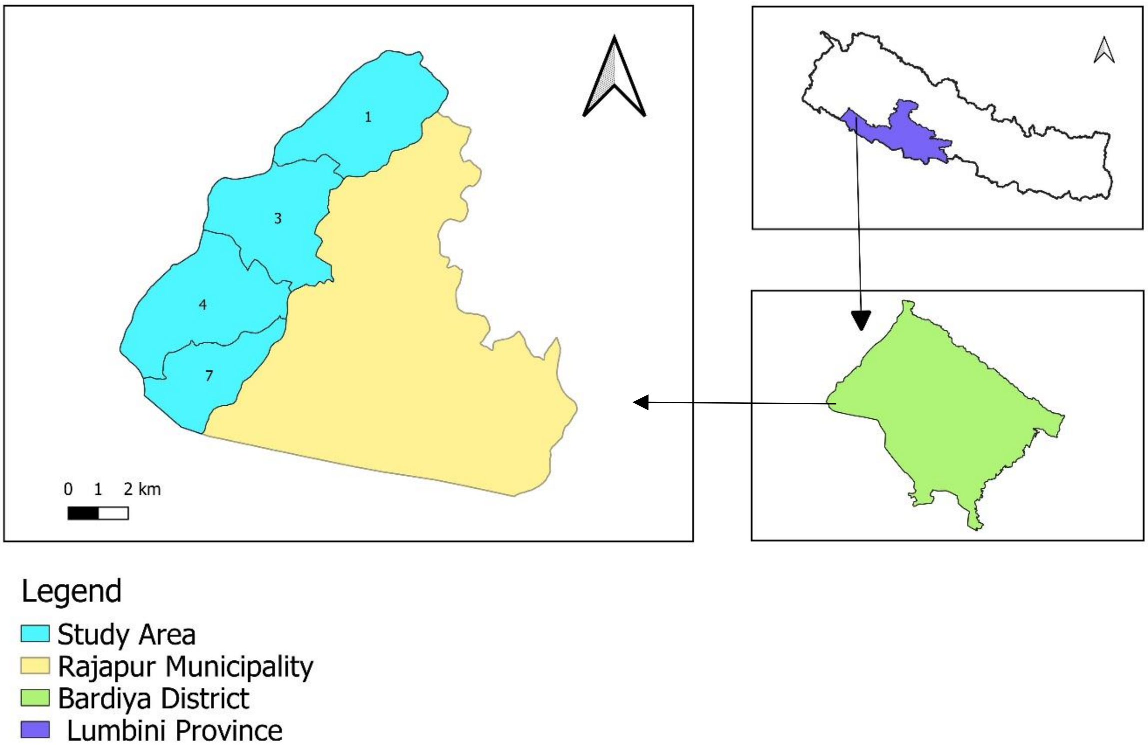


Figure 4: Map of the Study Area

3.2 Research design

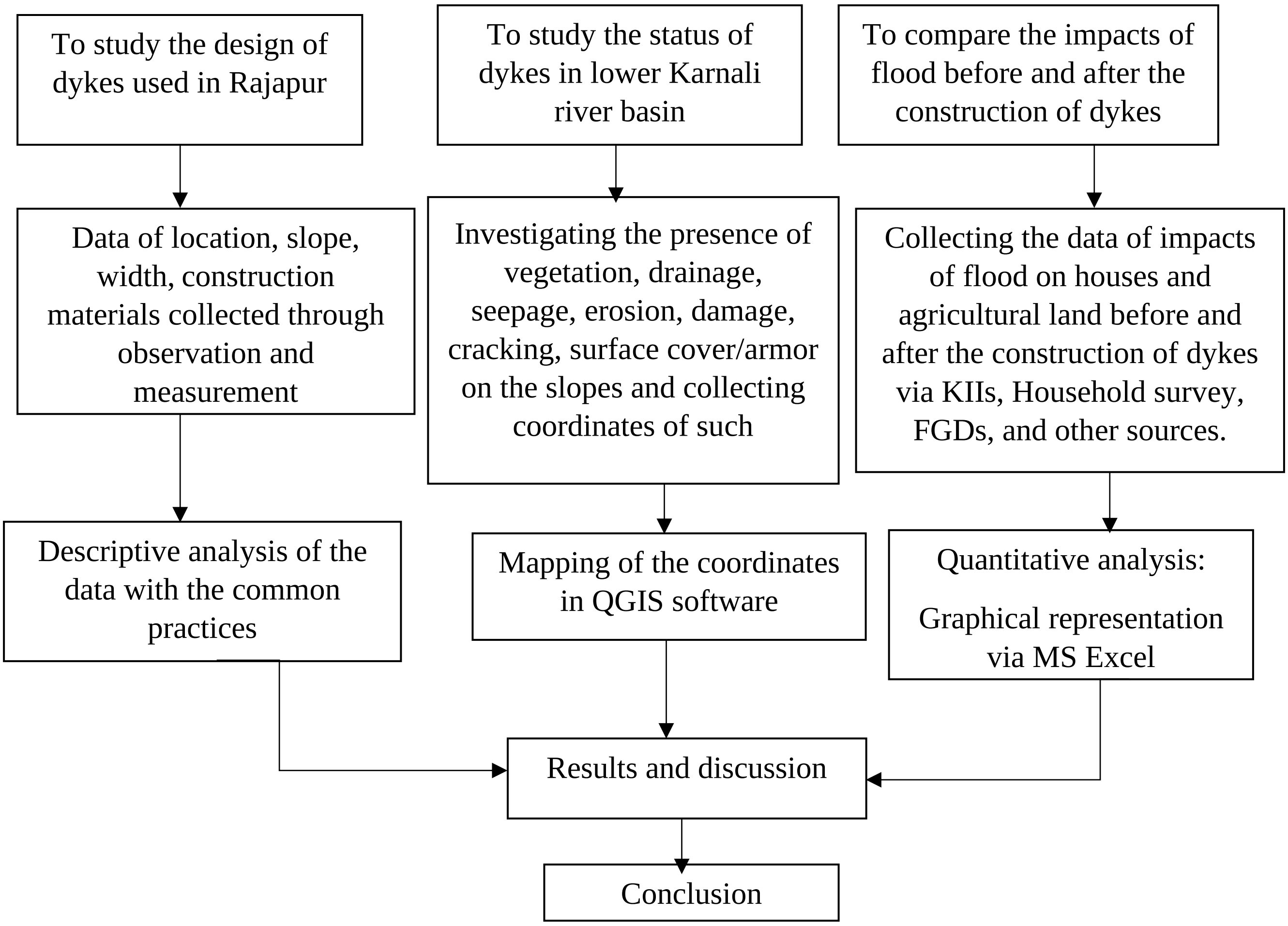


Figure 5: Flowchart of research design

3.3 Objective-wise research matrix

Table 2: Objective-wise research matrix

Objectives	Data needed	Data collection methods	Data analysis methods	Excepted outcomes
To study the design of dykes used in lower Karnali river basin, Rajapur	Data of location, slope, width, height, construction materials	Observation and measurement	Descriptive analysis and comparing with flood control guidelines and general practices	Design of dykes
To study the status of dykes in lower Karnali river basin, Rajapur	-Data about presence/absence of vegetation, drainage, seepage, erosion, damage, cracking, surface cover/armor on the slopes and collecting coordinates - Data about maintenance and monitoring system	Observation, KII, GPS collection	Qualitative analysis, QGIS software	Status of dykes in lower Karnali river basin
To compare the impacts of flood before and after the construction of dykes in Rajapur	Data of impacts of flood on houses and agricultural land before and after the construction of dykes	KIIs, Household survey, Municipality and other sources	MS Excel	Impacts of flood before and after the construction of dykes

3.4 Sampling Technique

Sample size is calculated using Slovin's formula,

$$n = \frac{N}{1+Ne^2}$$

Where,

n= sample size

N= total population of the item

e= error margin

According to Rajapur Municipality Housing Plan 2077 B.S., the study area i.e., wards 1, 3, 4, and 7 have 5,077 households, out of which 257 households are selected, with a confidence level of 90%.

3.5 Research methods

Both primary and secondary data collection methods were used in this research.

3.3.1 Primary data collection

Data regarding the location, height, slope, width and drainage of dykes were collected through field observation and measurement. The co-ordinates of dykes along with the areas that are damaged or deteriorating and are in need of maintenance were collected with a hand-held GPS. These co-ordinates were mapped via QGIS software. Meanwhile, the data about the impacts of flood before and after the construction of dykes were collected through Household surveys, Focus Groups Discussions (FGDs), and Key Informant Interviews (KIIs). Data were collected via KoboToolbox. In KIIs, village chiefs, senior citizens, members of local clubs and NGOs, as well as the administrative officer of Rajapur municipality were be interviewed.

3.3.2 Secondary data collection

Secondary data collection methods were also used to collect the information of impacts of flood before and after the construction of dykes in Rajapur municipality. Secondary data were collected from Rajapur Municipality Office, BIPAD portal, Karnali River Management Committee, and Local Disaster and Climate Resilience Plan (LDCRP) of Rajapur. Similarly, data and information were also collected from published journals, as well as from the articles, documents and reports of various NGOs and INGOs.

3.6 Data analysis

Data regarding the location, height, slope, width and drainage were compared with guidelines and common practices followed in Nepal and other countries. The collected co-ordinates of the areas of dykes, which are damaged, degraded or are in need of maintenance were mapped using QGIS software. Similarly, the impacts of flood before and after the construction of dykes were represented via MS Excel.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Dykes in Rajapur

4.1.1.1 Building Materials

The construction of dykes on lower Karnali river basin followed cut and fill method, where the riverbed materials such as clay, sand, and stones are excavated, and are used to build dykes. Similarly, clay from nearby regions were also brought for the purpose of constructing dykes. Boulders were also brought from the Chure region for this purpose. The parts of dykes which were partially or completely affected by floods in previous years are rebuilt with large boulders. One of the key informant reported that many boulders are as large as a spur and do not need much cost and resources for maintenance.

Angular and round boulders were packed on the gabion wire mesh to provide cover/armor to the riverside part dykes in the study area. The dimension of gabion used were 3*1*0.3m, 3*1.5*0.30m, 3*1*0.8m, 3*1.5*0.5m, 3*1.5*0.6m, and 3*1*0.6m. Machine woven as well as hand woven gabion were used in the study area. These gabions were galvanized.

4.1.1.2 Design of dykes

4.1.1.2.1 Location

The dykes on the lower Karnali river basin is constructed longitudinally along the length of the river. Majority of its sections are on the public land including the forest areas, especially in ward 4. The dykes were also built on private property too. According to the sub-engineer of Karnali River Management Project (KRMP), no compensation schemes were available.

4.1.1.2.2 Height

The height of the dyke on the lower Karnali river basin is approximately 7-8 meter, depending on the geography of the riverbank. Taller dykes can accommodate large amount of water.

4.1.1.2.3 Slope

The slope of the dykes on the lower Karnali river basin was 2:1 on both riverside as well as on land ward side.

4.1.1.2.4 Width and top width

The top width of the dykes on the Karnali river basin is 5m. Similarly, the bottom width of the dyke is 24-27m, which is almost three times the height of the dykes.

4.1.1.2.5 Turnings platforms

A turning for vehicles is available approximately at every section of 0.76 km-1 km in the study area.

4.1.1.2.6 Anti-flood sluices/drainage

According to Karnali River Management Project office, anti-flood sluices were constructed in 11 locations of the study area. Among them, 5 were constructed in Ward 1, 5 were constructed in Ward 3, and 1 in Ward 4. These sluices closes when the discharge in the river is high so that this prevents entering of river water, and opens when the river discharge is low, allowing the drainage of water collected behind the dykes.

