MORPHOLOGICAL EVOLUTION OF KOSI RIVER

A DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE
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In
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Submitted *By*

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CANDIDATE'S DECLARATION

I Anurag Labh Aman, Roll No. 2K17/HFE/16, student of M. Tech (Hydraulics and Water Resources Engineering) hereby declare that the project dissertation titled"**Morphological Evolution of Kosi River**" which is submitted by me to Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment for the requirement for the award of the degree of Master of Technology, is original and not copied from any source without prior citation. This work has not previously formed the basis for the award of any Degree, Diploma associateship, Fellowship or other similar title or recognition.

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CERTIFICATE

I hereby certify that the project Dissertation titled **"Morphological Evolution of Kosi River** " Which is submitted by **Anurag Labh Aman (Roll No:2K17HFE/16**) to Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment towards the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the students under my supervision. To the best of my knowledge this work has not been submitted in part or full for any degree or diploma to this university or elsewhere.

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ABSTRACT

The river Kosi is well known for its shifting tendency. The river shifted a distance of more than 150 km in a period of last 200 years. The shifting of river occurs due to the heavy amount of sediment that it carries from the young mountains of Himalaya. The change in morphology of the river is to be studied regularly and to be compared with its pattern in previous years, which will give an idea about the change in pattern. This is because the sudden change in path of the river causes huge loss of life and property as in the case of 2007 flood in the Kosi river.

In this study the braiding pattern of Kosi river in the area upstream of Barrage from Barahkshetra to Birpur is obtained by using several indices. The Landsat 5 images of two different year i.e. of 2005 and 2016 to know the parameters such as length of sandbar, length of center channel, length of mid channel etc. to find the intensity of braiding in two different years. Several researchers provided various equations to calculate the braiding intensity, three of the equations are selected to calculate braiding intensity in two different years. The intensity thus obtained from the three equations are compared and analyzed to show the change in the braiding of the river.

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1. INTRODUCTION

1.1 General

The Kosi river also known as Kaushki in Sanskrit literature, is a major tributary of Ganga river. It emerges from Tibet at a height of approx 18,000 ft, traveling a distance of 720 km and draining an area of 74,500 sq km it joins river Ganga at Kursela. The river kosi have largest alluvium deposit in the world covering from Nepal to Northeast Bihar and eastern area of Mithila region. The upper catchment of the river lies in Tibet and Nepal while the lower catchment lies in northern plains of Bihar. The river Kosi carries huge amount of sediment load each year which causes frequent change in shape of river.

