OVERVIEW OF RIVER HYDROLOGICAL ISSUES IN KAKARBHITTA-PATHLAIYA ROAD SEGMENT OF EAST-WEST HIGHWAY OF NEPAL

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Abstract

The East-West Highway of Nepal is the main trade and physical mobility corridor and of a two-lane bituminous road. Therefore, the Government of Nepal (GoN) is planning to improve it to a standard four-lane highway. In the first phase, the Government of Nepal is planning to upgrade the Kakarbhitta-Pathlaiya road which is the segment of the East-West Highway. It is vital to examine the river hydrology accurately for the appropriate location and design of the structures associated with it. This study aims to work out the features of flood and sediment of the major rivers intersecting the Kakarbhitta-Pathlaiya road. A review of the previous studies and field observation via a walk-through survey was conducted to assess the hydrological issues. The road segment passes through the Terai. The study revealed that the issues of flooding and inundation within the Terai are more critical, and the rivers crossing the road segment transport significant amounts of sediment as well. In the stages of planning and design of the road segment, the capacity of the rivers must be enhanced for transporting water and sediment in the places of bridges. Besides, watershed management techniques and integrated water resources management approaches should be intervened.

Keywords: *Kakarbhitta-Pathlaiya Road; East-West Highway; Flood; Sediment; Inundation; Watershed*

1. Introduction

Nepal entered a systematic construction of road networks throughout the country after the emergence of democracy in 1950. The East-west Highway of Nepal is the longest road network (1035 km long) of the country that joins its eastern to the western border. This road traverses through the southern low-lying Terai (southern flat plain) of Nepal. The East-West Highway is the main trade and physical mobility corridor for Nepal. It was designed and developed about 50 years ago, with single-lane bituminous carriageway width, and has been upgraded to the double lane during different periods between 1998-2005. The existing condition of the East-West Highway is poor, and the majority of the bridges (most of which are more than 40 years old) require replacement. With an increase in country population, associated increase of vehicle number, and frequency of travel, the Government of Nepal (GoN) is planning to upgrade the two-lane East-West Highway to a four-lane standard on a phase-wise basis. In the first phase, the GoN is planning to upgrade the Kakarbhitta-Pathlaiya corridor; approximately 366 km. Kakarbhitta-Pathlaiya road is the segment of East-West Highway that encompasses 10 districts (Jhapa, Morang, Sunsari, Saptari, Siraha, Dhanusa, Mahottari, Sarlahi, Rauthat, and Bara) in the zone of influence (Figure 1).

Site hydrology is vital to the successful performance of a road. Understanding the interaction of hydrology with the proposed road structures must be thoroughly investigated. The accurate hydrological investigations lead to determining the best alignment of the road and the location of the structures associated with it. Consequently, the proper hydrological investigation also minimizes the costs associated with the road structures, and determination of accurate dimensions of the cross drainage works for streamflow passing across the road and prevents future flood hazard events that may destroy the road. Therefore, the present study deals with the existing hydrological condition of the Kakarbhitta-Pathlaiya road segment of East-West Highway which includes characteristics of flood and sediment of the major rivers intersecting it. A review of the former studies, and a walk-through and field observation were adopted to evaluate the hydrological issues.