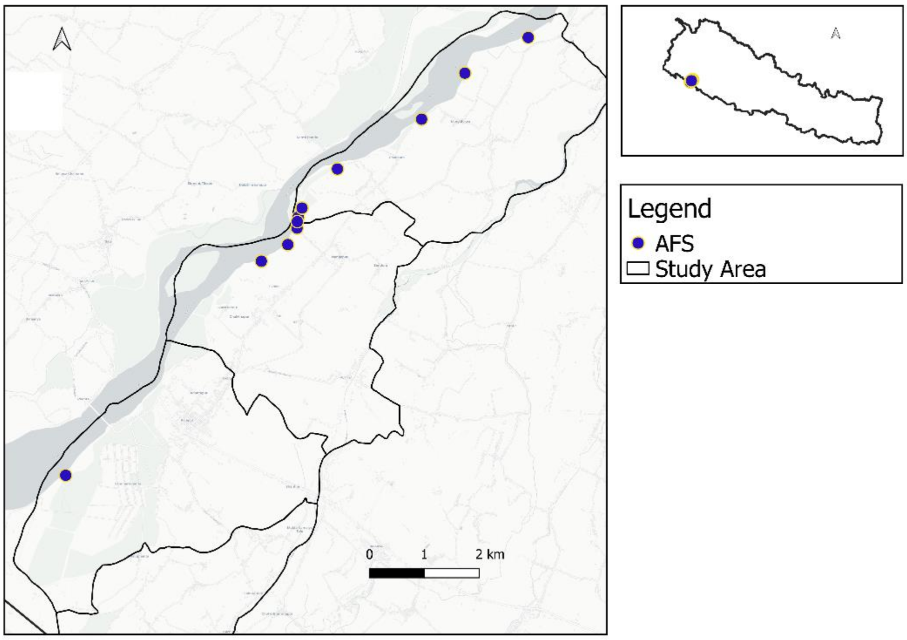


Figure 6: Locations of Anti-flood sluices

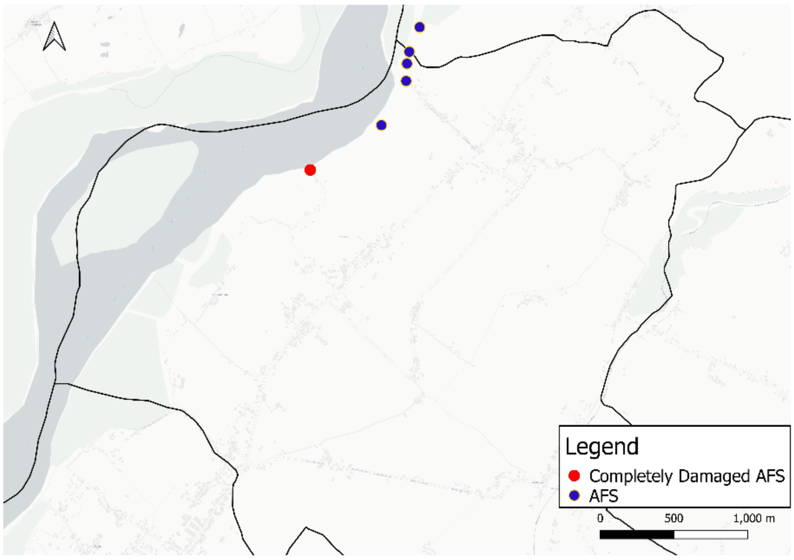


Figure 7: Completely damaged Anti-flood sluice (Ward 3)

4.1.1.2.7 Cover/armor

The stones of the river packed in the gabion mattress protect the slope of the dykes. These stones are round as well as angular which helps in slope protection.

Figure 8: Riverside slope of the dyke

4.1.1.2.8 Free board

The free height of the dykes in the study area is in the range of 1.5m-2m, which aligned with the common standard of South Asia.

4.1.1.2.9 Length

The length of dykes on the study area is 11.39 KM, out of which 6.11 KM is in ward 1, 1.9 KM in ward 3, and 3.38 KM in ward 4.

The stretch of 2.05 KM along the river basin of study area does not have dykes, out of which 0.41 KM in ward 1, 1.39 KM in ward 3, and 0.25 KM in ward 4. The stretch of 0.72 KM (0.50 KM in ward 1 and 0.22 KM in ward 3) was found to be damaged from the flood of 2078 BS and is still under maintenance. According to KRMP, the maintenance is being done with large boulders brought from nearby regions as well as from Chure region.

4.1.1.2.10 Launching

The launching of 15-20m were built in the study area in order to prevent scouring of the dykes.

4.1.1.2.11 Burrow pit

Burrow pits were not observed in the study area.

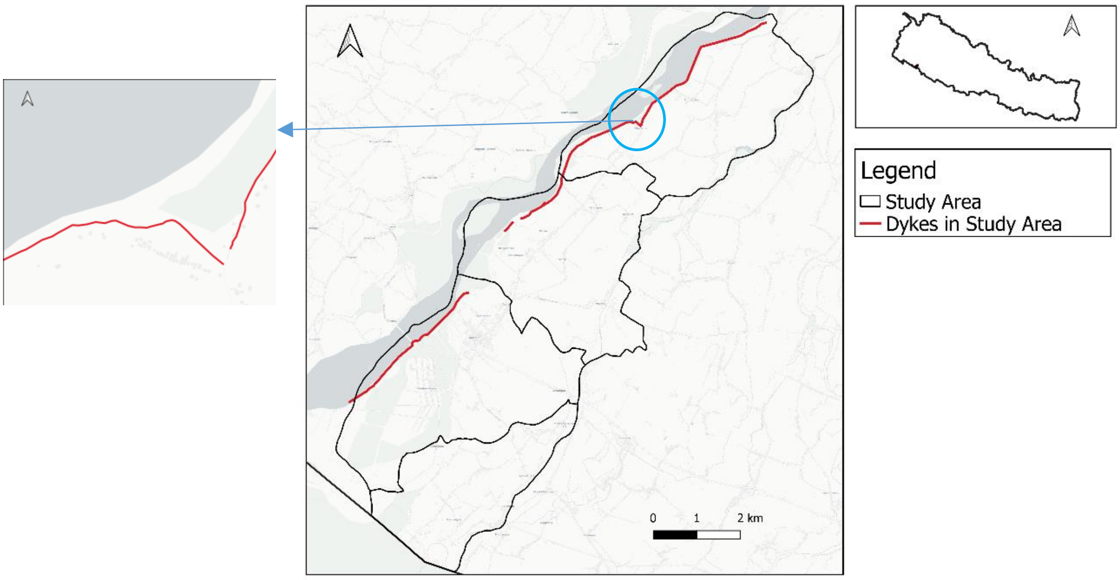


Figure 9: Dykes in the study area

4.1.2 Spurs and studs

There are 287 spurs and studs remaining along the length of dykes in the study area i.e. 32 spurs and 135 studs in Ward 1, 9 spurs and 39 studs in ward 3, 6 spurs and 66 studs in ward 4. The spurs as well as studs are placed at the interval of Length (L)*3 along the length of the dykes. The height of the spurs is approximately 4 meter and the length is approximately 24 meter. Studs are smaller in length and height than spurs, approximately 17 meter in length and 2 meter in height. Inclined spurs were also observed in the study area. Spurs in the study area are constructed with gabion boxes filled with boulders. These spurs are semi-permeable which allow some water to pass through. These structures are constructed transverse to the river flow.

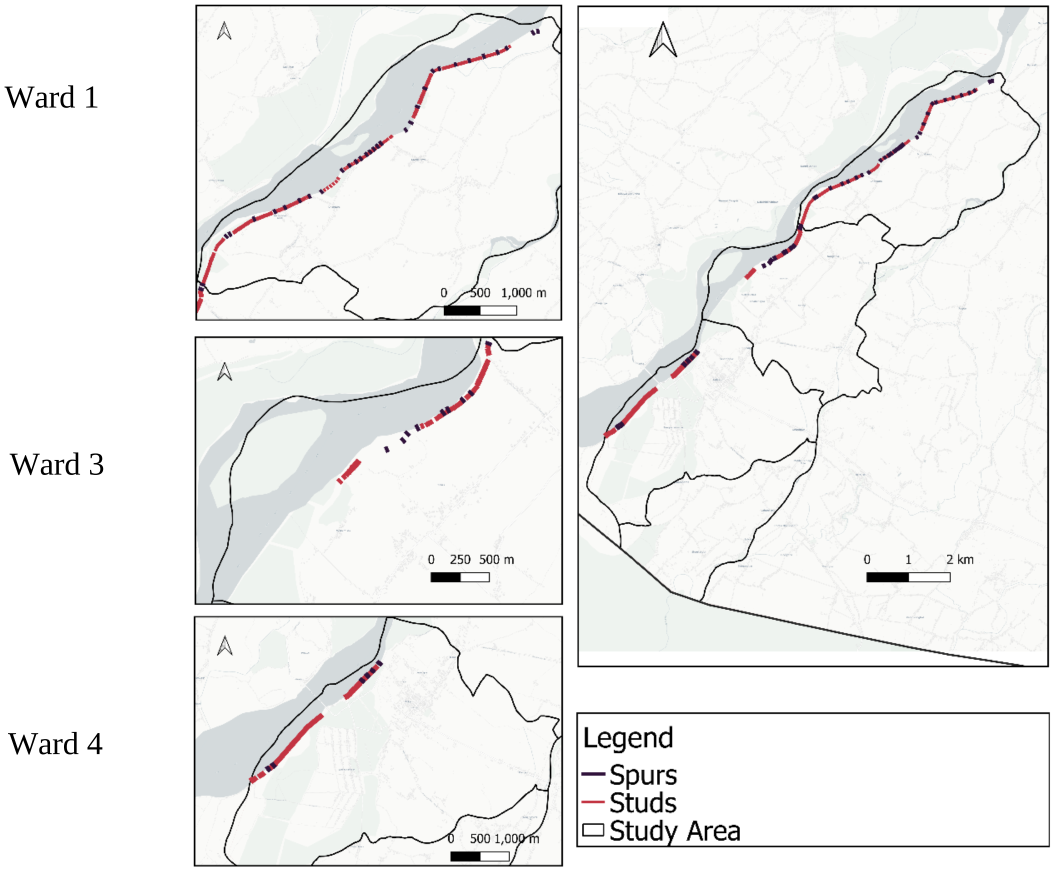


Figure 10: Spurs and studs (Ward 1, 3 & 4)

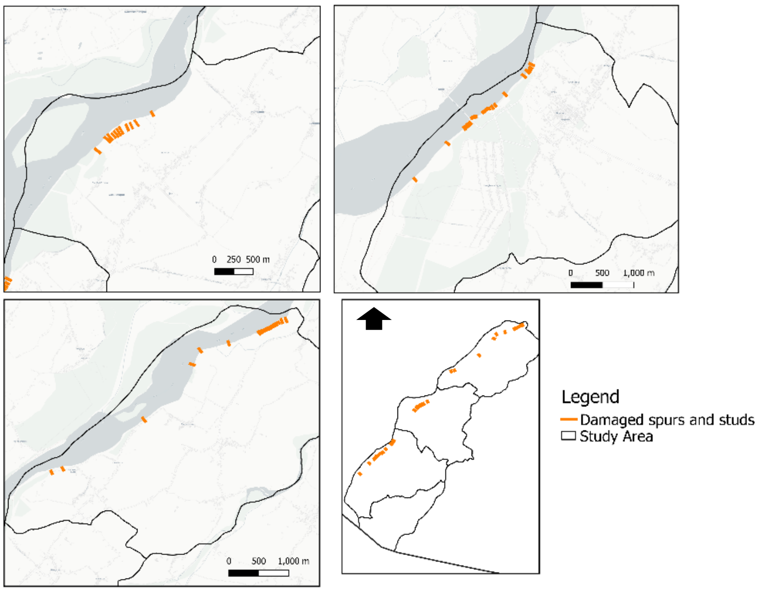


Figure 11: Damaged spurs & studs

4.1.3 Maintenance and Monitoring

There is a provision of pre as well as post flood inspection of dykes in lower Karnali river basin. Maintenance materials are also kept ready for the time of emergency. The top width of the dyke and the availability of turning platforms at every 1km helps for vehicular movement at the time of maintenance. Areas were dykes are destroyed or damaged are now maintained using big boulders on the slope which are often cost effective as well as requires little to no regular maintenance. In our FGD with village chiefs, they reported that when the dykes breach, the communities often donate their labor for the maintenance of the dykes. Similarly, they are also involved in cleaning of sluices as well as Kulos such as Bhadali Kulo. There is also a provision of excavation of river materials of Karnali River through tender. The excavation provides additional income to the municipality, as well as removes sediments deposited on the river.