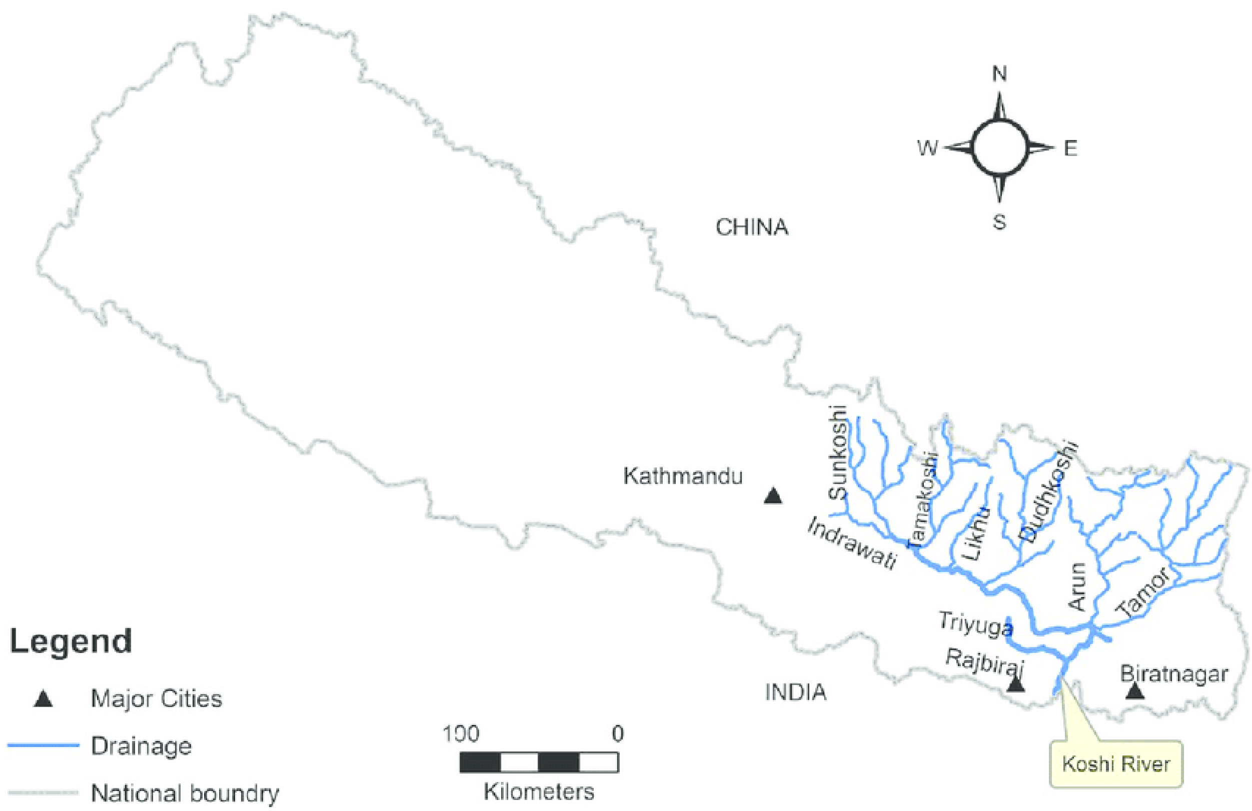


Fig 1.1: Location of Kosi river and its tributaries (source: Wikipedia)

The Kosi river is also called as Saptkoshi due to its seven tributaries in the upper catchment. Its three main tributaries in the upper section are ,Sun kosi rising east of Kathmandu , the Arun rising from Mount Everest in Tibet and the Taimur rising from Kanchanjunga .The other four tributaries are Dudh kosi , Tama kosi ,Bhut kosi ,Likhu khola, and Indravati. After flowing through mountains, it joins the plain at Chatra. In the plain the river Kosi have number of tributaries, the main tributaries of the river in the plane are Bagmati ,Kamla, Budhi Gandak and Bhutahi Balan. The river carries huge amount of silt approximately 1082 million tones of silt is deposited by the river in the last 54 years. This is the highest amount of silt carried by any river in the Ganga basin. Due to high amount of sediment supply and decrease in flow velocity, huge amount of sediment deposition occur which causes rise in the level of flood and also cause the shifting of river. Due to frequent flood and its capricious nature the river is also known as sorrow of Bihar.

1.2 Morphology of River

1.2.1 Introduction

The term river morphology describes the change in the plan and cross section of river channel with respect to time. It deals with pattern of river and change in cross section shape due to sedimentation, erosion and other human activities. Study of morphology of river plays a vital role in order to obtain knowledge about shifting pattern of the river.

The shape of the river is determined mainly by the topography of the valley and the mechanical characteristics of the river basin. The current shape of Rivers is the result of changes in the climatic conditions of past years, in tectonic behavior, sedimentation and human intervention.

1.2.2 Study of River Morphology

The study of river morphology is the detailed study of the various factor which causes the change in the ratio of the width of the bed to the depth of the river, sinuosity, tractive force on the sediment versus load due to silt concentration, aggrading or degrading behavior of the bed etc. While studying the morphology of the river the first step is to identify the order of streams. The second step is to collect the data of the river through field survey or through the help of remote sensing. On the basis of these data morphology of the river can be studied which include flow characteristics, river bed characteristics, sediment transport, change in pattern of river etc. Proper study and understanding of morphology of river helps in design and planning of water management projects .It also helps to know the shifting pattern of the river and occurrence of flood in the area.

1.2.3 Morphology of the Kosi River

The upper catchment of river Kosi lies in the Shiwalik range, where high rainfall occurs which causes landslides and soil erosion and also there is extreme variation of slope from upper catchment to lower catchment in Chatra. There is also no flat valley in the upper catchment which causes the entire sediment load to move in the lower catchment. While entering into the plain the bed slope of river becomes as flat as 0.4 m/Km to 0.2 m/Km. Thus there is huge fall in velocity of river. The silt carrying capacity drops suddenly in the plain due to sudden decrease in stream velocity. This causes huge sediment load in the lower catchment or in the area where the river attains plain. The river kosi is among the highest silt carrying rivers of the world. It carries a total silt of 95 MCM/yr. in which the amount of different types of sediment are

a) Coarse sediment 18.00 Million cubic meter
b) Medium sediment 23.85 Million cubic meter
c) Fine sediment 53.14 Million cubic meter