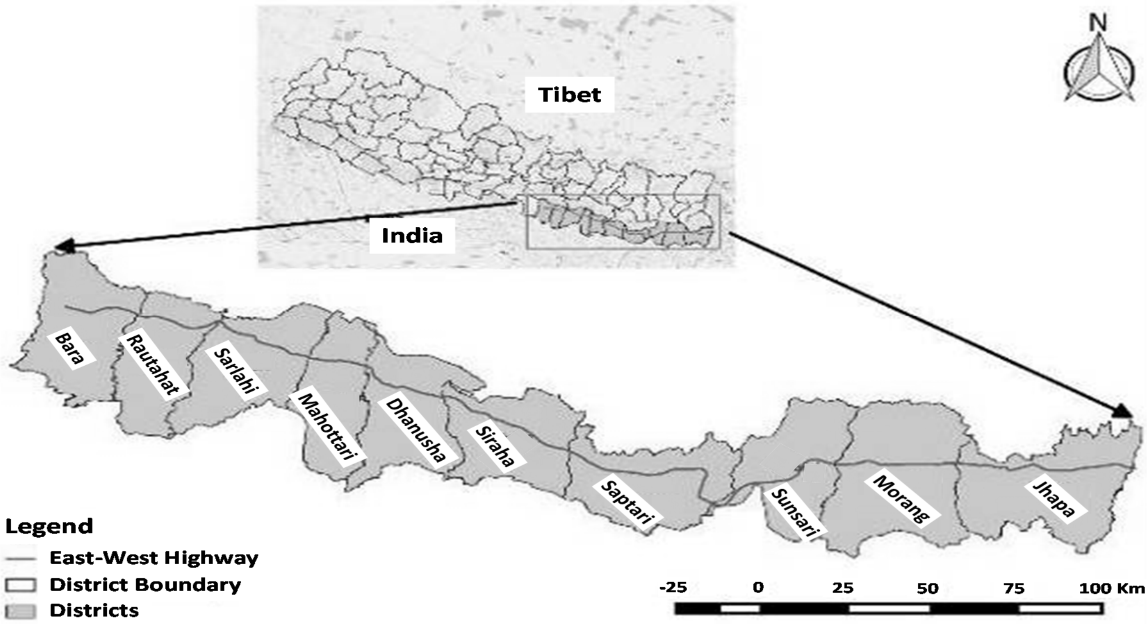

Fig 1: Map showing districts through Pathlaiya-Kakarbhitta road section of East-West Highway

2. Literature Review

Road networks and systems are vital to today's economy and society (Button and Hensher, 2001) and its vitality is extremely important for a country like Nepal, where other means of transportation are either unavailable or unaffordable. There is no extensive railway linkage in Nepal. However, the construction scheme of the East-West Railway linkage is in progress. In this scenario, roads not only provide means for the safe and efficient movement of people and goods across the nation, but they have also become a permanent part of the physical, cultural, and social environment (Robinson, 1971; Lay, 1992).

Roads and their linkages are one of the most prominent man-made features on the modern landscape today (Sanderson et al., 2002). They are the most common disturbance to the physical characteristics of a watershed (Jones et al., 2000; Wemple et al. 2001; Ziegler et al. 2007). Roads and their associated structures have influences on the surface and subsurface water flow, infiltration rates, and the production of sediments (Tague and Band 2001; Wemple et al., 2001; Ziegler et al. 2004; Dutton et al., 2005; Cuo et al., 2006; Ziegler et al., 2007). At the watershed scale, road networks can significantly alter both the magnitude and time of peak flow of rivers (King and Tennyson, 1984; Jones and Grant, 1996; Wemple et al., 1996; Bruno and Bardossy, 1998; Jones et al., 2000; Iroumé et al., 2005).

3. Methodology

3.1 Study area

The Kakarbhitta-Pathlaiya road section is approximately 366 km, traverses through forests, settlements, commercial, and farmlands. The climate of the region is tropical with hot and wet summer with maximum temperature up to 42°C and winter minimum temperature up to16°C. There is very high annual rainfall in many areas along the highway. It is quite 1500 to 1800 mm per annum. Rainfall is more intense during the monsoon season (June-September) with large local variations relevant to orography and specifics of local conditions. Rainfall is high on some regions of the southern Himalayan slopes and along the Chure ranges as well (Shrestha, 2009). Regions close to the Indian border receive about 1500 mm rain in a year, while at the foothills of Chure the annual rainfall reaches 2000 mm. On the northern side of the Chure, the rainfall reduces again. In the lee-ward side of the ranges, rainfall is reduced due to the effects of a rain shadow.