Figure 12: Materials for maintenance of dykes

Figure 13: Boulders' dyke

4.1.4 Situation of dykes

4.1.4.1 Scouring

Scouring was not observed in the study area.

4.1.4.2 Sediment deposition

Sediment is deposited between spurs and studs in several parts of the study areas. Much of the area of Ward 1 had large amount of sediment deposit. The areas with high sediment deposit is shown in the figure below.

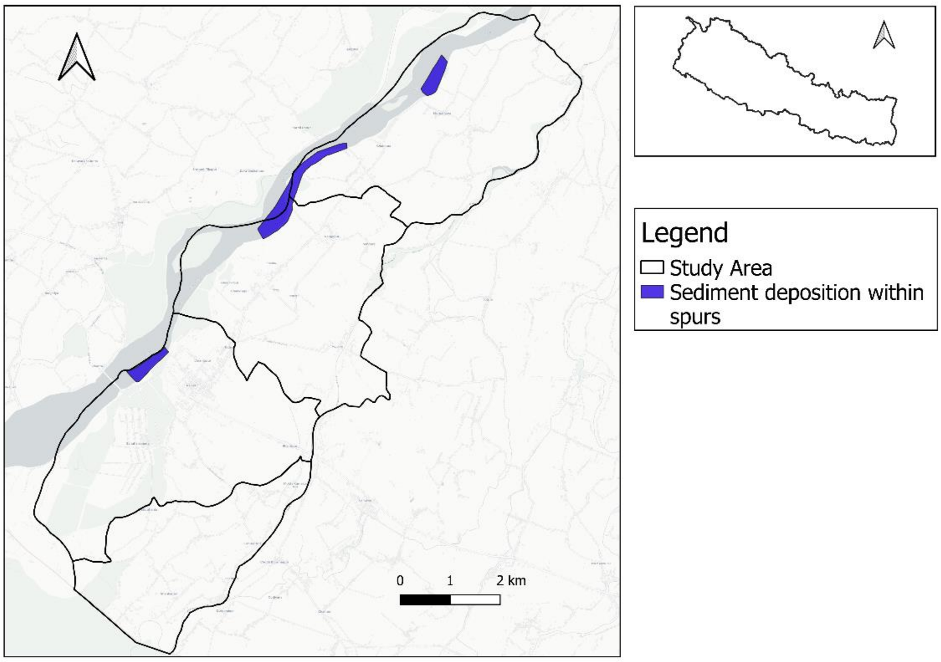


Figure 14: Sediment deposit on spurs

4.1.4.3 Seepage

Seepage was also a problem, especially in Tighra (Ward 3) and Tihuni (Ward 1). Flood often gets stagnant in some areas behind dykes because of lack of passage/drainage from land to the river. The areas where seepage are a problem are shown in the figure below.

figure below.

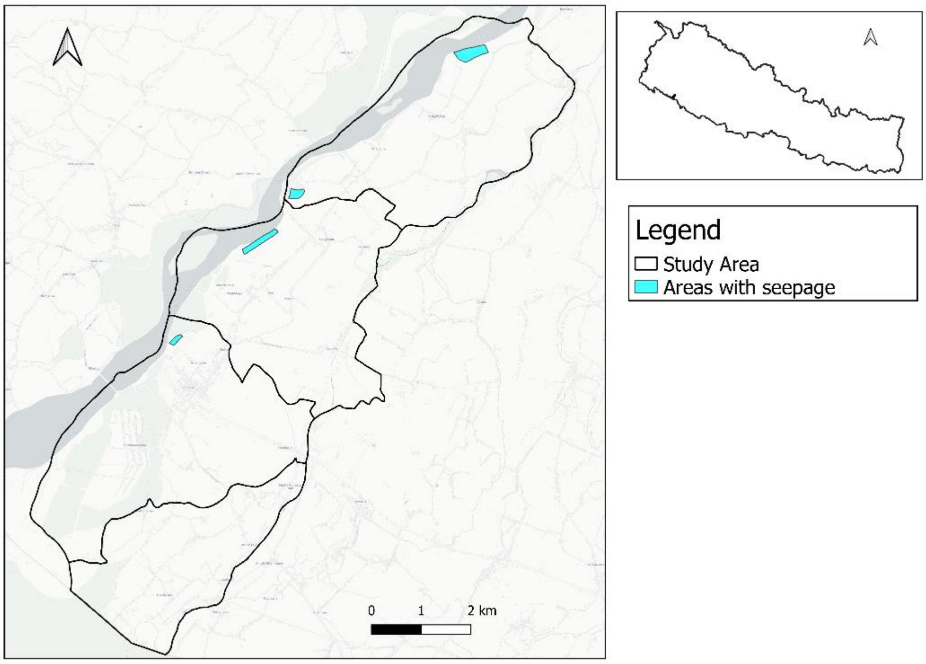


Figure 15: Areas with seepage & water stagnation behind dykes

Figure 16: Stagnation of water behind dykes

4.1.4.4 Growth of Vegetation

There were growth of grasses along the stretch of dykes, mostly Hakia and vetiver (Khus/Khaskhas) grass. In Ward 1, deep-rooted trees were seen in some part of the dykes, especially in the land ward side region. The areas with large deep-rooted trees are shown in the figure below.

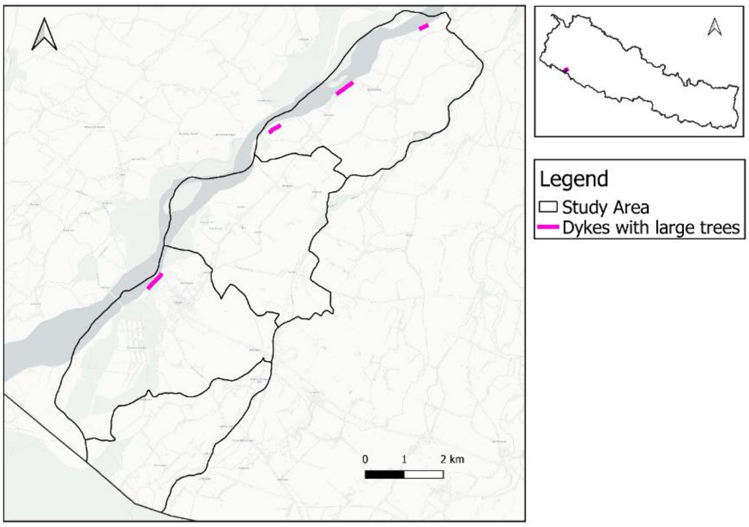


Figure 17: Areas with large trees growing on dykes

4.1.4.5 Movement of cattle

Almost all of the sample had livestock. Leaving livestock free for grazing in areas nearby river is a common practice. The cattle roam around the river bank and stay in the shallow water of the river to escape intense heat of Terai during summer.

4.1.4.6 Lifespan of gabion

The lifespan of gabion wire mesh is usually 20-25 years.

4.1.4.7 Return period

The return period of 50 years is taken into consideration.

4.1.4.8 Width of the river

The width of river from the embankment of Tikapur to that of Rajapur was as less as 435m in some areas.

4.1.4.9 Not all areas are covered with dykes

Not all areas have dykes. Dykes constructed in one region might flood another region, which usually does not flood, due to the disturbance in the flow of river. Some part of the study area with dykes were flooded because of intrusion of floodwater from Geruwa Rural Municipality. Moreover, the budget might not be big enough to cover all the expenses of construction and maintenance of dykes.

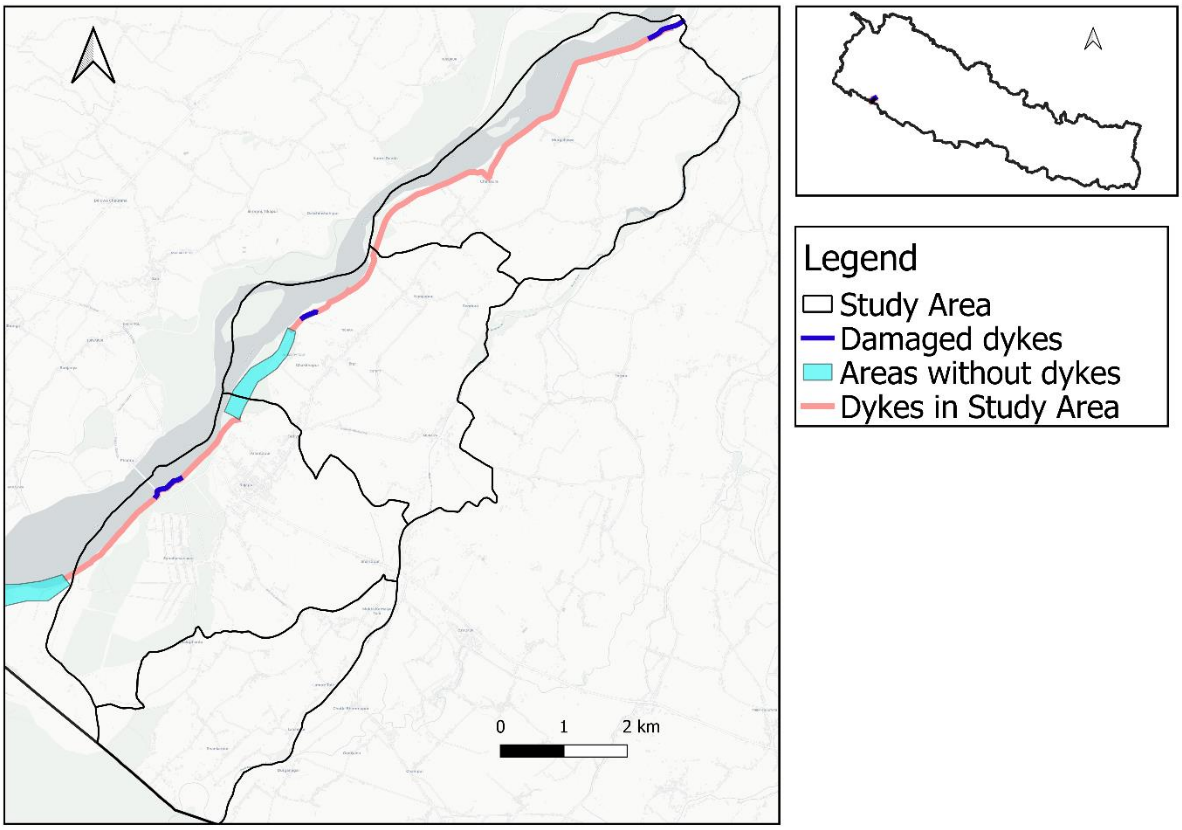


Figure 18: Areas with dykes, no dykes and damaged dykes

4.1.4.10 Overtopping

This study found no occurrence of overtopping of dykes in the study area until date.