The river Kosi have stream of large braided network .A number of small islands are created in the channel due to the braiding pattern of river .The river below chatra is divided into several channels spread over a width of 6.4 to 16 km. The high silt yield is carried by the river in a very narrow alluvial plain , this resulted into aggrading channels and formation of a large megafan . This conical shaped megafan is indicated as world largest megafan. The average discharge of the Kosi is 55,000 cusec ,during peak flood it increases to 10 to 15 times.
In order to counteract with the problems a barrage was at Bhimnagar and flood embankments on both sides of river were constructed. The barrage was constructed to keep control on the steep

gradient in the upstream reach of the river. The eastern embankment extends upto 125 km and the western embankment of 101 km were constructed and the construction material used was the local earth.

The study of the morphology of Kosi River is of much importance, due to the distinctiveness of the problem created by river and its shifting nature which cause huge loss of man and resource.

1.3 Shifting of River

The river kosi is well known for its capricious nature .Due to frequent floods and carrying of huge sediment load which it is unable to transport and unload into Ganga ,it has shifted over 150 km from east to west in the last 200 years ,building up an island delta .In this movement about 8000 sq km of land in Bihar have been laid waste due to send deposition, so it is known as sorrow of Bihar .

The movement of river channel involving large spatial shift is termed as avulsion, which commonly originates from a nodal point and is different from slower movements through meander migration or lateral tilting. This movement causes extreme flooding which is also different from usual floods that occur during monsoon.

The silt carrying of the river is one of the highest in the world, that is about 95 MCM/yr. When the river reaches the plains, high accumulation of sediment causes rise in the bed of river which prohibit flow of, forcing the river to find different paths, resulting in shifting of the river course in the lateral direction.

1.4 Kusaha Breach 2008

A major breach occurred in August 2008, in the eastern embankment of the Koshi River at Kusaha region which is around 12 km upstream of the barrage. It was the first time ever when the breach occurred in the upstream side of barrage. This breach resulted in eastward shifting of river for several kilometers. The resulting flood left thousands of people homeless in Nepal and millions in India. The breach completely changed the course of river. The river started flowing along different course and the flow through barrage become negligible. Earlier eight times the breach occurred in the Kosi embankments but none of the breach was so devastating and this breach was unique as it was first breach which occurred in the upstream side of river. Several researcher worked to find the reason of the breach. It causes huge loss of life and property

Kusaha Breach which occurred in upstream of barrage was a major incident because all the other breaches in the embankments occurred downstream of the Kosi Barrage(Mishra,2008).So the Kusaha breach indicated the need for study of dynamics of kosi river upstream of the barrage.

Fig 1.2: Kusaha Breach in 2007 (Source :Indian Express)

1.5 Objective of Present Study

Several studies and research on the Kosi River was done by many researchers, inspite of large number of research there are still some significant issues about the dynamic nature of the river upstream of the barrage, which have not been properly studied yet. Devkota (2018) also in his study revealed that a qualitative understanding about the overall evolution of this dynamic river is required to protect from losses due to frequent flood and channel shifting. The sedimentation and erosion processes, shifting tendency of the river, morphological evolution and their effect like increase in water level and thereby the flood level at upstream reach which causes embankment breach are still themes of further research and investigation.

The purpose of this section is to study the change in the braiding pattern of the river due to natural processes or engineering activities in the area upstream of barrage from Barahkshetra to Birpur. Satellite data of the river of years 2005 and 2016 are obtained and through the data required information have been extracted and with the help of existing braiding equations braiding intensity is calculated to study the change in braiding pattern of the river. Different methods suggested by researchers have been used to calculate the braiding intensity. Thus the braiding of two different year in a period of eleven years are calculated and compared.

2. LITERATURE REVIEW

2.1 Introduction

The river Kosi has attracted many researcher due to its most dynamic characteristics. The huge amount of sediment carried by the river, its shifting character and frequent floods in the river affected the whole area of Bihar and is the one of the reason of the backwardness of the state. Several researcher worked to find the solutions of the problem caused by the river. It has been a long time since the study about shifting , huge sediment carrying of the river is being studied. In the early days it was believed that the shifting of the river is caused due to tectonic activities but later the researchers found it to be not true and the reason behind this is the huge sediment carried by the river. The river passes through young mountains of Himalaya where it carries a huge amount of sediment load. The sediment carried by the river is a continuous process. The river requires proper training work and frequent study about its morphology in a definite time period. Several researcher worked for the purpose but still the problem exist.