Table 1 presents the major landuse within the 10 districts, located along East-Way Highway. Land cover within the proximity of the road Right of Way (RoW) zone as well as within the Direct Impact Area (DIA) with buffer 150 m on each side and within the Indirect Impact Area (IIA) with the buffer in 10 km on each side, also shows that the major land cover types of the study area are forest, agricultural land, and settlements or built-up areas (Table 2).

Table 1: List of districts with major landuse and major cites through which Pathlaiya-Kakarbhitta section traverse

District	Major Landuse	Major City/Town
Bara	Forest, agricultural lands	Pathalaiya, Nijgadh, Piluwa
Rautahat	Forest, agricultural lands, and settlements	Chandrapur, Bagmati
Sharlahi	Forest, agricultural lands, and settlements	Lalbandi, Nawalpur, Hariwan
Mahottari	Forest, agricultural lands, and settlements	Bardibas
Dhanusha	Agricultural lands and settlements	Lalgadh, Dhalkebar, Golbajar
Siraha	Agriculture lands and settlements	Lahan, Mirchaiya
Saptari	Forest, agricultural lands, and settlements	Kalyanpur
Sunsari	Forest, agricultural lands, and settlements	Itahari, Jhumka
Morang	Forest, agricultural lands, and settlements	Urlabari
Jhapa	Forest, agricultural lands, and settlements	Damak, Birtamod, Kakarbhitta

Table 2: Land Cover Types in the Study Area

Land Use Class	Right of Way		Direct Impact Area		Indirect Impact Area	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Forest	374.19	20.38	2498.77	22.64	231915.37	32.78
Shrubland	59.95	3.26	349.55	3.17	13762.04	1.94
Grassland	36.14	1.97	208.48	1.89	15678.41	2.22
Agricultural land	1123.66	61.19	6598.99	59.78	393347.85	55.60
Barren land	75.48	4.11	467.33	4.23	36027.40	5.09
Water bodies	19.79	1.08	117.26	1.06	9358.48	1.32
Built-up area	146.99	8.01	798.04	7.23	7407.72	1.05
Total:	**1836.20**	**100.00**	**11038.42**	**100.00**	**707497.27**	**100.00**

3.2 River Hydrology

Based on the nature of the origins, Nepalese rivers are classified into three categories: i) Himalayan rivers which originate from Himalaya and carry snow-fed flows with significant discharge even in the dry season, ii) Mahabharat Rivers which originates from Mid-Hills are fed by rainfall, springs and groundwater and iii) Terai (Southern) Rivers which originates from Chure Hills are characterized by flash floods in the monsoon season (June to September) and no flow in the dry season (NDRI, 2016). They drain about 16% of the Nepali area contributing to about 13% of the total annual runoff.

Figure 2 presents a river basin map of Nepal (NDRI, 2016). The estimated run-off of Nepali rivers is 174×10^9 m^3 of water per annum as surface run-off and is based on an average annual rainfall of about 1400 mm (Regmi, 2018). Koshi, Narayani, Karnali and Mahakali are Himalayan Rivers and Mechi, Kankai, Kamala, Bagmati, West Rapti and Babai are mid-hill Rivers. Some parts of the Himalayan River basins fall outside Nepal. About 65% of the Mahakali basin lies outside Nepal, most of which is in the Indian Territory bordering Nepal. The Mahakali River is the Nepal-India western border. Almost 47% of the Koshi River basin, 20% of the Narayani River basin, and 5% of the Karnali River basin lie in Tibet (Joshi and Shrestha, 2008). The catchment area within Tibet is generally drier as it falls within the rain-shadow created by the huge Himalayas.

The river network within the study area is represented by 23 major rivers, which can be grouped as old pre-Himalayas (Koshi River), young Mahabharat (Kankai, Kamala, and Bagmati Rivers), and very young Post-Chure (other rivers) (Adhikari, 2013). Only the Koshi River is snow-fed, all other rivers depend on rainfall for their runoff.