4.1.5 Economic Impacts in the study area

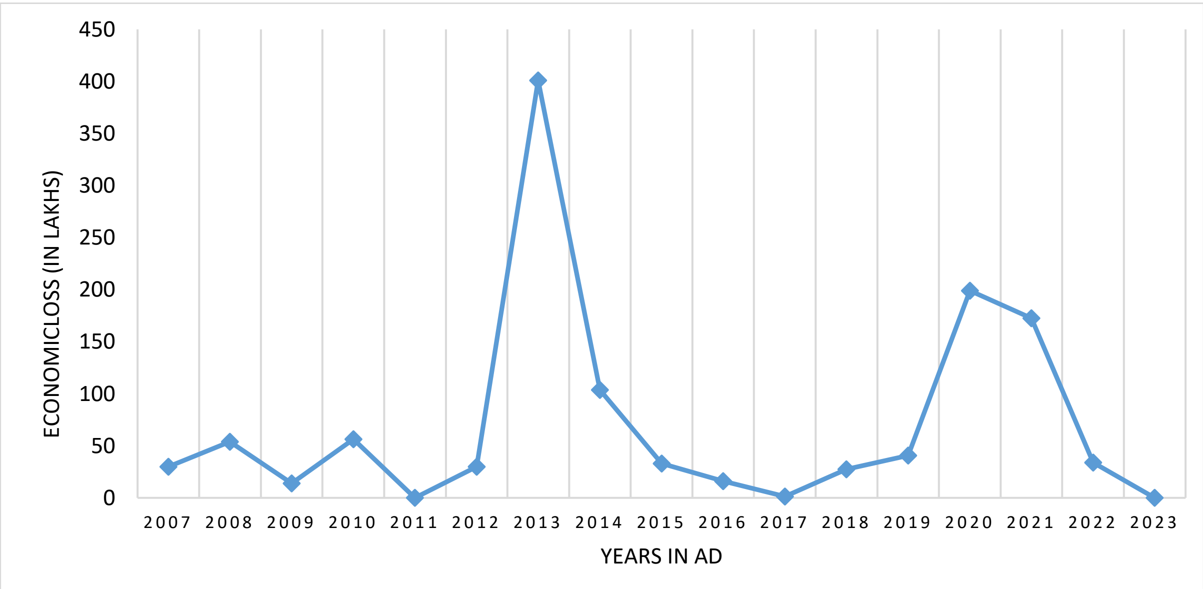
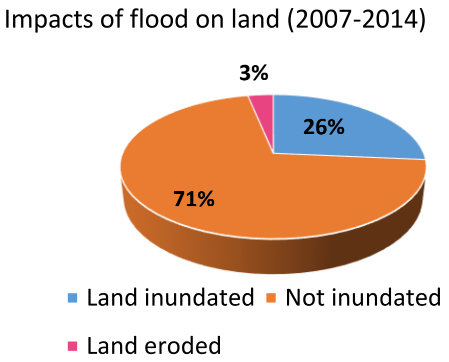


Figure 19: Economic loss of study area (2007-2023) (Source: BIPAD portal, LDCRP, KRMP)

The economic loss due to flood in the study area fluctuated between 2007 and 2012, but was found to be more than 4 crore rupees in 2013 economic loss. The impacts significantly decreased after the initiation of dykes in the study area. However, the loss again increased and reached 2 crore rupees in 2020. The dyke in Tihuni (Ward 1) broke in 2020 and caused more than 200 crore worth of damage in the study area alone. The flood of 2022 caused small damages, while there was no recorded flood in the study area in 2023.

4.1.6 Impacts on agricultural land and Houses



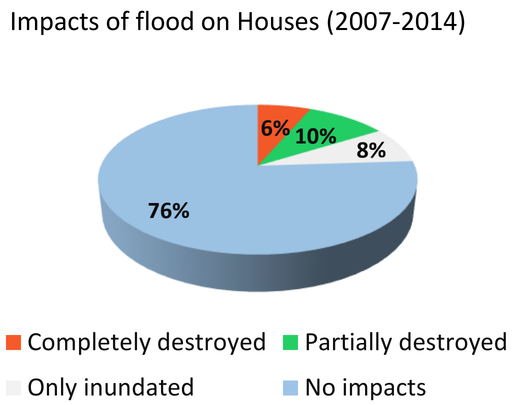
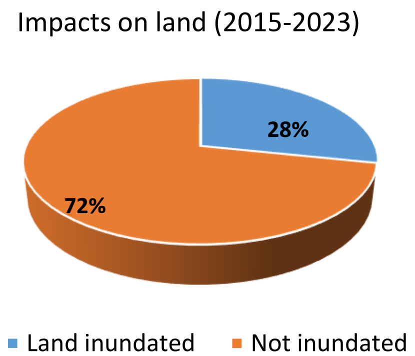


Figure 20: Impacts of flood before the construction of dykes (2007-2014)

Between 2007 and 2014, 3% of the samples said that some portion of their land were eroded completely and currently are under river. Almost all of the cutting and erosion of agricultural land was due to the flood of 2014. It was also reported that they still pay taxes of the land that was completely eroded, in a hope that the river would change its path as it always did and the land would re-surface and can be used by the generations to come. Similarly, 26% of them reported that their agricultural land were inundated in every minor and major flooding i.e. in 2007, 2008, 2009, 2010, 2012, 2013 and 2014. Similarly, 24% of samples reported that they felt some impacts on their houses with 6% reporting complete damage of their house, 10% saw partial damage while 8% said the some portion of houses were inundated only, with no any major/minor damages.



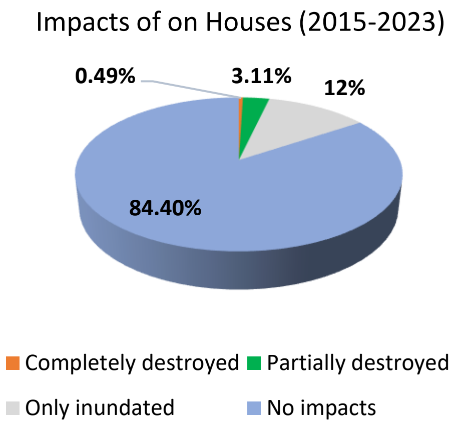


Figure 21: Impacts of flood after the construction of dykes (2015-2023)

Between 2015 and 2023, 2017, 2018, 2020 and 2021 saw flood. The flood of 2020 and 2021 caused some major damages than the rest of the year. In the flood of 2021, damaged the dykes of Tihuni (Ward 1) as well as the dykes of Loharpur and Sankati of Geruwa Rural Municipality, while the dykes in Rajipur of Geruwa Rural Municipality was incomplete. 77% of respondents reported that their agricultural land felt no impacts of flood between 2015 and 2023, while 28% reported that their agricultural fields were inundated. Between 2015 and 2023, 84.40% felt no impacts of flood on their houses, while 0.49% of respondent said that their houses were completely destroyed by flood between 2015 and 2023. In addition, 3.11% felt partial damage to their houses, while 12 reported that some parts of their houses such as toilets, which are often outdoor and fodder stock houses were inundated with no any major or minor damages. The impacts of flood on houses were seen to be decreased because the development pattern in Rajapur is linear and the road are often elevated which prevents the flood reaching to the lands on the other side of the road.

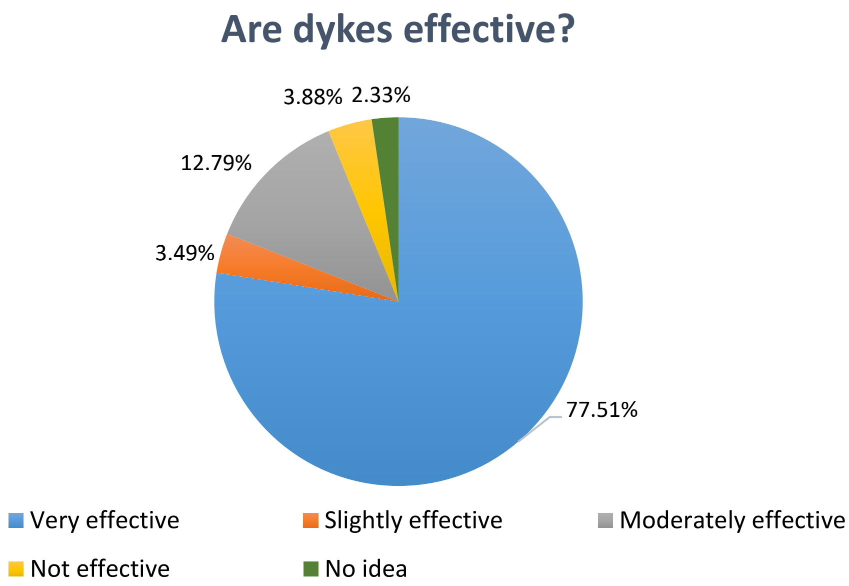


Figure 22: Peoples' perception on effectiveness of dykes on flood prevention

77% of the respondents said that the dykes are only the effective means of flood adaptation measures available at present and consider them to be very effective to reduce the impacts from the high water discharge of Karnali during monsoon. Meanwhile, 3.49% and 12.79% believed them to be slightly effective and partially effective respectively. In contrast, 3.88% of people reported that the dykes are becoming less beneficial than expected. They reported that the runoff water runs through their front door as drainage channel is not available on the either side of the road in majority of its parts. In addition, the AFS were not enough to carry the runoff water back to the river. Some people apparently block the inlet of AFS on the land side with sand and straws to make a trap for fish, which often comes with flood water. This also disturbs the flow of runoff water and often get stagnant for a while. Additionally, 2.33% had no idea about the function of dykes or were not interested.

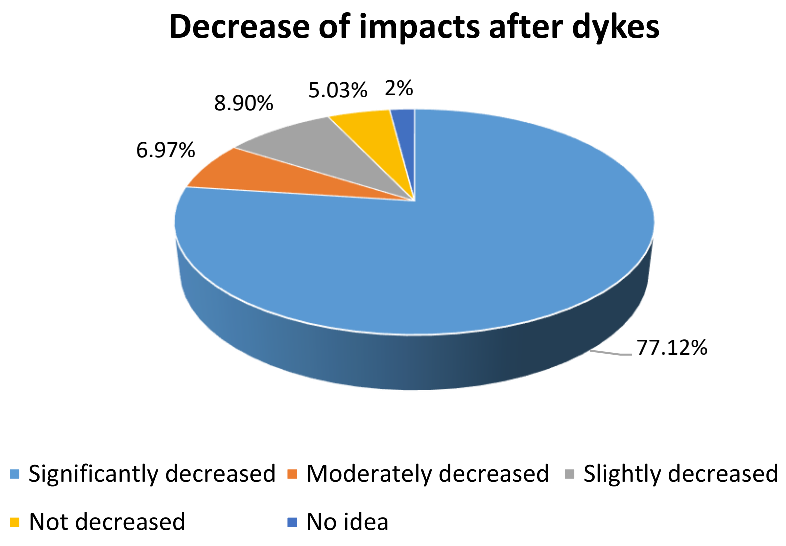


Figure 23: Decrease of impacts of flood after dykes' construction

77.12% of people said that the impacts of flood on agricultural field as well as on their houses got decreased after the construction of dykes. Similarly, 6.97% said the impacts moderately decreased. While 8.90% said that the impacts were slightly decreased. It was reported that 5.03% felt that the impacts were not decreased and 2% had no idea about the concerned topic.

