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DYNAMICS OF THE KOSHI RIVER ON THE PERSPECTIVE OF MORPHOLOGY AND SEDIMENTATION WITH EMPHASIS ON POST DISASTER IMPACT OF THE 2008 KOSHI FLOOD

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ABSTRACT

Koshi river is one of the most dynamic rivers in the world. It has shifted about 115 km westward due to sedimentation and tectonic activities during the past 200 years. Dynamic nature of the Koshi is revealed by its erosive nature and high capacity of carrying silt and sand from highlands. Disaster from floods are frequent in this river channel because of encroachment in watershed, high denudation rate, torrential rainfall in the upland as well as poor design of manmade structures along the river channel.

The 2008 Koshi flood is one of the most catastrophic events in last decade. In this flood, millions of people are affected and lost their properties amounting to billion dollars. Most researches on Koshi flood disasters were concentrated on immediate effects that spanned about 1-2 years post flood period. Research works over last 50 years on Koshi revealed that the lowland Koshi basin, specially downstream from Chatara, has high flood disaster risk because of the poor maintenance and monitoring of the river training works done with poor understating of the dynamism of the river. Adversely, the disaster management was always ineffective, though the flood incidences were frequent since last 4 to 5 decades. The study on long term effect to health and long term effects of sedimentation on agricultural land in post flood disaster management phase are highly insufficient. Thus, for the lowland area of Koshi, adaptation strength and resilience on the future flood disasters need to be thoroughly investigated for the effective and efficient post disaster management.

Key words: Koshi, sedimentation, flood, disaster

INTRODUCTION

Flood in the Himalayan region is common due to steep topography and active hydro-meteorological and geological settings. Flood disaster is the oldest known disaster that has been threatening people around the world [1]. The impact of flood disaster has been mentioned into two groups, direct- related to morbidity & mortality and indirect- damage of infrastructures and properties [2]. Asia is counted as the most flood-affected continent for last 25 years having 50% of flood-related fatalities [3,4]. In Asia, over 1.3 billion people are dependent on 10 major river systems of the Hindu-Kush-Himalaya region only [5].

Flood hazard is one of the most prominent problems in the Himalayan river basins [6]. Annually large area of agricultural land adjacent to rivers is affected by erosion as well as deposition of silt and sand due to flooding. Therefore floods are considered as the one the worst water induced disasters in Nepal [7]. Floods are essentially belongs to hydrological phenomenon where as the variation of the floods in the river basin dependent on the geomorphological and geological factors.

Mountainous country Nepal consists of landforms with high relief, rugged topography, complicated geological structures and torrential rainfalls. The melting of glaciers and increasing trend of monsoon rainfall have also contributed to flood in Nepal as well as the adjacent countries [8]. These factors are responsible for flooding every year. Kale (1997) has indicated that the intensity of flood is rising on Gangatic plain including Nepal [9]. Every year, many people and their properties are affected by floods in Nepal. The narrow width (less than 200 km) and great altitudinal variations in north to south are the leading factors for high flow velocity as a form of flood across the low land (Terai) area [8]. Intense monsoon precipitation and synchronization of flood-peaks of the major rivers are generally considered to be the main causes of the floods [10].

Nepal has more than 6000 small and big rivers (Fig. 1) including four major watersheds: Koshi, Gandaki, Karnali and Mahakali. Nepal's rainfall is governed by monsoons which contribute about 70-80% of rainfall [11,12] within four months (June to September). The average rainfall of the country is about 1500 mm. The rivers are heavily affected by monsoon that causes flooding during the June-Sept period. Amongst them, Koshi ranks at the top for the silt discharge with 0.4 million ton/day [13] with variable discharge and high sediment flux [14]. Similarly the river systems that emerge from mountains are classified into four groups on the basis of source area (i) mountain-fed, (ii) foothills-fed, (iii) plains-fed and (iv) mixed-fed rivers. The quantitative estimate of water and sediment flux suggests that the these river transfer the 99.9% sediments mass through water and remaining 0.1% retained in the basin [15].

Flood disaster has been a pivotal reason for sedimentation in agricultural lands-primarily sand and silt- and this leads to deterioration of land quality and its normal productivity. The flash flood affects the soil fertility, land use, flood plain and land morphology [16]. Most of the floods cause human casualties and property losses. In addition, sediment can itself be a major part of disaster. Therefore, sediment disasters are defined as the phenomena that cause direct or indirect damage to the lives and properties of people, inconveniences to the life of people, and/or the deterioration of the environment, through a large-scale movement of soil and rock [17]. Thus, erosion and sedimentation because of flood should be considered as major issues for the investigation in context of physical and socio economical impacts as a part of effective post disaster management.

Recent studies indicate that the rainfall patterns are changing in the Himalayan region and its impact is significant in sediment dynamics mainly during the flood. The resultant effects are damages to floodplain agricultural land, effects to irrigation diversions, and unusual mass wasting by undercutting [18]. Changing land use and encroachment along with reservoir construction are the main causes of the change in sediment load of the world's major rivers [19]. World's most dynamic hydrological system that exists in dense population of Gangatic basin including Koshi River is therefore vulnerable. Shifting the channel with huge amount of sediments directly affects the people settled in this basin [20].