Several studies in early time proposed the construction of Barrage at Bhimnagar and flood embankments on the both sides of river. It was believed that after the construction of barrage sediment load will reduce and below the barrage the course of thye river will deepen and stabilize. But contrary to expectation several breach in embankment caused heavy flood.

To study the morphology of a river many researcher have provided several indices to calculate the braiding intensity of a river. Braided channels are number of river channels separated by small islands. Braiding intensity is calculated by different author based on different characteristics, e.g. bar dimension and frequency , number of channels in the network and total channel length in a given river.

2.2 Past Studies

Gole and Chitale (1966) after analyzing the data of silt load, cross sections of the river course during the past years he concluded that other rivers have built longitudinal valley whereas kosi is building inland conical delta. He further explained that the conical delta building, sediment deposition, rise of bed level and shifting of river course occur progressively from one edge of the cone to the other edge of cone and after the completion of cone ,river will start migrating in the east direction. He also concluded that in recent times the rate of river movement is increased due to increase in sediment load caused by deforestation and intensive land use in kosi catchment

Wells and Doer (1987) studied the maps of Kosi river of past years and concluded that the kosi river shifts over the Himalayan foreland plain and this shifting was not due to earthquake. They found that the shifting of river in the plain is by minor cutoffs, bank cutting ,and large sediment flux. The records of last 200 years were analyzed and it was concluded that during this period the change in course of river occur in westward direction and it has shifted about 150 km during this period.

Sinha (1994) showed that very high sediment concenteration in the kosi river is due to the result of the area being tectonically active and heavy rainfall in the entire catchment. He also found that annual rainfall in the kosi plains is 1000-1600 mm.Average monthly discharge of kosi river varies from >6000m3/s to 500m3/s and the mean annual flood discharge is of the order 7000m3/s.

Nayak (1996) studied the characteristics of rainfall in the region, after analyzing the rainfall data of previous years and studying the rainfall data of whole country, he concluded that the kosi river carries 25% of countrys rainfall and 57% of its sediment into alluvial fan. Approximately 90% of the total sediment load transported by river is in monsoon period.

Mishra (2008) analysed the previous flood data and found that before the kusaha breach , which occurred upstream of kosi barrage in 2008 ,all previous seven breaches in the embankment occurred downstream of the barrage. He focused on need for study of dynamics of river kosi upstream of barrage and also point out that construction of barrage enhanced sedimentation in upstream part and embankments preventing natural path of river.

Sinha (2009) explained that the shifting of the river which occurred previously was in the westward direction, but in the year 2008 kosi recorded first time in its entire history a jump of 120 km in the eastward direction .This occurred due to breache in the eastern embankment which causes diversion of about 80-85% of new course of river. Since new course had a much lower carrying capacity ,water flowed like a shit ,15-20 km wide ,and 150 km long with velocity of 1 m/s. He also suggested that the possibility of another breach in near future at any other location cannot be ruled out .Discharge at the time of breach in new course was calculated by him as 1,44,000 cusec ,while the usual discharge is 25,744 cusec

Devkota (2009) found that the total sediment load entering from chatra (a place located upstream of barrage) has been estimated as 120 million cubic meter per year .He also found that the kosi river reach between Chatra and the barrage show degradation and narrowing trends. The narrowing of river caused large morphological activities along eastern belt.

Chakraborty and others (2009) studied the kosi megafan and concluded that the kosi megafan have a convex up cross profile and concave up longitudinal profile .The maximum slope of megafan surface is 0.05 near its apex and that near the toe is 0.01.

Sinha (2008) and others analyzed the flood risk zones in the Kosi river basin using Analytical Hierarchy Process. He used this method for mapping of flood risk zones. It was GIS based flood risk analysis constituted on topographic, morphological, and demographic data.

Devkota and others (2012) found that the barrage and embankment play significant role for channel avulsion and upstream degradation .He found that barrage was constructed on eastern side led to huge sedimentation on western side and caused sediment deposition upstream of barrage causes breach in the embankment in upstream of barrage in the year 2008.

Devkota and others (2018) estimated that ~248million m3 of sediment was scoured eroded from the river bed resulting from changes in river bed level by 4.5m in the main channel during 2008 event .He also found that the reduction of flow conveyance capacity of the river due to narrowing appears to have caused large morphological activities along the eastern belt .