4.1.7 Challenges of dykes

4.1.7.1 Breaching of dykes

4.1.7.1.1 Breaching in Geruwa Rural Municipality

Geruwa Rural Municipality had dykes in few areas years before the construction began in Rajapur Municipality. The dykes at Patabhar, Banghusra, Rajipur of Geruwa Municipality broke in 2013, and the runoff water reached Rajapur too, causing damages.

4.1.7.1.2 Breaching in Rajapur Municipality

In 2001 AD, small bunds with some spurs were built at Tihuni. The present dykes construction in Ward 1 of Rajapur Municipality started in 2014 and was completed in 2019, but 0.68 km dykes of Tihuni (Ward 1) broke in the flood of 2020. In 2021, the broken section of dykes at Tihuni was rebuilt in with large boulders. Similarly, the construction of dykes in Ward 3 was started to built in 2016 AD, and almost covered most section of this ward in 2018, expect Lajipur, Phoolbari and Lali Gurash Community Forests. In 2020, the flood destroyed 0.44 km of the dykes near Lajipur community forest. More of the remaining dykes of that area were hit by another flood in 2021 and destroyed 0.25 km of its section as well as most of Phoolbari Community Forest was eroded. Currently, this section is being re-built with large boulders. In Ward 4, small bunds were created in 2011 near Karnali Bridge. Dykes were started to being built in 2017 and was completed in 2018, but 0.44 km of its section in Kauriala-Karnali bridge was partially damaged in 2020 and was rebuilt with boulders that same year. The remnant of sliding of slope of dykes was seen in Tihuni. The figure below shows the points where dykes were affected to some extent, including minor and major damages.

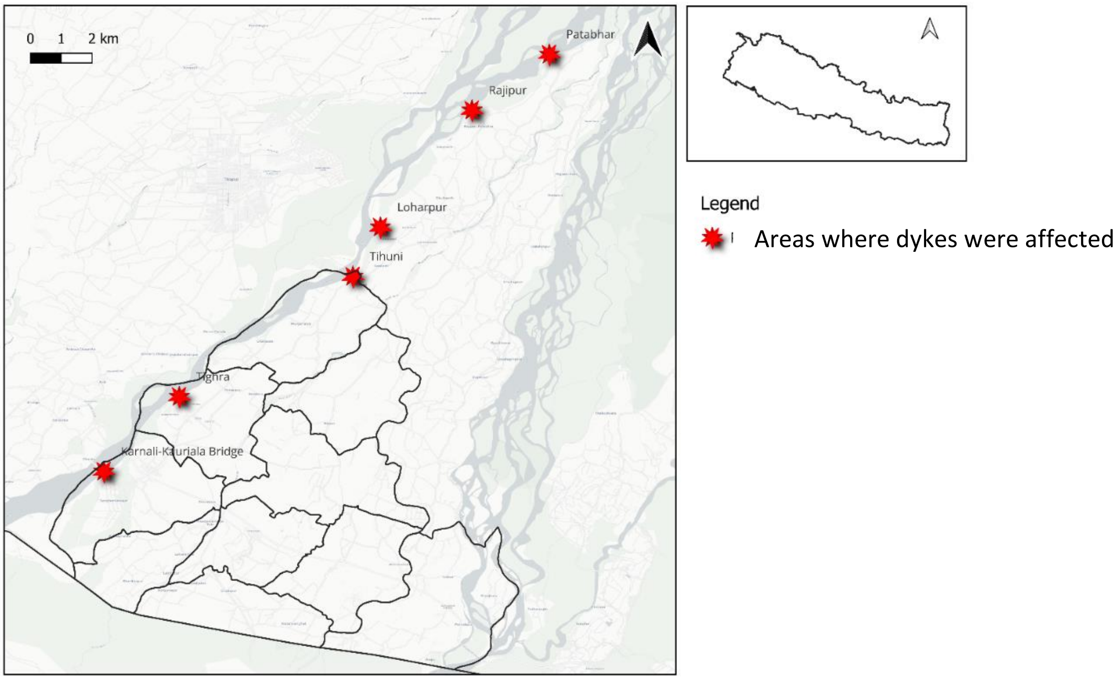


Figure 24: Points where dykes were affected to some extent in Rajapur and Geruwa

4.1.7.2 Backflow of Bhadali Kulo

During monsoon when the water discharge in Karnali River increases, it causes the backflow of water of Bhadali Kulo back to agricultural land and even human settlement. 12% of the samples of Ward 1 said that this was one of the reasons of flood in Ward 1 of Rajapur Municipality.

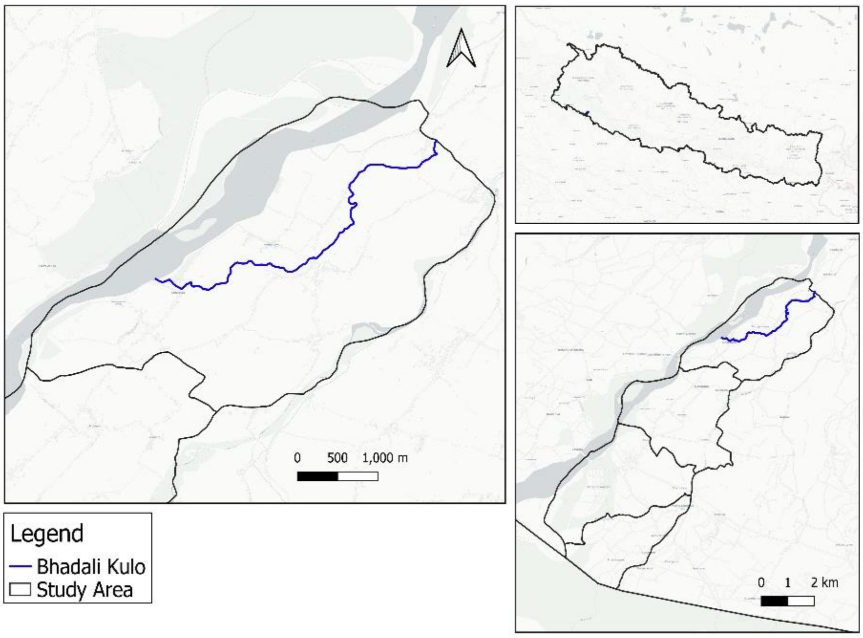


Figure 25: Study Area with Bhadali Kulo in Ward 1

Figure 26: Meeting point of Bhadali Kulo and Karnali River (Source: Google Earth Pro)

4.1.7.3 Sediment deposit in Geruwa Khola

As we can see from the satellite image of 2005, much of Karnali River used to flow from the east side of Rajapur Municipality, but the river began to shift towards west from 2008. As the river shifted towards west, sand and silt deposition has increased on the east of Rajapur. Sand mining is strictly prohibited in the east branch of Karnali, as it lies within the buffer zone of Bardiya National Park. This deposition of sand has redirected the flow of Karnali to the west for more than a decade. The change in the river flow between 2005 and 2022 is shown in the figure below.

2005 2022

4.1.7.4 Budi Kulo

Budi Kulo is one of the oldest community managed irrigation system in whole of Asia and is more than a century old. Although the Kulo grew over the years several decades ago, it has not seen much change at present. This Kulo also had little to no effects on agricultural land and houses in recent decade. There is a presence of a gate in Geruwa Rural Municipality, which blocks the water at the intake when the water level increases in Chisapani. This redirects the water to the west branch of Karnali. There is presence of small bunds and gabion floodwall in several parts of Budi Kulo too.

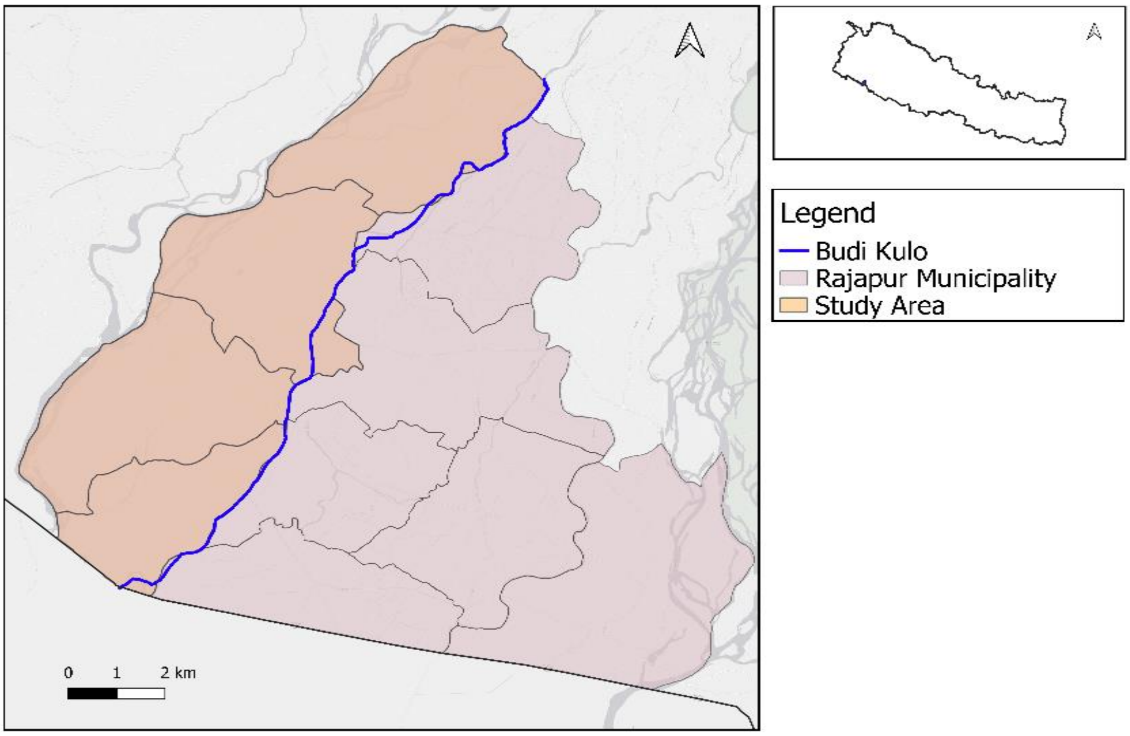


Figure 28: Budi Kulo in Study Area

4.1.7.5 Seepage

The locals of Rajapur Municipality reported the problem of seepage. Especially in the Ward 1 and 3.

4.2 Discussion

4.2.1 Dykes of Rajapur

The dykes of Rajapur is constructed using cut and fill method, where the riverbed materials are used for construction. Newly rebuilt sections are made with large boulders, which are brought from nearby region as well as from Chure as they are not that common in the study area. These fall under homogenous embankments, where same construction materials are used along their length and are uniform throughout their construction [38]. Homogenous sections which are made from pervious materials can have the problem of seepage [42], which was found on the dykes at Tighra, Rajapur Municipality, Ward 3. Central Water Commission of India have the provision of having internal drainage filter like horizontal filter which are kept as 3 time the height of the embankment to provide stability and reducing the effects of seepage, which was not found in the study area of Rajapur Municipality. The filter and drains help in preventing internal erosion and maintain slope stability [61].