Small rivers that originate from middle mountains also greatly affect the agricultural land of the country. Many studies have shown that the erosion and sedimentation from highland to lowland is significant in terms of the volume and rate of deposition. It has been estimated that the Koshi occupies 25% of Nepal's total river runoff and creates about 50% of Nepal's soil erosion [21]. Similar estimation has been calculated by another study which found that 40-96% [22] of Nepal's total sediments loss, with an average of 18 tons/ha of the annual sediments losses. In context of erosion, there is significant statistical correlation between monsoonal precipitation and sediment load [23]. Another research has estimated megafan deposit to be about 5-10 m thick with the rate of more than 5 cm per year on the basis of deposition averaged over about 100-200 years [24]. Similarly, it has found three major fluvial hazards: rapid lateral migration, frequent flooding and extensive bank erosion[25] in the Koshi River low land basin. Lateral shifting of the Koshi river, along with other rivers, have become dynamic because of neotectonic tilting and subsidence of the area, as well as local topography and sedimentological readjustments in the basin. A significant rising trend of flash flood frequency is also noticed in the Koshi River [12,26].

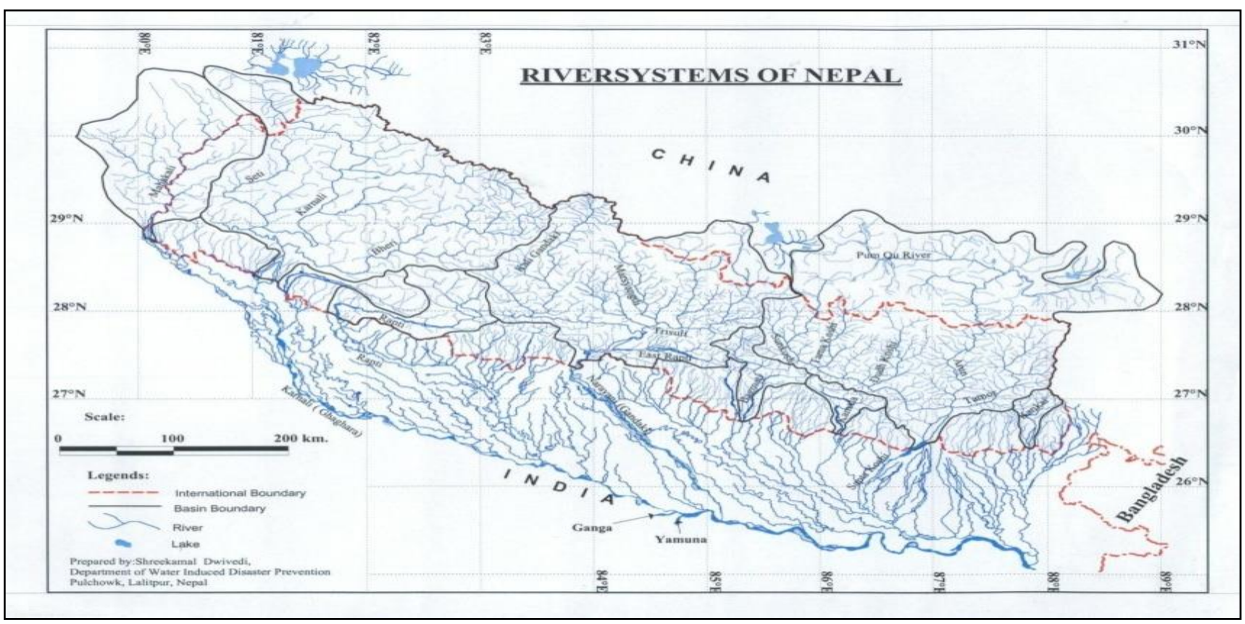

Figure 1 River system of Nepal [27].

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Elevation range of Koshi varies from 60 m (Gangatic Plain) to 8848 m (Mt. Everest), covering different types of climate, soil & vegetation (Table 1) along with various socio-economic zones. The rising population and encroachment has severely declined the ecosystem and climate change can worsen the rate of hazard [29]. Koshi has the largest alluvial fan with avulsive shifting. The flooding in Koshi is frequently destructive caused by its fluctuating discharge [30].

Fig. 2 illustrates physiographic divisions of Nepal Himalaya which classify the landform divisions longitudinally in east-west direction. The southern part of Nepal consists of an alluvial plain and it is known as Terai in Nepal, and it also can be described as a geological unit of the northern part of Gangatic plain. It is followed by sedimentary rock units in Siwalik range and moderate to high grade metamorphic rock units of the Mahabharat and Himalayan ranges northwards.

Table 1- Physiographical division of the Nepal Himalaya [28].

SN	Geomorphic Unit	Width (km)	Altitudes (m)	Main Rock Types	Main processes for landform development
1	Terai (Northern edge of the Gangetic Plain)	20-50	100-200	Alluvium: coarse gravels in the north near the foot of the mountains, gradually becoming finer southward	River deposition, erosion and tectonic upliftment
2	Churia Range (Siwaliks)	10-50	200-1300	Sandstone, mudstone, shale and conglomerate.	Tectonic upliftment, erosion, and slope failure
3	Dun Valleys	5-30	200-300	Valleys within the Churia Hills filled up by coarse to fine alluvial sediments	River deposition, erosion and tectonic upliftment
4	Mahabharat Range	10-35	1000-3000	Schist, phyllite, gneiss, quartzite, granite and limestone belonging to the Lesser Himalayan Zone	Tectonic upliftment, Weathering, erosion, and slope failure
5	Midlands	40-60	300-2000	Schist, phyllite, gneiss, quartzite, granite, limestone geologically belonging to the Lesser Himalayan Zone	Tectonic upliftment, Weathering, erosion, and slope failure
6	Fore Himalaya	20-70	2000-5000	Gneisses, schists, phyllites and marbles mostly belonging to the northern edge of the Lesser Himalayan Zone	Tectonic upliftment, Weathering, erosion, and slope failure
7	Higher Himalaya	10-60	>5000	Gneisses, schists, migmatites and marbles belonging to the Higher Himalayan Zone	Tectonic upliftment, Weathering, erosion (rivers and glaciers), and slope failure
8	Inner and Trans Himalaya	5-50	2500-4500	Gneisses, schists and marbles of the Higher Himalayan Zone and Tethyan sediments (limestones, shale, sandstone etc.) belonging to the Tibetan-Tethys Zone	Tectonic upliftment, wind and glacial erosion, and slope degradation by rock disintegrations