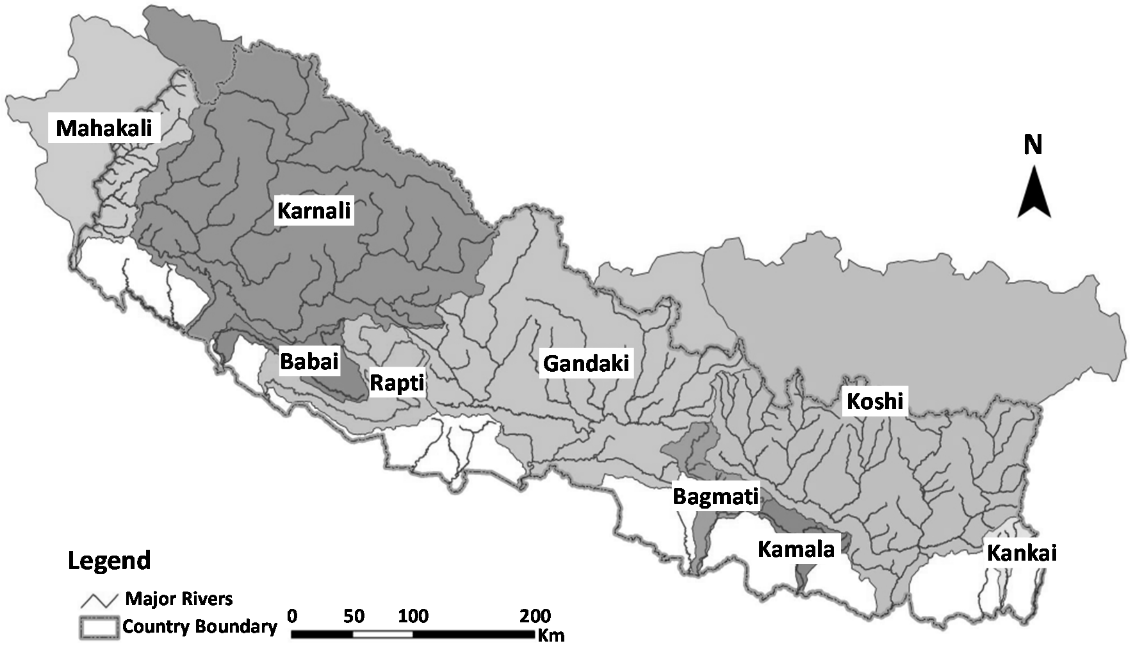

Fig 2: River Basin of Nepal with Major Rivers (NDRI, 2016).

3.3 River System

The Kakrbhitta-Pathlaiya Road is located in the Terai landscape. It runs across 23 rivers from Kakrbhitta-Pathlaiya. Rivers crossing the Kakrbhitta-Pathlaiya Road are listed in Table 3. It has several bridges over these rivers, among which Koshi, Kankai, Kamala, and Bagmati Rivers are the major ones.

Table 3: Rivers along Kakrbhitta-Pathlaiya roadside

1. Kankai River	9. Balan River	17. JhanjKhola
2. Teli River	10. Chure River	18. DhansarKhola
3. Pathari River	11. Kamala River	19. BhamaraKhola
4. Dash Khola	12. Ratu River	20. LalBakaiya River
5. ChisangKhola	13. PhuljorKhola	21. Pashah River
6. Gachhiye River	14. Puljor River	22. Balganga River
7. BudhiKhola	15. Narayan Khola	23. Dudhaura River
8. Koshi River	16. Bagmati River	

3.3.1 Koshi River

The Koshi River is 720 km long and drains an area of about 92538 km^2 in Tibet, Nepal, and Bihar (Nayak, 1996). The river has three main tributaries, comprising the Sunkosi, Arun, and Tamor Rivers, and can be broadly divided into two parts from hydrology and hydro-meteorological point of view. The upper catchment covering almost 80% of the whole basin area that lies in Tibet and Nepal has quite different characteristics with reference to the lower basin area (almost 20% of the whole area) laying in Bihar (Kumar, 2015). The Koshi alluvial fan is one of the largest in the world and its lateral channel shifting is exceeding 120 km during the past 250 years (Agarwal and Bhoj, 1992).