Dykes in the study area were constructed from upstream to downstream, but in countries like Japan, it is constructed from downstream to upstream. Although the flood in upstream will decrease if the dykes are constructed in the upstream region before constructing in the downstream region, it will increase the velocity of river water and the risk of flooding increases in the downstream [62].

The length of dykes on the study area is 11.39 KM. The areas without dykes are mostly forested areas. In addition, several areas of Geruwa Rural Municipality does not have dykes or other physical form of flood adaptation measures which might also flood Rajapur Municipality.

Launching of 15-20m were present in the study area. Launching provides protection of the toe of the dykes and prevents scouring [42]. Launching is made of gabion, and the lifetime of these does not exceed 10 years in all of Terai rivers, and fails to check the bank erosion after a few flood seasons [48]. According to KRTP, scour study is done before constructing the launching, and this helps to prevent failure in dykes and spurs. The foundation of launching bed starts below the scour depth.

Gabions were used to armor the slope of the dykes as well as to build spurs in the study area. This reduces the impacts of the river on the earthen dykes. Woven gabion mattresses are used in river bank protection, slope protection, and coastal protection. The gabion mattresses can be both machine woven as well as hand woven, but machine woven mattresses are more preferable because of tightness of twisting, uniform manufacture and thickness. Many areas still use hand woven mattresses because of production cost and lack of availability of machines [63]. Both hand woven as well as machine woven gabion mattresses were used in the study area. Gabion mattresses used in the study area were galvanized to prevent rusting.

After the preparation of foundation of the slope, a geotextile fiber mattress is usually placed, which was not used in the study area. The stones are then filled into the gabions from the bottom, either by hand or via machineries. The gabions should be laced together to prevent the structural failure. The stones should be hard, round or angular in shape, long lasting and the quality to withstand the pressure of water throughout the life of the structure. Small stones are filled in between the large stones. The surface should be uniform and smooth.

The minimum distance between two embankments i.e. Tikapur in the west and Rajapur in the east should require a 1500 meter wide channel to contain a 50 year flood without breaching

[64]. Karnali River Management had a provision to maintain the width of the river at least 700m. However, this width has not been achieved in some regions, where the width of the river was as less as 500m. Department of Water Induced Disaster Management (DWIDM) erected 90% of embankments directly on the riverbank or through its bed to accommodate landowner who have already lost property to bank carving and refuse to give up more. Most of the section of dykes are on public land and has no compensation mechanism if private land falls under dykes.

The height of the dykes is 7-8m. Similarly, the top width is 5m and bottom width is 24-27m. Top of the dykes can be used as a path as well as provides a motor able way for vehicles for the maintenance of dykes during the time of emergencies. Timo Fullerton and John J. D'Auria [65] studied the effectiveness of river bank reinforcement, including dykes, in reducing flood in Chesapeake bay region, and found out that dykes that were taller and wider demonstrated better performance in reducing flood risks compared to those of smaller dimensions [65]. Similarly, boarder base provides resistance against the water pressure exerted by the river [66]. Wider base helps to enhance the stability against sliding or over turning [67]. Although, overtopping of earthen structures is one of the reason for its failure [46], it was not reported in the study area.

There are 11 AFS in the study area. The masterplans for river training in Nepal aims for flood protection by embankments, but drainage facilities are not included. If sufficient drainage are not made, water logging problem might arise [48], which was seen in some parts of the study area.

The minimum free board of 1.5m over the design High Flood Level is designed to carry the discharge up to 3000 m^3/s, while for a discharge higher than this has a minimum free board of 1.8m [38]. According to DHM, Nepal, the average annual discharge of Karnali River was 1502.225m^3/s in 2021. Thus, the free height of the dykes in the study area is in the range of 1.5m-2m, which aligned with the common practice of South Asia.

At almost every km, a turning platform is available. Turning platforms at every 1 km of the dykes is a requirement [42]. This might help those whose livelihood depends on the river. These turnings also provide path to the river from the land ward side. Many people of Rajapur municipality are involved in fishing. Similarly, Sohanas are known for their livelihood by searching gold in sand of Karnali River. This might also provide a path for livestock to cool and escape from the intense heat of the summer in the shallow river.

The slope of 2:1 is maintained along the dykes of the study area. According to the sub-engineer of KRMP, dykes of 2:1 and 3:1 maintain same height, but the base width the dyke increase with the increase in the ratio and the steepness decreases, which eventually requires more construction materials.

4.2.2 Spurs and studs

The spurs in the study area are semi permeable. Permeable spurs are preferable in the river system carrying considerable amount of slit [42]. Spurs deflect the current of water away from the embankment, while studs prevent cutting of the land. Spurs protect critical areas by pushing the water flow away, reducing flow velocity near bank and promoting deposition of sand and slit [68]. Inclined spurs present in the study area causes “a less sharp transition in velocity from river to bank” and might reduce the formation of deep scour holes [48]. Sediment deposition was seen in most part of the spurs along the length of the dykes in the study area. If the sediment trapped between the embankments is not removed, the breaching is unavoidable [69]. Practical Action (2007) suggests that spurs make permanent change in the river by catching sediments and help to reverse bank erosion. Spurs in the study area are in series, where one spur helps in reducing the scour on other spurs [71].

4.2.3 Present Situation

Seepage of water was seen in some parts of study area. Seepage through embankment can cause sliding of the embankments as well as internal erosion [72], which happened in 2078 BS in Tihuni, Ward 1. Stagnation of water behind the dykes was also found in the study area. These stagnant water are breeding ground for mosquitos and other parasites [73].

Presence of grasses as well as deep-rooted trees were seen in the study area. Many countries use grasses like vetiver, whose root can penetrate 1m at one year, which can reduce erosion and maintain slope stability. Appropriate and well maintained vegetation provide slope protection and increase the life of an embankment [74]. Vetiver grass can also withstand drought, fire, grazing, storm and human activities [75]. For controlling run off erosion of the dykes, grasses like vetiver, in association with Napier grass, Para grass, German grass, and other suitable plants like Ipil-Ipil, Jhau, Akashmoni etc. are suitable. Trees and bushes can deteriorate the embankment body via growth of root and can lead scouring [74]. The presence of deep rooted trees weakens these earthen structures [45].

The movement of cattle to the riverside for grazing as well as to escape heat during summer puts pressure on the dykes. Most earthen embankments are influenced by animal action. Uncontrolled grazing of cattle on the surface of the embankment causes loss of soil cover. Similarly, movement of heavy cattle likes cows and buffaloes on the slopes often forms a path and subsequently forms micro-terraces, where the upslope soil material is deposited at the lower side of the path and finally reaches the embankment toe in successive down-slope movements. Community often do not consider the influence of this factor on earthen structure [76].

Not all areas are covered with dykes in the study area. Some sections were being rebuilt, while some sections were to be constructed soon. The available budget might not have been sufficient to include maintenance, rebuilt as well as construction of dykes, where it was not available. In the fiscal year 2080, the budget for the construction and maintenance of dykes is 12 crore. In 2079, it was 22 crore. The estimated budget to construct dykes from 2078/79-2081/82 is 50 crore [22]. In addition, Budi Kulo, which runs along the edge of the study area, has not caused any significant impacts on houses or agricultural lands. This study found out that sand mining in this Kulo has deepen its bed, which helps the river to contain more water. Dredging can increase the cross sectional area and the volume of a river, but dredging in upstream can affect downstream, resulting bank failure [78]. Similarly, the presence of gate at the intake has controlled the amount of water going through Budi Kulo. This has prevented flood in recent days.

4.2.4 Impacts before and after the construction of dykes

The impacts of flood in the study area was around 50 lakhs per year before the construction of dykes between 2007-2012, this increased suddenly to more than 4 crore in 2013. Between 2007 and 2014, 29% reported that flood had some kind of impacts on their agricultural land, out of which 3% said that some portion of their land was eroded. Most of this erosion occurred in

2014. Similarly, 24% felt some kind of impacts on their houses with 6% representing complete destruction of houses. This sudden increase in impacts might have been from different reasons. According to our FGD with village chiefs, the major reasons for this increase in the impacts of flood in 2013 pointed to the increase in the forested area along the bank of Tikapur. The landowner of Tikapur convinced DWIDM to construct embankments in 2010 and 2011 to armor Tikapur's bank. This has deflected the Karnali river to the unprotected bank in Rajapur, carving several hectares land in 2014 [64]. Between 2015 and 2023, erosion of agricultural land has not been observed (as a lot of land was eroded before 2014), but 28% felt some level of inundation of their agricultural land. In addition, the complete and partial destruction of houses has decreased significantly representing 0.49% and 3.11% respectively. However, even after the construction of dykes, inundation of houses as well as agricultural land is a problem.

As we discussed above about the width of the river to be made at least 750m between the two embankments of Karnali River, this was not been able to be achieved, as Tikapur Municipality had already constructed embankments few years earlier and it was also necessary to accommodate the interests of all stakeholders in Rajapur for the construction of dykes. This led to the construction of 90% dykes close to the river [64]. This might have led to the breakage of dykes at Tihuni and Lajipur and minor damage on the dykes at Karnali-Kauriala Bridge in 2020. Again, in 2021, some section of dykes were destroyed near Phoolbari community forest. The width of the river in these locations were less than 550m. Similarly, one of the sub-engineer of KRMP said that the increase in the impacts of the flood in Rajapur might be because of increase of sand on the east branch of Karnali River, which might also be responsible for the redirection of river to the west since 2008. The other reason for the flood in recent years are due to the breakage and insufficient dykes on Geruwa Rural Municipality as well as runoff water coming to Rajapur from there.

4.2.5 Breaching of dykes

According to Dixit (2009), there are two types of embankments i.e. those that have already been breached and those that will breach. The foundation condition and building materials for earthen embankments are not completely fulfilled, and due to this even with the best construction techniques there is a hazard of failure [80]. In fact, breaching is an intrinsic feature of any flood control techniques. Many minor and major breaching have occurred throughout the world. Many minor breaching of embankments in Uttar Pradesh, and major breaching in Mississippi, New Orleans, Sacramento, river Tray in Scotland are some of them [81]. Height of embankments are often raised to adapt with the discharge of river during the return period, but with the increase in height of the embankments increases the cost and are often uneconomical. Similarly, the breaching of the embankments of upstream destroyed the downstream region with embankments in Sunsari district, which was also the case in Rajapur municipality too, where the breaching of dykes in Geruwa Rural Municipality (upstream) caused significant impacts in Rajapur [82].

Embankments and levees show high-level flood protection soon after its construction, but its ability to provide protection decrease overtime, depending on the rate of sediment deposition, maintenance and how it is constructed. The structural measures of flood adaptation measures such as "embankments, bank stabilization and flow modification structures" have not decreased the impacts of flood. Embankments of Kosi breached in 2008 even when the river flow was lower than the historical average monsoon flow, which pointed a major flaw in conventional approach of flood control measure [79].

CHAPTER V

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This thesis aimed to study the locations, construction materials and other guidelines for the construction of dykes along the Karnali River in Rajapur Municipality as well as analyze the impacts of flood before and after the construction of dykes to understand how effective were the dykes to prevent flooding in Rajapur Municipality.