Physiographically, Nepal can be divided into nine different geomorphic units [28]. The main rock types vary from alluvium deposits to high-grade metamorphic rocks from southern to northern part of Nepal respectively.

Table 1 describes the geomorphic units with respect to altitude, width, rock type and landform development.

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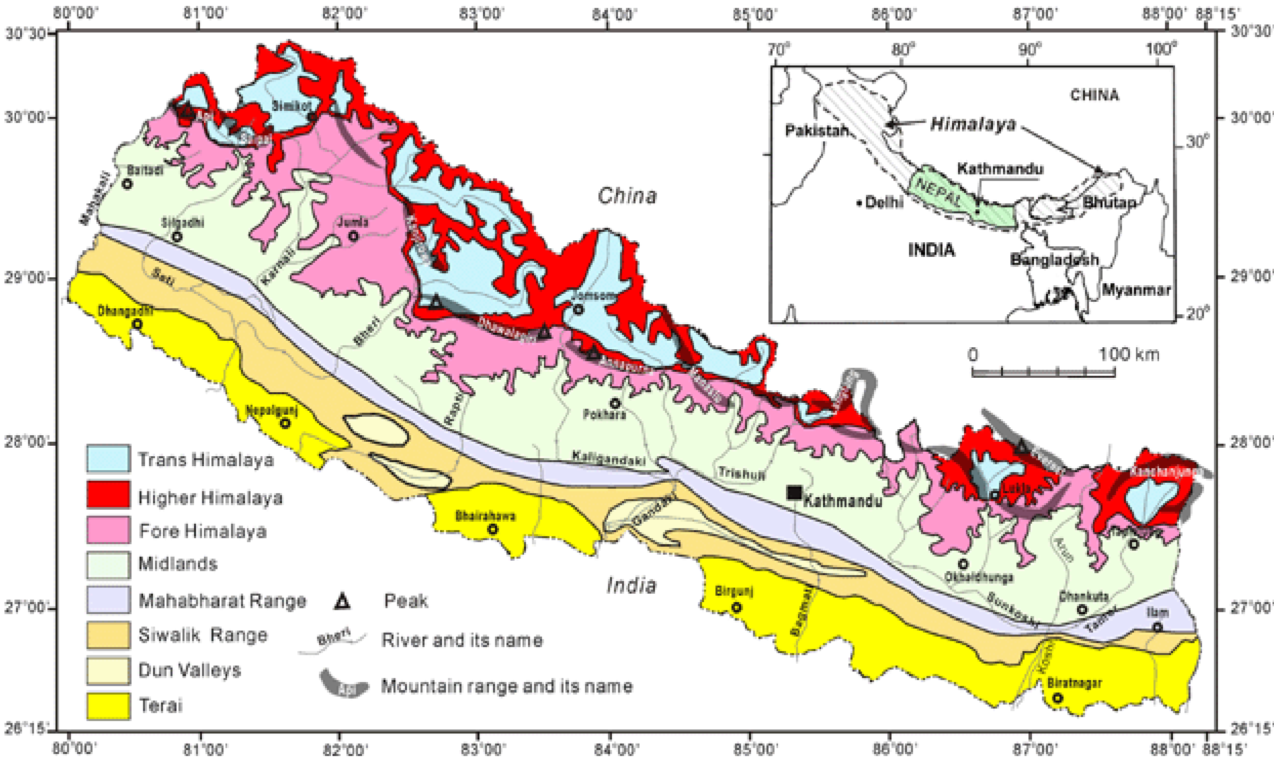

Figure 2 Physiography of the Nepal Himalaya [31].

FLOOD DISASTER IN NEPAL

The major flood prone area of Nepal lies in the southern part and it extends longitudinally east to west. Within 20th century the major discharges were recorded within the range of 24000-26000 m3/sec in three years 1924, 1954 and 1968 [32,33,34] in Koshi.

Existing highly fertile agricultural lands in the lowland areas have densely populated settlements, and most of the settlements are on the flood plain. Therefore, the area is vulnerable to flood disaster every year, particularly in the rainy season. According to Central Bureue of Statistics of Nepal in 2011, about 51% people live in Terai (southern lowland region) [35]. Sthapit (1995) has calculated that 35 times more sediment load can be brought by single flood in one event of torrential rainfall than that of normal [36]. Three floods of 1985, 1993 and 2004 are the major floods in Nepal that lead to the food scarcity because of farm land as well as other land washout. The infrastructure construction in Terai region constrained drainage of rainwater and that promoted frequent flooding [37]. The rate of denudation is also four-fold higher than the rates in global comparison [38] in the Himalayan rivers' catchment which leads to the heavy sediments than that of world average. The intensity of the Koshi flood has been seen to be doubled as a result of increase in intensity of floods in the sub-catchment of Arun and SunKoshi [39]. The major recent floods (2010-2013) in various rivers are shown in Table 2.