3.3.2 Kankai River

Kankai River is a transboundary rain-fed perennial river situated in the eastern part of Nepal bordering India on two sides. The southern reach of the river hits the Indian side about 28 km reach and again returns to the Nepal side at the southern part (Khadka and Bhaukajee, 2018). At the upstream area of the basin, the river channel is narrow and steep and extends up when it reaches the lower flat landscape of Nepal (Khadka and Bhaukajee, 2018). The catchment area of the Kankai River basin is 1284 km^2 (Karki and Pradhan, 2011). The entire basin area is dominated by forest and cropland. 702 m long bridge in the downward course of the river is one of the longest bridges of Nepal.

3.3.3 Kamala River

Kamala River basin mainly lies in Siraha, Sinduli, Dhanusa, and Udayapur districts of Nepal, has a drainage area of about 2050 km^2 at the Nepal-India border (NDRI, 2016). Half of the Kamala basin lies in the Sindhuli district, while a quarter of the basin lies in the Udayapur district (NDRI, 2016). The origin of the Kamala River is Chure Range nearby Maithan close to Sindhuliagarhi in Sindhuli District.

3.3.1 Bagmati River

The Bagmati River emerges from the Shivapuri hills in the Mahabharata Range. It flows across the Kathmandu Valley of Nepal and moves down south into the Terai Plains, before crossing the Nepal-India border. The river lies in central Nepal and covers an area of 3610 km^2 to the Nepal-India border (Gautam and Pokhrel, 2004). The Kathmandu valley comprises 15% of the basin area in Nepal (Dahal et al., 2011). The Nakkhu, Kulekhani, Kokhajor, Marin, and Chandi River are the key tributaries of the Bagmati River. These tributaries are extremely contaminated.

3.4 Floods

Floods are common throughout the country in the monsoon season of recent years. Extremely high-intensity precipitations in hilly areas cause landslides and debris flows in that area (WECS, 2011), consequently causing destructive floods on many rivers in the areas of lowland. On the other hand, rivers originating from the Mahabharat and Chure ranges are generally wide, particularly in the Bhabar zone, and these rivers are susceptible to flash floods. Such rivers are causing more flood problems than large rivers such as Koshi, Narayani, and Karnali (Yogacharya and Gautam, 2008). Riverbank cutting, shifting of river channels, waterlogging, and sedimentation are some of the major geo-hydrological processes that are intensified during flash floods. The problems of flooding and inundation in the Terai are more critical generally due to climate change and particularly due to changes in the rainfall pattern and intensity (Adhikari, 2013).

In August 1987, intense rainfall of 200 mm had caused flooding and inundation in the Eastern Terai and damaged several places of the East-West Highway of the study area (Adhikari, 2013). In some locations, 50 cm deep water was flowing over the road pavement (Sharma, 1988). Jhapa, Morang, Sunsari, Saptari, and Udayapur were the most flood-affected districts by that event.

The average discharge of the Koshi River is 2166 m^3/s and it increases to as much as 18 times the average during floods (Jain et al., 2007). The greatest recorded flood was 24200 m^3/s on 24 August 1954. The Koshi Barrage has been designed for a peak flood of 27014 m^3/s. Studies over 50 years have concluded that the Koshi River basin below Chatara lies in a high flood disaster risk zone due to the poor maintenance and monitoring in existing civil structures with a poor understanding of the river dynamics (Kafle et al., 2017). The flood-prone area of the Koshi River includes Sunsari district, Saptari district, and the major part of Bihar (India). On 18 August 2008, 4 village development committees of Sunsari district of Nepal were affected due to the breach of the left embankment of Koshi River near Kusaha village that caused more than 100 thousand people homeless in Nepal and more than 3 million people displaced in India (Yogacharya and Gautam, 2008). The Koshi River is confined to flow within embankments. On the downstream of the Koshi Barrage, 387 km long embankments on both sides of the Koshi River have been built at about 12 to 16 km apart to check the river flow towards the west (Kumar, 2015).