This study found out that not all sections along the Karnali River had dykes. The erosion of agricultural land has not been observed after the construction of dykes, but inundation of houses and agricultural land is still common during monsoon. This might be because of breaching of dykes in the study area as well in Geruwa Rural Municipality and lack of drainage for run off from settlement areas into the river. Although dykes are considered as the only flood prevention measure, it has breached at multiple locations, in multiple times in less than a decade, resulting some economic losses. This study also compared the breaching of such earthen embankments in other parts of the world, and points that construction of such structures are not completely satisfiable and have limitations to prevent flooding.

5.2 Recommendations

Based on this study, some suggested recommendations are as follows:

- Concrete tetrapods can be used as a reinforcement for earthen embankments and gabions that can prevent erosion and reduce energy of water.
- More Anti-Flood Sluices can be built at appropriate locations to discharge the rainfall collected in human settlement. This would reduce water logging behind the dykes.
- Drainage filter and other technologies could be used to prevent seepage of water from river to land ward sites.
- Effective measures can be taken to control the backflow of Bhadali Kulo.
- Proper coordination should be obtained between the stakeholders of opposite sides of Karnali River, as the activity taken at one part affects the other parts and vice-versa.
- Sediments deposited between spurs might be used for land reclamation.
- River widening can also done so that it can carry large amount of water.
- The weak points on the embankments can be identified and monitored using fluid dynamics principles and hydraulic engineering software.
- People still have to pay taxes of land completely eroded by water. So, proper administrative steps should be taken on that.

CHAPTER VI

REFERENCES

[1] J. Rentschler, M. Salhab, and B. A. Jafino, “Flood exposure and poverty in 188 countries,” *Nat. Commun.*, pp. 1–11, 2022, doi: 10.1038/s41467-022-30727-4.

[2] B. Jongman, P. J. Ward, and J. C. J. H. Aerts, “Global exposure to river and coastal flooding: Long term trends and changes,” *Glob. Environ. Chang.*, vol. 22, no. 4, pp. 823–835, 2012, doi: 10.1016/j.gloenvcha.2012.07.004.

[3] F. Dottori *et al.*, “Increased human and economic losses from river flooding with anthropogenic warming,” *Nat. Clim. Chang.*, vol. 8, no. 9, pp. 781–786, 2018, doi: 10.1038/s41558-018-0257-z.

[4] H. Arefi, F.-J. Behr, and F. Alidoost, *Geoinformation-Supporting Crisis and Disaster Management*, no. February. 2018. [Online]. Available: https://www.researchgate.net/publication/323187625

[5] IPCC, “Summary for Policymakers. In: Global Warming of 1.5°C: An IPCC Special Report on Impacts of Global Warming of 1.5°C above Pre-industrial Levels in Context of Strengthening Response to Climate Change, Sustainable Development, and Efforts to Eradicate Pover,” *Glob. Warm. 1.5°C*, pp. 1–24, 2018, [Online]. Available: https://www.cambridge.org/core/product/identifier/9781009157940%23prf2/type/book_part

[6] H. Hayat, T. A. Akbar, A. A. Tahir, Q. K. Hassan, A. Dewan, and M. Irshad, “Simulating Current and Future River-Flows in the Snowmelt-Runo ff Model and RCP Scenarios,” *Water*, vol. 11, no. 4, pp. 1–19, 2019.

[7] M. S. G. Adnan, A. Y. M. Abdullah, A. Dewan, and J. W. Hall, “The effects of changing land use and flood hazard on poverty in coastal Bangladesh,” *Land use policy*, vol. 99, no. March, p. 104868, 2020, doi: 10.1016/j.landusepol.2020.104868.

[8] A. Goonetilleke, E. Thomas, S. Ginn, and D. Gilbert, “Understanding the role of land use in urban stormwater quality management,” *J. Environ. Manage.*, vol. 74, no. 1, pp. 31–42, 2005, doi: 10.1016/j.jenvman.2004.08.006.

[9] V. Whitford, A. R. Ennos, and J. F. Handley, “‘City form and natural process’ - Indicators for the ecological performance of urban areas and their application to Merseyside, UK,” *Landsc. Urban Plan.*, vol. 57, no. 2, pp. 91–103, 2001, doi: 10.1016/S0169-2046(01)00192-X.

[10] M. Monirul Qader Mirza, “Global warming and changes in the probability of occurrence of floods in Bangladesh and implications,” *Glob. Environ. Chang.*, vol. 12, no. 2, pp. 127–138, 2002, doi: 10.1016/S0959-3780(02)00002-X.

[11] UNDRR, “Human cost of disasters: An overview of the last 20 years,” 2019, [Online]. Available: https://www.undrr.org/publication/human-cost-disasters-overview-last-20-years-2000-2019

[12] C. W. F. Yu, “Indoor and Built Flooding and EcoBuild – Strategies for the Future : Dykes , Dams , SUDS and Floating Homes,” vol. 44, no. 0, pp. 595–598, 2010, doi:

10.1177/1420326X10388063.

[13] W. Silva, J. P. M. Dijkman, and D. P. Loucks, “Flood management options for The Netherlands,” *Int. J. River Basin Manag.*, vol. 2, no. 2, pp. 101–112, 2004, doi: 10.1080/15715124.2004.9635225.

[14] F. Saathoff, S. Cantré, and Z. Sikora, *South Baltic Guideline for the Application of Dredged Materials, Coal Combustion Products and Geosynthetics in Dike Construction*, no. January. 2015. doi: 10.13140/2.1.2419.7923.

[15] W. W. Müller and F. Saathoff, “Geosynthetics in geoenvironmental engineering,” *Sci. Technol. Adv. Mater.*, vol. 16, no. 3, pp. 1–20, 2015, doi: 10.1088/1468-6996/16/3/034605.

[16] P. J. A. Baan and F. Klijn, “Flood risk perception and implications for flood risk management in the Netherlands,” *Int. J. River Basin Manag.*, vol. 2, pp. 113–122, 2010, doi: 10.1080/15715124.2004.9635226.

[17] R. Kumar, M. J. C. Van Den Homberg, G. Prasad, and C. Mcquistan, “International Journal of Disaster Risk Reduction Cost-benefit analysis of flood early warning system in the Karnali River Basin of Nepal,” *Int. J. Disaster Risk Reduct.*, vol. 47, no. August 2019, p. 101534, 2020, doi: 10.1016/j.ijdrr.2020.101534.

[18] K. Venkateswaran, K. Macclune, K. M. Dixit, R. Yadav, Shobha Kumari Maharjan, and D. S, “Risk Nexus Urgent case for recovery: what we can learn from the August 2014 Karnali River floods in Nepal,” no. August. p. 44, 2015.

[19] IPCC, “Climate change widespread, rapid, and intensifying,” 2021, [Online]. Available: https://www.ipcc.ch/2021/08/09/ar6-wg1-20210809-pr/

[20] K. Kocanda, J., & Puhakka, “Living with floods along the Karnali River,” 2012.

[21] S. R. Gladfelter, “Training Rivers, Training People: Interrogating the Making of Disasters and the Politics of Response in Nepal’s Lower Karnali River Basin,” 2017.

[22] LDCRP, “Local Disaster and Climate Resilience Plan,” 2021.

[23] F. Dottori, L. Mentaschi, A. Bianchi, L. Alfieri, and L. Feyen, *Adapting to rising river flood risk in the EU under climate change*. 2020. doi: 10.2760/14505.

[24] E. A. Albright and D. Crow, “Beliefs about climate change in the aftermath of extreme flooding,” *Clim. Change*, pp. 1–17, 2019.

[25] B. Legese and B. Gumi, “Flooding in Ethiopia ; Causes , Impact and Coping Mechanisms . A Review,” *Int. J. Res. Anal.*, vol. 7, no. 3, pp. 707–717, 2020.

[26] T. Emberga, “An Assesment of causes and effects of flood in Nigeria,” *Stand. Res. Journals*, vol. 2, no. April, pp. 307–315, 2015, [Online]. Available: https://www.researchgate.net/publication/275409380_An_Assesment_of_causes_and_effects_of_flood_in_Nigeria

[27] S. . Chithra, N. Harindranathan, A. Amarnath, and N. S. Anjana, “Impacts of Impervious Surfaces on the Environment,” *Int. J. Eng. Sci. Invent.*, vol. 4, no. 5, pp. 27–31, 2015, [Online]. Available: www.ijesi.org%7C%7CVolumewww.ijesi.org

[28] P. Shah, “Study of the fresh water fish diversity of Koshi river of Nepal,” *Int. J. Fauna Biol. Stud.*, vol. 3, no. 4, pp. 78–81, 2016.

[29] NDRRMA, “Monsoon Preparedness and Response Plan 2080,” 2022. [Online]. Available: https://bipad.gov.np/np/587

[30] DWIDP, “Disaster Review 2013,” 2013. [Online]. Available: https://reliefweb.int/report/nepal/disaster-review-2013

[31] B. Rimal, L. Zhang, H. Keshtkar, X. Sun, and S. Rijal, “Quantifying the Spatiotemporal Pattern of Urban Expansion and Hazard and Risk Area Identification in the Kaski District of Nepal,” 2018, doi: 10.3390/land7010037.

[32] J. D. Ives and B. Messerli, “Mountain Hazards Mapping in Nepal Introduction to an Applied Mountain Research Project,” *Mt. Res. Dev.*, vol. 1, no. 3, pp. 223–230, 1981.

[33] NDRRMA, *Monsoon Preparedness & Response Plan-2077*. Kathmandu, 2022.

[34] S. Manandhar, D. S. Vogt, S. R. Perret, and F. Kazama, “Adapting cropping systems to climate change in Nepal: A cross-regional study of farmers’ perception and practices,” *Reg. Environ. Chang.*, vol. 11, no. 2, pp. 335–348, 2011, doi: 10.1007/s10113-010-0137-1.

[35] MoHA, “Nepal Disaster Report,” 2019, [Online]. Available: http://drrportal.gov.np/uploads/document/1594.pdf

[36] F. Dottori, L. Mentaschi, A. Bianchi, L. Alfieri, and L. Feyen, “Cost-effective adaptation strategies to rising river flood risk in Europe,” *Nat. Clim. Chang.*, vol. 13, no. 2, pp. 196–202, 2023, doi: 10.1038/s41558-022-01540-0.

[37] WECS, “Flood Control and Management Manual,” 2019.

[38] BIS, “Guidelines for Planning and Design of River Embankments (Levees),” 2000.

[39] S. Sunder and C. Vipulanandan, “Dikes and Levees – Classification , Formation , Morphology , Failure and Rehabilitation,” 2011.

[40] USACE, “Levee Owner’s Manual for Non-Federal Flood Control Works,” 2021.

[41] J. Smith, “The use of leeves in flood control systems,” *Water Resour. Res.*, vol. 56, no. 8, pp. 1782–1795, 2020.

[42] CWC, “Handbook for flood protection, anti erosion and river training works,” 2012.

[43] M. Dyer, “Performance of flood embankments in England and Wales,” pp. 177–186, 2004.

[44] FloodSite, “Flood risk and impacts,” 2009. https://web.archive.org/web/20150210032450/http://www.floodsite.net/html/impacts_of_flooding.htm ↗

[45] T. W. Miller, “Managing vegetation in flood control infrastructure,” *J. Soil Water Conserv.*, vol. 65, no. 4, pp. 122A-126A, 2010.

[46] M. S. Altinakar, M. Al-riffai, and N. Bergman, “Earthen Embankment Breaching,” *J. Hydraul. Eng.*, no. May 2014, pp. 1549–1564, 2011, doi: 10.1061/(ASCE)HY.1943-7900.0000498.

[47] 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.