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Table 2 Recent floods in Nepal with disaster details [40].

Region	Year	Disaster
Mahakali	June 2013	77 buildings and displaced 2,500 people in Dharchula only. (http://www.nepalnews.com/archive/2013/jun/jun18/news12.php)[41]
Dang	June 2012	145 families were displaced and 2,200 household were affected by flash floods
Batadi, Achham, Kalikot, Jajrkot, Rukum, Rolpa, Kaski, Tanahu, Makwanpur, Gorkha, Nuwakot, Sindhuli, Sarlahi, Solukhumbu	June 2011	14 districts affected by floods and landslide; 25 deaths; 2 missing; 4 injured; 515 houses destroyed
Dailekh, Jajarkot, Rukum, Palpa, Rupandehi, Parbat, Dhading, Sindhuli, Solukhumbu,	August 2011	9 districts affected; 65 deaths; 35 missing; 24 injured; 110 houses destroyed
Kanchanpur	September 2010	60 houses damaged on the Mahakali river
Dadeldhura, Bajura, Achham, Rukum, Kaski, Illam	June–August 2010	6 districts affected; 98 deaths; 8 missing; 29 injured; 2,835 houses destroyed; 39,000 people affected

THE KOSHI RIVER (*Saptakoshi* in Nepal)

Sedimentation in the Koshi River

The major sediment sizes during flooding vary from suspended clays to boulders in most of the Himalayan river. This means the river transports all sizes of sediments from the highlands. The major sources of sediments are from bank erosion, sheet erosion, landslides, terrace erosion, and glacial outwash. Table 3 has shown the status of sediment yields and erosion rates of major rivers of Nepal.

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Table 3 Summary sediment yields and erosion rates, modified after [42].

River	Catchment area Km^2	Annual sediment load million ton	Sediment load ton/ha/yr	Erosion rate ton/ha/yr
Koshi catchment rivers and measurement places				
Tamur at Tribeni	5,900	47.20	80.00	240.0
Arun at Tribeni	36,533	54.80	15.00	45.0
Sunkoshi at Tribeni	19,230	86.53	45.00	135.0
Koshi at Barahchhetra	31,773	177.00	55.71	169.0
Narayani catchment rivers and measurement places				
Trishuli at Betrawati	4,110	7.60	18.50	55.0
Marsyangdi at damsite	3,850	27.60	69.35	210.0
Kaligandaki at damsite	7,618	37.40	49.10	148.0
Narayani at Bhaisalotan	-	170.00	-	
Other rivers and measurement places				
Karnali at Chisapani	42,890	218.00	51.00	153.0
Bagmati at chovar	585	2.66	45.50	96.0

Sedimentation in natural fluvial process subsiding sedimentary basin must be balanced by distribution of long-term sedimentation areally, whereas in the short term sedimentation is localized on the adjoining areas of river courses [43]. Such accumulation of sediments eventually forces the existing channel in braided system and enters the settlement in a destructive way. Specially, this happens frequently in most cases in monsoon seasons at lowland area in the Gangatic Plain.

The existing sedimentation problem in the low land is frequent and it is directly related to rural economics and livelihood because a majority of the population is dependent on agriculture resources. Despite the agricultural potentials, frequent floods from high lands to lowland and their huge quantities of bed and suspended loads are major problems. Challenges need to be met for the sustainable management of flood events as pre and post disaster management. The sedimentation accumulation has been increased by 4 m relative to surrounding parts [44] after a construction of embankment in the Koshi river area.

The Koshi river basin (Figure 3) lie in the eastern part of Nepal. The river is counted as one of highest silt yield rivers in the world [39], and it has 118 million cum /year sediment [45] due to extensive soil erosion and landslides in its upper catchment areas. A major tributary, the Arun

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river, is the major contributor bringing huge amounts of silt in proportion to its total sediment load. The Koshi potential runoff and sediment contributor indicated Arun sub catchment [39].