Saikia and others (2018) studied the braiding pattern of Brahmputra river by using seven different methods and also introduced a new index to measure the braiding intensity of river which uses number of mid channel bar to study, fraction of area covered by bar, maximum width of reach and length of reach to study the change in braiding pattern of the river in years 1973 and 2014.

3. STUDY AREA AND DATA USED

3.1 Introduction

The river Kosi meander between its eastern and western embankments and it travels a distance of 720 km approximately. In plain it covers a distance of 200 km. The study of change in braiding pattern of river requires systematic approach to obtain the result. The first step is to select the area of study and then to collect the data related to the study of the confined area. The data related to discharge, size of sediment, rainfall and slope variation of the two regions that are Barakshetra and Birpur are collected from the water resource department of Bihar and Landsat image data are collected online through various websites. The selection of study area and the availability of data plays an important role in order to find the solution of the problem.

3.2 Area of Study

The area of study have been selected in the upstream region of the Kosi barrage. Since the flood in 2008 occurred in the upstream section of barrage so the area of study have been confined in the region upstream of barrage. Several research have been carried out in the downstream of barrage area but the research carried out in the upstream of barrage is not so much sufficient. The root of most of the problems which occur in the downstream side lies in the upstream of barrage. Since the sediment carried by the river is accumulated in the upstream of barrage the river forms sandbars more frequently in that region. So it requires detailed study.

The length of the river in the plain is about 200 km. The area from Chatra to Kosi barrage a distance of about 40 km have been considered for the study. Geographically the latitude and longitude of the region are Lat 26.830 Longt 87.129 and Lat 26.538 Longt 86.916 respectively. The length of 40 km have been divided into four reaches of 10 km. We consider the study of each of the four reaches.