The rivers that originate from the Mahabharat range experience monsoon discharge of 2000 m^3/s to 8000 m^3/s and create a disaster of flooding and inundation in the Terai (Adhikari, 2013). The Kankai River basin frequently suffers from flash floods as the catchment response to high intensity and short duration precipitation is swift, leading to flooding and water-logging downstream. Yogacharya and Gautam (2008) observed the flood record of the river from 1972 to 2007. The large floods were noted in 1981, 1990, 2001, 2002, and 2003 that vary from 992 m^3/s to 7500 m^3/s. They also pointed out that the frequency of massive floods is increasing in recent years.

The annual average flow of the Kamala River is 99 m^3/s, where almost 80% of discharge occurs in monsoon months (July to September); the minimum and maximum flows generally occur in April and August respectively (NDRI, 2016). The seasonal variation of flow is very high with 30 m^3/s in August and 17 m^3/s in April. The Kamala River cannot contain its extreme flood discharge within the defined banks and as a result, overbank flow and branching are common phenomena (Shrestha, 2016).

The annual average flow of the Bagmati River is 178 m^3/s (WECS, 2011). The floods of the river have caused extensive suffering to the people in the Terai and northern regions of Bihar. In 1993, there was a highly disastrous flood, which had washed away part of the Bagmati Barrage and inundated vast areas in the Sarlahi and Rautahat districts (Adhikari, 2013). The peak flood of the river was 16000 m^3/s (Gautam and Pokhrel, 2004). Poor water management, and improper weather forecasting and awareness were the main cause of the massive destruction (Bhusal, 2002).

3.5 Sediment

The river network of Nepal transports millions of tons of sediment every year. The short-term sedimentation covers the local area along the river channel (Richards et al., 1993) and the river is forced to form the braided system by the accumulated sediments. Then the river often enters nearby areas, especially in low lands, in an aggressive way during the monsoon seasons in the Terai region of Nepal (Kafle et al., 2017).

Extensive soil erosion and landslides in the upper catchments of the large rivers (Koshi, Kankai, Kamala, and Bagmati) in the study area have produced a high silt yield. Sedimentation is a serious problem in the Koshi River and its tributaries, which spans a staggering length of 720 km with about

92,538 km^2 of drainage area (Nayak, 1996). The Koshi River is the extreme silt-producing river in the world (Subramanian and Ramanathan, 1996) with an annual estimated sediment volume of 118×10^6 m^3 (Dixit, 2009) which is contributed by the soil erosion and landslides in its catchment areas. Extensive soil erosion and landslides in its upper catchment, one of the highest in the world, have produced a silt yield of about 19 m^3/ha/year (Varghese, 2008).

The rivers that originate from the Mahabharat range transport significant amounts of sediment while flowing through the Chure range and exhibit lateral shifting (Adhikari, 2013). Kankai River is a gravelly river consisting of more than 60% gravel of gneiss and the remaining others are of different metamorphic and sedimentary rocks (Raghubanshi, 2007). The annual sediment yield of the river is 148×10^3 tons. The fragile geological nature of the Chure hills in the Kamala Basin produces high loads of sediment. The annual sediment load estimated for the basin is about 7×10^6 tons (Thapa and Pradhan, 1997). The Chure range within the Bagmati Basin contains wide valleys of the Bagmati River and its tributary Marin Khola. Low to high terraces adjacent to the river, alluvial fans, badlands, and thin sandy soil covers are the features found in this range (Shrestha and Tamrakar, 2012). The annual sediment load estimated for Bagmati Basin is about 25.68×10^6 tons (Jha, 2002).