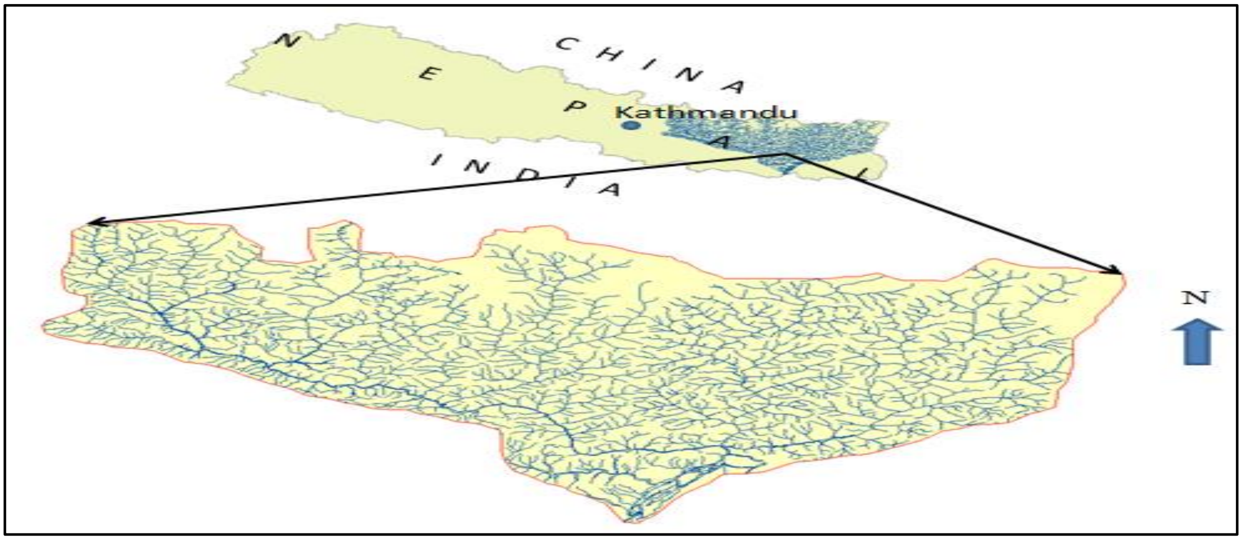

Figure 3 Location map of the Koshi river and its catchment

The history of shifting pattern of the the Koshi river shows its uniqueness of sedimentation characteristics because it shifted by 115 km west [46] from its original course during the last 200 years. However, Hooning (2011) has mentioned that reliable data of previous floods and sedimentation parameters of the Koshi river are not available satisfactorily[47]. The salient features of the Koshi River have been given in the Table 4.

Table 4 Salient features of the Koshi [45]

S. N.	Features	Details
1	Total length	729 km
2	Catchment area	60,400 km^2
3	Average annual flow	1590 m^3/s
4	Average annual sediment volume	118 million m^3
5	Past maximum flood	913,000 cuse (25849 m^3/s ;5th Oct.1968)
6	18th August, 2008 flood	168,500 (4770 m^3/sec)

The major cause of the heavy sedimentation in the river is its change in gradient. The drop in gradient from mountain region to lowland area is from 10 m/km to 1 m/km. The coarser fractions of the sediments settle on the lowlands that belongs to Nepal. From the study in Gandaki and Koshi interfans, the relative abundances of light and heavy mineral of channel sands were estimated to the range of 5-10% [48]. The sediment composition of river load is mainly detrital sands and illitic clays [38]. Most of the fine sediments of the Koshi which are suitable for agriculture practice usually flow to India. Therefore, there is only negative impact on Nepalese farmland due to sedimentation process in Nepal occupied lowland basin of the Koshi River. Hooning (2011) has described Koshi's huge sedimentation as challenging phenomena due to its infertility properties and uselessness, except for small quantities that can be used as construction materials[47].

Dixit (2009) has calculated from topographical maps that the riverbed at the Koshi is 4 m higher than that of adjoining settlements of beyond the embankment [44]. He has mentioned that in some cases, 500 mm of precipitation within 24 hours definitely promotes heavy sedimentation. In addition, the condition of the embankments is not good enough because of annual sedimentation and poor maintenance and other flood protective works. To prevent the risk of embankment failures in the future, its safety needs to be assessed regularly and monitored closely [49].

Morphological Impacts in Koshi River

The discussions arose after the finding that the Koshi river has been shifted westward by 115 km over the past few hundred years [46] as shown in Figure 4. That investigation was followed by [50,51,52 & 53]. Its dynamic characteristics and challenges on flood control issues have been mentioned by [44,54,55]. The dynamism of the river has a major relationship with sedimentation accumulation. However, in Koshi river, tectonic activities also play some role in the westward shifting process [44,54,55]. The Koshi River has made a new (Holocene) fan in Bihar, India which is about 180 km long and 150 km wide and it is on the biggest river- built alluvial fan in the world [56]. The whole basin of north Gangatic Plain is of higher sedimentation with short-period [57]. Studies relating tectonics to the processes at the Earth surface has provided substantial information about agents of shallow denudation [58]. In Gandaki-Koshi region, fan building process is started at 4920 BP [59] because of thrusting of the extensional normal faults which are is parallel/sub-parallel to the Himalayan Frontal Thrust (HFT).

The Koshi river has a convex-up shape topography. The remnants of paleochannels on the fan surface display the paths of the river made during 200 years of its travelling. It is also believed that the Koshi is on continual fan-building process [61]. Structural contour map at the basement has suggested that the tiltation of east to west along the fault may have resulted the westward migration of the river. The catchment is uplifting rapidly because of neotectonic movements [56]. The Gangatic plain annual floods are more effective geomorphologically than that of large flood for the modification of the channel in terms of dimension, position and pattern [62].

The channel braiding pattern in Koshi low land basin has been classified as gravelly-sandy, sandy and straight to meandering north to south along with river. The northern part megafan consists of sand with minor gravel and sand with mud (45 vol. %) in southern part [63]. Arsenic contamination is also reported in suspended river sediments in Koshi along with other major rivers in Gangatic region.

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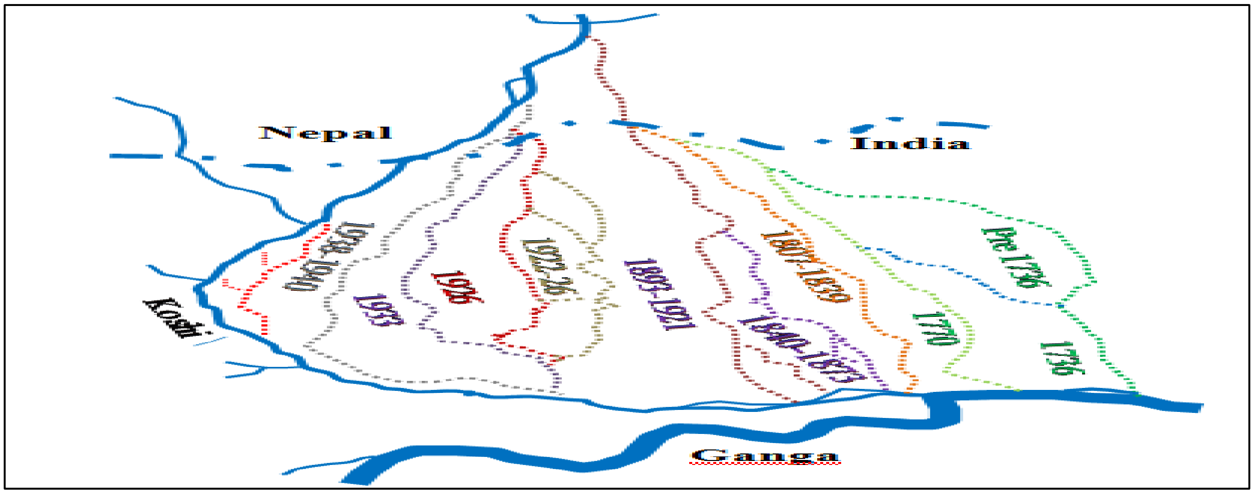