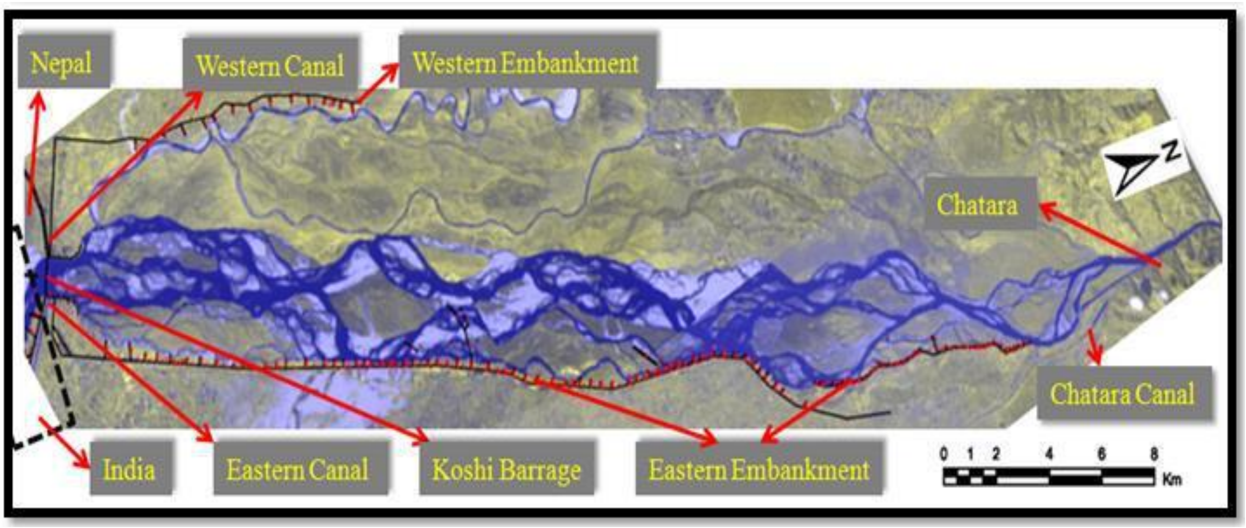


Fig 3.1: Map showing plan view of study area

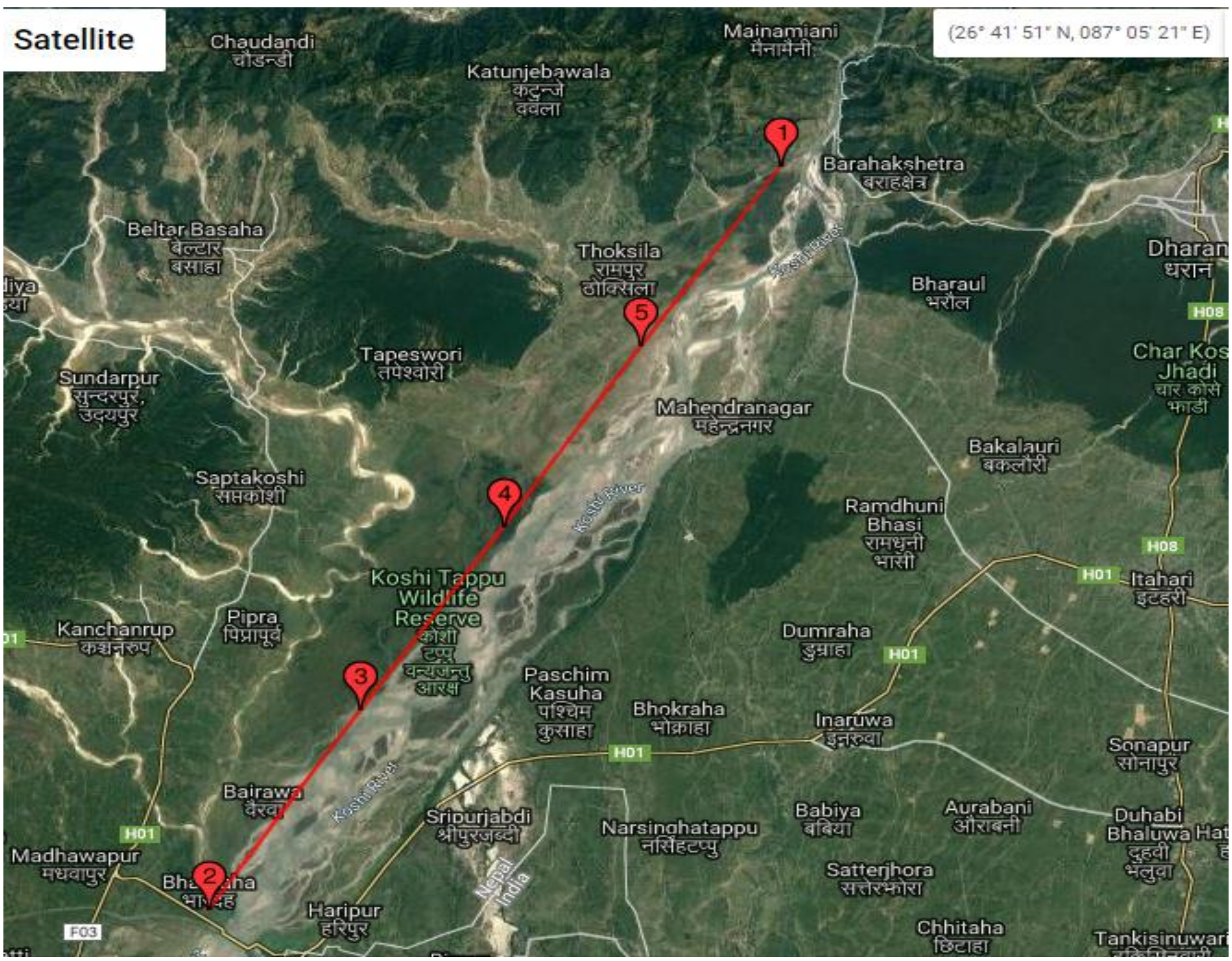


Fig 3.2: Map showing division of study area in four reaches

3.3 Data Used

The basic data used in this study are the digital satellite images of Kosi river for the years 2005 and 2016. The year of 2005 and 2016 have been selected due to the availability of the data and to observe the change in this eleven year period. The years were purposely selected to study the change before the 2007 flood and after nine years of flood. The Digital Globe Imagery of the year 2016 and the Landsat image of the year 2005 is obtained from USGS Earth Explorer. The georeferenced image of the river is downloaded from USGS Earth Explorer website, the website have option to download the geo referenced image and it is available free of cost. The Universal Transverse Mercator coordinate system and World Geodetic system datum has taken for georeferencing. ArcGis 10.4 software have been used to extract the required parameters used for this study.

Table 3.1:Features of Remote sensing Data

Satellite/Sensor	**Acquisition**	**Path/Row**	**Spatial Resolution**
IRS Landsat 5	2005	140/42	30m
IRS Landsat 5	2016	140/42	30m

The general data related to river such as slope at different location, discharge and size of sediment at different regions are obtained through various authentic research papers and water resource department of Bihar.