4 Result and Discussion

The road networks are commonly developed perpendicular to the streams and in lowland positions. The road embankments also disturb natural streams. During extreme events, the magnitude of the disturbance depends on the type of embankment construction that directly influences the watershed drainage density (Ziegler et al., 2004; Borga et al., 2005; Cuo et al., 2006). Road networks and their related structures influence hydrologic responses by changing hydrological connectivity within fluvial systems and shortening the time of concentration of a watershed (Nickman et al., 2016). This is particularly factual during extreme events when surface flow processes govern the hydrological response (Ziegler et al., 2004; Borga et al., 2005; Cuo et al., 2006; Ziegler et al., 2007; Blanton and Marcus, 2009; Soulis et al., 2015). The impact of the road on hydrologic response depends on the pattern of the road-stream network in the watershed, location of the road, and the road embankment construction type (i.e., cut or fill) (Ziegler et al., 2007; Blanton and Marcus, 2009). This makes it difficult to forecast the actual impact of road networks on hydrologic responses, such as flooding or flow duration (Nickman et al., 2016).

In this regard, different hydrological approaches and modeling tools have been used to identify the various impacts of different road types on the hydrologic response of watersheds (Kalantari et al., 2014). The studies conducted by (Jones et al., 2000; Loague and VanderKwaak, 2002; La Marche and Lettenmaier, 2001; Cuo et al., 2006) have clearly indicated that the hydrologic models provide an opportunity to understand and explore the impacts of roads in response to hydrological processes occurring at the watershed scale. This idea of using a model-generation scenario will be applicable to explore the possible impact of the road section, under consideration of this study, on hydrological responses, such as magnitude and duration of floods, and sediment yield as well.

The dynamic features of rivers and river systems and the natural beauty make the design of roads in the river environment one of the most challenging and stimulating of all engineering designs (NHI, 2001). Most of the soils along the Pathlaiya-Kakarbhitta section are residual or old alluvial deposits that consist of boulders and cobble, sands, and silts. The soils are quite stable, but there is still a possibility of their erosion along the riverbanks. So, riverbanks protection is required during the construction of bridges and other road infrastructures of the study area.

Climate change can also contribute to the severity of the floods; because it is predicted in climatic scenarios that rainfall amount might be increased within the Terai region, especially in the monsoon season. Meteorological stations in the Terai region show an increasing level of precipitation in July from 1970 to 2009. The frequency and intensity of rainfall are also increased, as well as rainfall causing a rise in flash floods and debris flows. Intensification in total rainfall intensity facilitated an increase in the number of landslides. In such scenarios, more floods can be expected along the road, and therefore, the design of the drainage structures should be made accordingly to prevent seasonal disasters in the specific areas of the river basins of the study area. So, climate scenarios and flood probability should be considered at the stage of planning and design of road upgrade activities.

5 Suggestion and recommendation

The Kakarbhitta-Pathlaiya road segment of East-West Highway lies in the Terai region. The prevailing river networks may cause drainage problems related to water-logging along the highway, especially during monsoon season. The areas of possible water-logging should be identified and mitigation measures should be proposed at the planning and design stages of the Kakarbhitta-Pathlaiya road. The large and small rivers within the study area have produced and transported significant amounts of sediment. The capacity of the rivers must be improved for water and sediment transport, especially in the places of bridges, considering climate change scenarios.

Not only the road section of the East-West Highway; the whole area of the Terai must be well safeguarded from flooding and inundation impacts. It is necessary to have proper coordination among several development initiatives working within the study area for the provision of sufficient waterways for the floods. A collective approach of the water resources management technique is the basic tool to address the flood and inundation problems. Apart from watershed management in the Chure hills, landuse regulations need to be promulgated and enforced to dovetail with integrated water resources management interventions.

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