Figure 4 Shifting of Koshi since 1730 modified After [60]

The value rages from 5.61 to 10.59 mg/kg. where as the iron ranges from 1.17 to 5.65 g/kg [64]. The manganese toxicity in mango tress are the lead agent for the destruction of mango trees which is carried by river as sediment during the flood. The physical impact lead to biological impacts in the case of the Koshi in the past flood- a 800 ppm maganese concentration from suspended sediment in solution culture caused plant manganese toxicity and it was alleviated by 1200 ppm iron [65]. The flood magnitude is very important and crucial event in term of human impact. Also of major importance is its impact on geomorphic effectiveness and geomorphic work [66].

2008 KOSHI FLOOD

On 18 August 2008 at 12:55, the river diverted its original course toward the eastern side by breaking (shown on Figure 5) its embankment and 95% of water was diverted toward its 100 years old channel [67]. The river destroyed Sripur, Haripur, and West Kusah Village Development Committees (VDC) totally and Laukahi and Narsingh VDCs were partially. The flood deposited large amounts of sand and silt on agricultural land. The number of affected people were in millions [68] including 60,000 in Nepal. It is estimated that 7572 families of Shreepur, Haripur, Paschim Kusaha and Laukahi VDC of the Sunsari district were adversely affected. A total 5985 Bigaha of cultivated land, 7 kilometer of highway, 6 bridges and 67 culverts were severely affected by the flood [69].

It is also reported that around 700 ha of fertile land swamped by Saptakoshi (Figure 6) is still (September, 2011) uncultivable due to sand deposits[71]. It is also observed that most of the affected cultivated land of Shreepur, Haripur and western Kushaha villages in Sunsari district are still in the form of deserts even after 6 years. There is a challenging task to manage the huge amount of the useless sediments [47]. The loss of their existing crops estimated at US$18.7 million and livestock estimated at US$ 2.1 million have reduced Government's Gross Domestic Product (GDP) by 0.3% during the fiscal year 2009 [49]. The issues of land change from

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cultivated to barren due to the flooding with heavy sediments needs to be a major focus of research. The evidence shows that the insufficient control measures have led to the recurring devastations time and again.