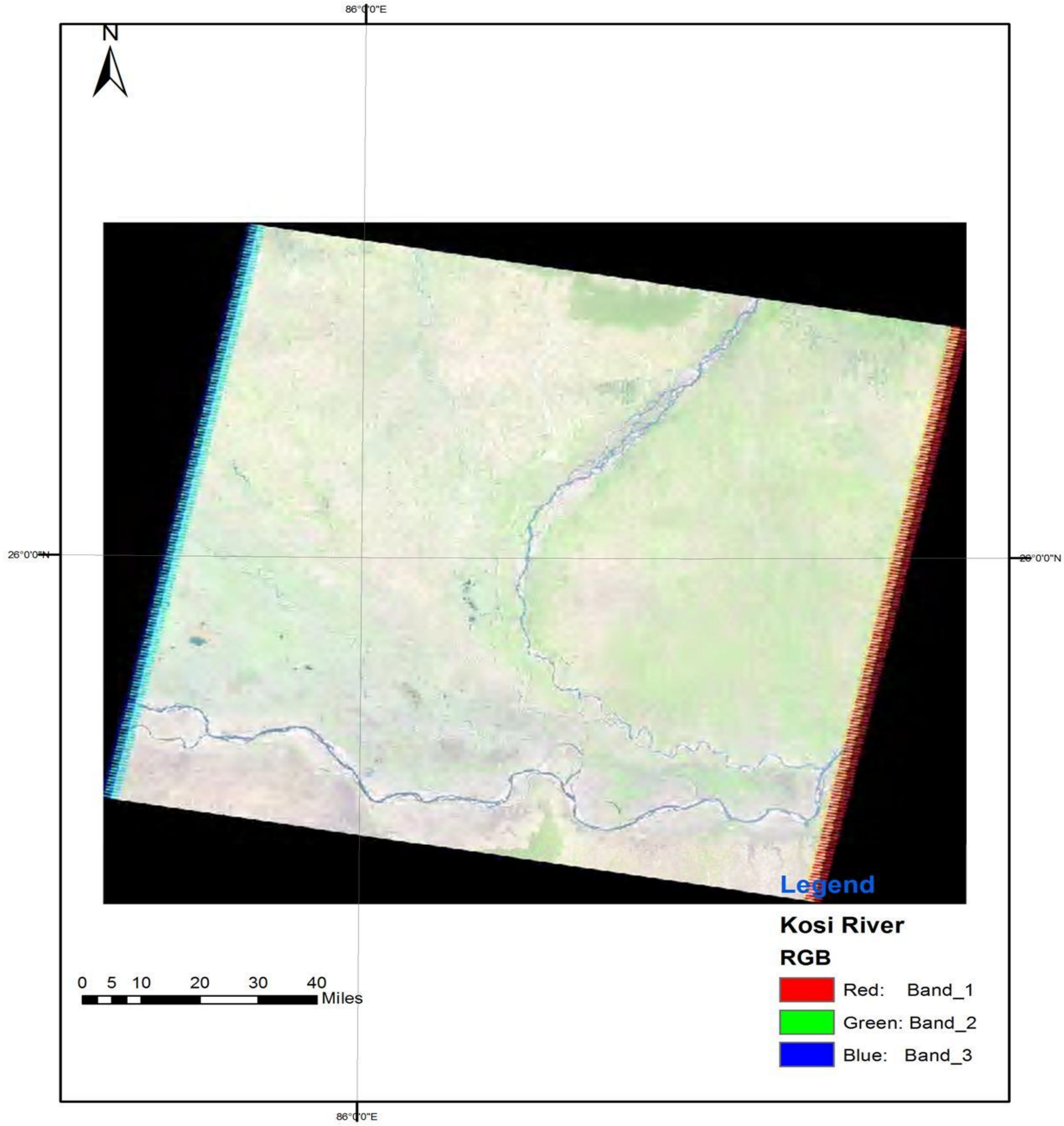


Fig 3.3: Landsat 5 image of Kosi river in 2005

Fig 3.4 : Digital Globe imagery of Kosi river

The other data related to discharge and slopes are also obtained. The discharge data for the two regions of Kosi river that are Barakshetra and Birpur is obtained from the research paper of R.Sinha and others for the purpose to gain information about the type of stream whether the river is straight, meandering or braided. The slope data has also obtained from water resource department Bihar to get the knowledge about variation in slope of the river.