[48] M. R. Kafle, “Critical Review and Improvement of Bank Protection Methods in Nepalese Critical Review and Improvement of Bank Protection Methods in Nepalese Rivers,” *J. Inst. Eng.*, no. April, 2021, doi: 10.3126/jie.v16i1.36530.

[49] TAW, “Clay for Dikes,” 1996.

[50] F. Barends, “Groundwater mechanics in flood risk management,” *Groundwater Engineering - Recent Advances*. Swets & Zeitlinger, pp. 53–66, 2003. doi: 10.1201/9781439833605.ch6.

[51] USACE, *Design and construction of Levees*, no. April. 2000. doi: 10.4324/9780080491080.

[52] J. Kind, “Sandbagging for Flood Protection,” no. January 2011, 2016.

[53] FEMA, “Floodproofing Non-Residential Buildings,” 2021, [Online]. Available: https://www.fema.gov/emergency-managers/risk-management/flood/floodproofing

[54] CIRIA, *The International Levee Handbook*. 2013. [Online]. Available: https://www.ciria.org/Resources/Free_publications/the_international_levee_handbook.aspx

[55] R. Smith, “Best practices for river dyke construction and maintenance,” *J. Hydraul. Struct.*, vol. 18, no. 5, pp. 735–752, 2021.

[56] J. Jones, “Predicting maximum flood levels for dyke design,” *Hydrol. Res. Lett.*, vol. 14, no. 1, pp. 52–59, 2019.

[57] M. Alam, R. Ahammad, and P. Nandy, “Coastal Livelihood Adaptation in Changing Climate : Bangladesh Experience of NAPA Priority Project Implementation,” *ResearchGate*, no. April, pp. 253–276, 2013, doi: 10.1007/978-4-431-54249-0.

[58] S. Vishnudas, H. H. G. Savenije, P. Van Der Zaag, K. R. Anil, and K. Balan, “The protective and attractive covering of a vegetated embankment using coir geotextiles,” *Hydrol. Earth Syst. Sci.*, pp. 565–574, 2006, [Online]. Available: https://hess.copernicus.org/articles/10/565/2006/

[59] S. N. Sathi, “EROSION CONTROL AND SLOPE STABILIZATION OF EMBANKMENTS USING EROSION CONTROL AND SLOPE STABILIZATION OF EMBANKMENTS USING VETIVER SYSTEM,” no. June, 2020, doi: 10.13140/RG.2.2.12012.80002.

[60] BIS, “Construction and Maintenance of River Embankments (Leeves) Guidelines,” 1995.

[61] C. Redlinger, B. Robbins, and M. Pabst, “Filter Design : The Why , When , and Where,” no. September 2016, 2017.

[62] T. Koma and T. Kono, “How should river embankments be spatially developed , from the upstream section or the downstream section ?,” no. January 2022, pp. 1–14, 2023, doi: 10.1111/jfr3.12870.

[63] R. Bhandari, “Riverbank Protection with Structure : Gabion Mattress Gabion,” no. May, 2019.

[64] S. Gladfelter, “DISPLACING DISASTERS : THE POLITICS OF LOCALIZED STRUGGLES TO (RE) POSITION RIVER TRAINING INFRASTRUCTURE AND

(RE) DISTRIBUTE VULNERABILITY ALONG NEPAL ' S LOWER KARNALI," vol. 25, no. June, pp. 111–142, 2020.

[65] J. J. Fullerton, T., & D'Auria, "Performance of Repaired and New River Structures in Reducing Flooding Risks in the Chesapeake Bay Region," *J. Hydraul. Eng.*, vol. 144, no. 7, 2018.

[66] M. Fleming, *Structural reliability and probabilistic analysis for engineers*. 2017.

[67] M. Boon, M., Jonkman, S. N., & Kok, "Probabilistic design and management of dikes," in *In Proceedings of the 29th ICOLD World Congress*, 2004, pp. 1–17.

[68] M. E. Haque and M. Alauddin, "A Review on the Effect of Spurs on Flow and Morphology of Channels," no. February, pp. 9–11, 2017.

[69] C. Inglis, "Discussion of Inland Delta Building Activity of Kosi River," *J. Hydraul. Div.*, pp. 93–100, 1967.

[70] P. Action, "SPURS AND DYKES FOR FLOOD WATER PROTECTION," 2007.

[71] H.Karami, A.Ardeshir, M. Saneie, K. Behzadian, and F.jalilsani, "Reduction of local scouring with protective spur dike," *World Environ. Water Resour. Congr.*, pp. 2–10, 2008.

[72] M. Polemio and P. Lollino, "Failure of infrastructure embankments induced by flooding and seepage : a neglected source of hazard," *Nat. Hazards Earth Syst. Sci.*, pp. 3383–3396, 2011, doi: 10.5194/nhess-11-3383-2011.

[73] A. Haroon *et al.*, "WATER RESOURCES HELPS IN THE EXPANSION OF MOSQUITOES COLONIES," *WATER Resour. Help. İN Expans. MOSQUİTOES Colon. Atif*, vol. 1, no. 1, pp. 16–21, 2020, doi: 10.26480/bdwre.01.2020.

[74] M. Morris, M. Dyer, and P. Smith, "Management of Flood Embankments A good practice review," 2007.

[75] S. Nasrin and M. S. Islam, "A Model Study on Erosion Control of Embankment by Vegetation," *Fareast Int. Univ. J.*, vol. 1, no. 1, 2018.

[76] M. N. Islam, "EMBANKMENT EROSION CONTROL: TOWARDS CHEAP AND SIMPLE PRACTICAL SOLUTIONS FOR BANGLADESH," no. August, pp. 307–321, 1999.

[77] K. Schroeder, "Embankments in Bangladesh – everyone is needed," no. July, 2014.

[78] CIWEM, "Floods and Dredging - a reality check," 2014.

[79] A. Dixit, "Kosi Embankment Breach in Nepal: Need for a Paradigm Shift in Responding to Floods," *Econ. Polit. Wkly.*, vol. 44, no. 6, pp. 70–78, 2009.

[80] R. K. Linsley, J. B. Franzini, D. L. Freybeg, and G. N. Tchoba-, "Water Resource Engineering," 1992.

[81] D. J. Gilvear and A. R. Black, "Flood-Induced Embankment Failures on the River Tray: Implications of Climatically Induced Hydrological Change in Scotland," *Hydrol. Sci. -Juornal des Sci. Hydrol.*, vol. 44, no. 3, 1999.

[82] R. J. Garde and R. R. Kittur G., "Mechanics of sediment transportation and alluvial stream problems," 1978.

APPENDICES

Appendix A: Sample size calculation of each wards

Ward 1 sample size:

=1271/5077*100% = 25%

(25% of 257= 65)

Ward 3 sample size:

=1233/5077*100% = 24%

(24% of 257 = 62)

Ward 4 sample size:

=1751/5077*100% = 35%

(35% of 257 = 89)

Ward 7 sample size:

822/5077*100% =16%

(16% of 257 = 41)

Appendix B: Questionnaire

General Information

GPS location

X-co-ordinate: Y- co-ordinate:

Altitude (m):

Ward no.:

Tole:

Name of respondent:

Gender:

Ethnicity:

Age:

a) 18-25

b) 26-35

c) 36-45

d) 46-55

e) Above 55

Family size:

Occupation:

a) Farmer

b) Government employee

c) Student

d) Business owner

e) Other (specify________)

Dykes & Flood

1. Nature of house:

a) Mud, stone, straw roof

b) Mud, stone, tin roof

c) Cement, stone/brick, tin roof

d) Concrete, bricks, concrete roofs

2. Distance of house from the river …

3. How long have you been residing in the Rajapur Municipality?

a) Born here

b) Less than 10 years

c) 10-20 years

d) More than 20 years

4. Do you own any land here? If yes, how much land do you own?

5. Are there any dykes on/near your land?

a) Yes

b) No

If yes, do you know the length of the dyke?

6. Have you received any compensation when dykes were constructed on your land?

a) Yes (specify how much_______)

b) No

7. Are you familiar with the dykes in the Lower Karnali River Basin?

a) Yes b) No

8. Have you received any information regarding the purpose and functioning of dykes?

a) Yes

b) No

9. How would you rate your knowledge about the role and importance of dykes in flood protection?

a) Very knowledgeable

b) Moderately knowledgeable

c) Slightly knowledgeable

d) Not knowledgeable at all

10. In your opinion, how effective are the dykes in the Lower Karnali River Basin in protecting against floods?

a) Highly effective

b) Moderately effective

c) Slightly effective

d) Not effective at all

11. Have you observed any instances of dyke failure or breaches in the past? If yes, please provide details……………..

12. Have the impacts of flood decreased after the construction of dykes?

a) Yes

b) No

c) Not sure

13. How much of your land used to be affected by flood before the construction of dykes?

a) Completely inundated

b) Partially inundated

c) Not inundated

14. Has the flooding of your land decreased after the construction of dykes?

a) Yes b) No c) Not sure

15. What was the effect of flood on your house before the construction of dykes?

a) Completely destroyed

b) Partially destroyed

c) No effect

16. Has the impact of flood on your house decreased after the construction of dykes?

a) Yes (Specify…)

b) No

17. Has this loss stopped or decreased after the construction of dykes?

18. Are there any negative consequences of dykes on the communities?

Dyke Maintenance and Monitoring

1. Are the dykes in the Lower Karnali River Basin well maintained?

a) Well-maintained

b) Poorly maintained

c) Not sure

2. What adaptation measures/structures did people used to prevent overflow of river water before the construction of dykes?

3. Who do you think is responsible for the maintenance of the dykes?

a) Government agencies

b) Local communities

c) Private organizations

d) Other (please specify _________)

4. Is there any provision for monitoring the status of dykes? If yes, when and how does monitoring and observation of dykes take place?

5. Is there a provision of maintenance of dykes before monsoon? If yes, has any upgrade or maintenance done on the dykes before monsoon? What was this maintenance?

6. Is there a provision of maintenance of dykes after the flood? Has any maintenance done recently? What was the maintenance?

7. Is there any specialized team for the maintenance and monitoring of dykes? Are they available in the time of need?

8. Do they train people for the maintenance and monitoring of dykes? If yes, who trains them? Please elaborate.

9. Do they hire the people from within the community or from outside for the maintenance/monitoring?

Community Engagement and Preparedness

1. Are there any community-based initiatives or programs related to dyke management and flood preparedness in your area?

a) Yes

b) No

If yes, what is it about, and how it helps in dykes management and flood preparedness?

2. Have you participated in the maintenance and monitoring of dykes or not? If yes, what was it about? Please elaborate.

3. Are women involved or motivated in maintenance and monitoring of dykes?

4. How well-prepared is local community for potential flood events?

a) Very well-prepared

b) Moderately prepared

c) Slightly prepared

d) Not prepared at all

5. In your opinion, what are the key challenges or issues related to dyke management and flood preparedness in the Lower Karnali River Basin?

Suggestions and Recommendations

1. What improvements or actions do you believe are necessary to enhance the effectiveness of dykes in the Lower Karnali River Basin?

2. Are there any alternative approaches or strategies that you think should be considered for flood protection in the area?

3. Is there any additional information or feedback you would like to provide regarding dykes and flood management in the Lower Karnali River Basin?

Appendix C: Photo Plate

Safe Shelter

Elevated house

Electric pole with flood level measurement

Water stagnation at AFS

Field survey

Karnali River Management Project

CSDR, Practical Action, Flood Resilience Nepal

Karnali-Kauriala Bridge

Budi Kulo