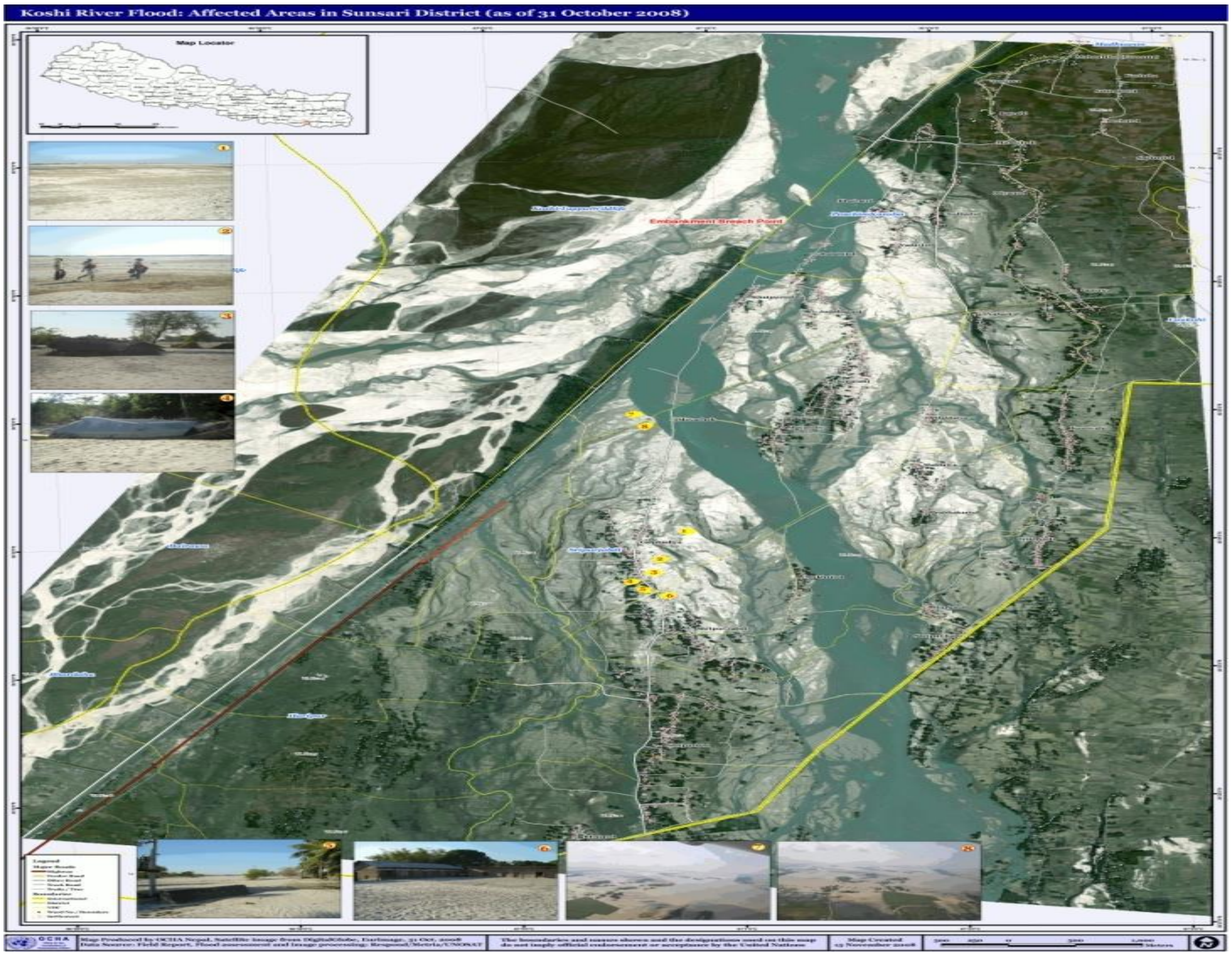

Figure 5 Koshi River breached an embankmant during 2008 August flood.[70]

An avulsion is relatively rapid shift of river to new course in a floodplain. Most researchers on this region have defined the 2008 Koshi flood as the most recent avulsion. It is believed that an avulsion is dependent on slope relationship between regional channel and floodplain slope along with lowest elevation available in the region. Although the threshold of avulsion is based on channel slopes, planform dynamics also plays an important role for directing a sediment charged river such as Koshi towards avulsion threshold [72].

After reviewing most of the research papers and working paper on the topic, it is evident that the published information are not enough to cover all issues of impact regarding flood and sedimentation in Koshi. The researchers are not enough to evaluate long term post disaster effects. The nature of flood disaster and the implemented solutions have always been deemed insufficient. The characteristics of sediments and their impacts on affected areas after flood disaster will be the main concerns of post disaster assessment.

Finally, the continuation of sediment deposit of 0.05 m/year and the subsequent increase in the level of sediments by 4-5 m compared to that of land outside the embankment led to the breaching of the eastern bank resulting in Koshi flood [73].

Figure 6 Inundation of the 2008 Koshi flood.[70]

It has been identified after examination of high avulsion threshold in the Koshi, that there are several structurally critical points which is potential for avulsion (breach) in the near future [72].

COMPARISION OF KOSHI FLOOD WITH OTHER FLOODS

Immediately after a month of the 2008 Koshi flood, 9 western districts of Nepal were also affected by the flood. The flood affected 16000 houses in 38 villages [69] . The nature of disaster management and other resources mobilization was similar to that of the Koshi flood.

Other examples of floods are in western Nepal and Uttanrakhand of India in 2013. In these regions, the recorded rainfall was up to 500 mm per day along with 60 hrs of continuous rainfall. This event destroyed property worth millions of dollars [40].

Another flood that resembles Koshi flood is 2010 Indus Flood which happened in Pakistan. The flood event in Indus river of Pakistan was also due to breach of the eastern marginal

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embankment in the upstream of Taunsa barrage as in 2008 Koshi breach [72]. In terms of human casualties and extensions, both can be placed at same intensity of disaster. Both floods happened in the same season. As in 2008 Koshi flood, Indus River sedimentation was one of the major factors that led to the 2010 event. However Indus had a greater intensity of rainfall in the catchment than that of 2008 Koshi flood. The nature of response and the management in context of disaster event was similar. Weakness in maintenance/monitoring of embankment and underestimation of the climate as well as morphology of river were the main similar responsible factors.

Flooding and impacts are also similar in central India. Few cases of flood disaster in peninsular of India can be compared with the floods occurring in Nepal in terms of management issues even though the magnitude, frequency and frequent changing geo-morphological behavior in rivers of the Northern India are different than that of peninsular. [74]. Some of the recent flood (2011-2013) in India has been tabulated in Table 5.

Table 5 Recent floods in India with disaster details [40].

Region	**Year**	**Disaster**
Uttarakhand, Shimla, Himachal Pradesh	June 2013	5700 including 934 locals [75]
Guwahati, Brahmaputra river overflow	July 2012	80 deaths from flood; 16 buried in landslide; 11 missing
Assam	July 2012	95 deaths; 12 missing
Uttarkashi district, Ganga flood	August 2012	34 deaths; 80 houses damaged
Uttar Pradesh, Bihar	September 2011	30 deaths; 10 missing in Brahmani river

In terms of sediment composition, Gandaki river in Western Nepal has more abundance of sand than that of grain variability of the Kosi fan. There is great variability in term of subsurface stratigraphy in their megafans even though both are from similar geographic region. This differences may be due to the fact that the Kosi River runs directly through mountain front and has capacity to transport course sediments into the plain [76].

DISCUSSION

The morphology and dynamics of river is unpredictable and could not avoid the natural flood disaster events. There are examples of the developed countries. Despite enough data about hydrology and meteorology, sedimentation, efficient monitoring and maintenance, sophisticated

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technology, the countries have been bearing the flood disasters frequently as in underdeveloped countries.

As we know the river system in the Himalayan region is dynamic because of the Himalayan orogeny and fragile mountains with high gradient. The studies on the behaviour of the Himalayan river are still insufficient. In this regards, the intervention without knowing morphological characteristics of the river could always lead to flood which could be disastrous to those who are near to the river. The data keeping system is still poor in terms of flood and precautionary measures and that are not considered in the potential flood hazard areas. On the other hand, in depth investigation of the river regarding behaviour or river morphology along with sedimentation characteristics could always be insufficient in the context of dynamics of the river in the Himalayan region.

Sediment load on the river and the flood time debris in the Himalayan region has always been a problem in every event of the flood disaster. The sediment brought by rivers in the Indian region have high seasonal fluctuation of discharge and sediment load. In this regard, the big rivers of this continent have always been attracting attention from fluvial geomorphologist as it is associated with monsoon that causes avulsion in channel, channel migration, anomalous variations in channel patterns, suspended sediments dynamics and impact of flood [74]. Since different rivers have different characteristics of channel in terms of vertical sequence, the different channel types could pose difficulty for scoping the study in different individual rivers [77]. Unusual large fan-shaped bodies of sediments that is carried by the river are referred to as fluvial megafans [78]. The source of sediments that influence the river morphology in the lowland area is catchment geology and hillslope sediments which influence basically bedload characteristics and bedload ratio.

Concave bank erosion activities along with high stages flow are the main causes of the channel shifting of the river as in the Koshi [79].Geomorphic analysis also suggests that the Koshi River was very dynamic in the past and it has been constrained by embankment in both sides along with several barrage across the river [80]. Before construction of the barrage the Kosi channel has a trend of shifting westward. The Koshi has been shifted as an avulsion due to the deposits on western side of river upstream of the barrage [81]. In addition, the research in climate change also shows that the flood and inundation problem is rising in lowland of Himalayan region at a critical rate [82]. On the other hand, to know the sedimentation and the dynamism of the Koshi river is a big challenge because of unavailability of the reliable data about the characteristics of the Koshi river

Hydrological Records of more than 100 years in the past are not available in the case of Koshi River [83]. As mentioned before, after comparing 2010 Indus and 2008 Kosi flood, it is of upmost importance to identify the potential areas and to carry out vulnerability analysis before the event, even in difficult cases like Himalayan region where river dynamics pose significant challenges to the analysis.

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The construction of embankments along the river is not permanent solution for the mitigation of flood. The work on the minimization of high sediment load, and stopping water level rising due to the sedimentation are also main tasks to be considered as watershed management in the Koshi catchment [25]. As an example in Koshi, the riverbed is up to 4-5 meters near the breaching area relative to the surrounding beyond the embankment. This perpetual level difference always poses a high risk of flood. This serious issue has never been discussed and no precautionary measure has ever been executed for preventing the potential flood disaster. Similarly, the shifting morphological characteristics of the river that has been constrained in between the embankments, was the challenging intervention at time of construction of the Koshi barrage even though it was thought to be mitigation intervention for the flood and sediments. After 50 years of construction, the breaching of the embankment occurred due to human negligence in terms of monitoring and maintenance.

The study of long-term disaster consequences is sensitive and equally important in the context of post disaster management, especially in underdeveloped country like Nepal. Physical impacts on lands and interruption of livelihood of affected people are more sensitive and important for assessment, analysis and long term management. It has been reported that despite efforts, advance technology and knowledge, the frequency and magnitude of disaster have not shown any significant improvements in the past decades [84,85].

The efficient and successful flood management measures must be adopted [86]. Understanding the response mechanism of the affected people should be seriously taken into consideration for the effective management of flood disaster [20]. The emerging technology has made revolution to the study of mass movement in the Himalayas [58]. The timely information is the key to management for the reduction in casualties and property loss [87]. Adaptation strategies during the post disaster phase is the crucial part of flood disaster management which can be learnt from past flood disasters. However lessons from past disaster as 2008 of Koshi flood are not adapted to improve the flood management system [88] in the following floods in different part of Nepal.

Human is the actor for the construction of infrastructures for the utilization of water for different purposes. The river channels have been manipulated and modified as per individual needs and requirements by making different structures around the river, which has posed a serious threat to human beings themselves [81]. The short-term solution of making embankment is quite effective, but the long term effects could be more harmful to the nearby floodplain [89].

The 2008 Koshi flood is the most destructive flood event in term of human casualties, properties loss and infrastructure damage during last recent decades. Therefore the investigation on post disaster phase in term of physical impacts are the most important task for the minimizing the risk for the next flood disaster. The 2008 Koshi flood impact assessment in term of post disaster phase can be taken as opportunity to minimize to next similar disaster.

CONCLUSION

The rivers that originate in Himalayan region are dynamic in context of nature of flood and sedimentation. The frequency of flood disaster and impacts on the human and their properties, infrastructure and agriculture land have always been challenging. Impact assessment by flood needs to be done intensively to minimize for the next disaster effects. However, in Nepalese context, there are not any efficient and intensive assessment in general regarding the long term impacts in post disaster phase. Example can be taken of 2008 Kosi flood that the immediate response was done for 1 year by various national and international organizations. However, the intensive assessment is not done after disaster in so many issues in long term as a part of post disaster management because of this the community near to river are always in vulnerable to the multidimensional effects of flood. There seems to be a major scarcity of assessments regarding long-term health issues including mental health and sedimentation impact in agricultural land. The understanding gained on adaptation issues on population and resilience should be thoroughly investigated to tackle these issues effectively during the upcoming disasters.

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