Table 3.2:Discharge in three reaches upstream of barrage

Discharge Parameter	Barahkshetra (m^3/s)	Birpur (m^3/s)	Baltara (m^3/s)
Max.observed Discharge (Q_{obs})	25838	14833	12043
Bankfull Discharge ($Q_b/Q_{2.33}$)	8023	7458	6615
Mean annual flood discharge ($Q_{maf}/Q_{2.3}$)	9925	9183	7547
100-year flood (Q_{100})	23085	21118	13992

$Q_{1.58}$ value is often taken as the bankfull discharge; $Q_{2.33}$ is a measure of mean annual flood (Q_{maf}) and Q_{100} is generally used as'design flood' for most engineering projects.

Total drainage area of the river is 95156 sq. km, while in India the drainage area is 31726 sq. km. Average annual rainfall in the kosi basin is calculated as 1456 mm. The river have huge variation in slope above the Kosi barrage while the slope variation reduces when enter into plains or in the lower catchment. The variation in slope is 1.4 m/km while travelling a distance of 40 km from Chatra to Kosi barrage but it reduces to 0.71 m/km from barrage to a distance of 30 km in the lower catchment. Moving in the lower catchment the variation in slope drops to 0.11 m/km while reaching Kursela where river Kosi joins river Ganga. The high variation of slope occurs in lower catchment compared to upper catchment. So the sediment accumulate in the lower reaches as the silt carrying capacity decreases with the decrease in velocity of river. This high variation of slope causing more prominent braiding pattern in the river.

4. MATERIALS AND METHOD

4.1 Introduction

The morphology of river is the study of change in behavior or pattern of the river. Pattern of the river is basically the plan view of the river. In this section we will discuss about the pattern of the kosi river by using mathematical equations and using the data. The conventional classification of pattern of the rivers classify the rivers into three types. These are a) Straight rivers b) Meandering Rivers c) Braided Rivers. After knowing the pattern of the river as braiding, the intensity of braiding will be calculated by using several indices provided by different researcher. The data are extracted from the GIS maps of two different years. This will be used to calculate the braiding in two different years using braiding intensity equations of the different researcher. The braiding intensity of the two different years are used for the comparative study of the change in the pattern of river. The braiding intensity equations of five researcher are taken in order to get a more accurate result. These equations are also described in this section. In a distance of 40 km from Barahkshetra to Birpur four reaches in a distance of 10 km are taken in order to discuss in the study. The results are then discussed based on the calculations which will show decrease or increase in the braiding of the river.

4.2 Braiding of River

4.2.1 Introduction

According to the conventional classification based on the static and dynamic characteristics alluvial river patterns are generally characterized in three different ways. The rivers are classified on the basis of sinuosity. Sinuosity is the measure of length of channel to the straight line down valley distance . The three conventional ways of classification are:

a) Straight Rivers- Straight rivers have minimum sinuosity ($S<1.1$) at the bankfull discharge condition. Such rivers exist only for short reaches and in the upper zones. Straight rivers mainly flow in the rocks.

b) Meandering Rivers- Meandering rivers have sinuosity less than 1.5. These rivers are in the form of sine curves, loop and turns. Rather than confined in a narrow area the river covers a broad plain. It occurs due to deposition of sediment load and river finds it unable to carry.

c) Braiding Rivers- Braided rivers flow through a number of channels which are separated by unstable bars or islands. These bars or islands are formed due to deposition of sediment. These rivers are wide and shallow and divided by bars. The bars are visible at low flow stage of the river whereas when the flood appears or when the river is in high flood stage the bars get submerged. The braiding pattern occurs in the middle zone of the river where the accumulation of sand takes place.

After knowing pattern of river we can apply various equations to know the intensity of braiding of two different years and then compare the change in braiding of the river. Different researcher have suggested various method to calculate the intensity of the braiding. After calculating from all the methods we will assign the braiding in the four regions as high braided, moderately braided or low braided.

4.2.2 Braiding Indicator

4.2.2.1 General

Leopold (1957) provided the simplest equation to define the changing of the river pattern from meandering to braiding involving riverbed slope S_0 and bankfull discharge Q_{bf} (cubic meter per second). He induced threshold bed slope above which the river will be in the braided form. Since the slope of the river is inversely proportional to the bankfull discharge the braiding of the river will decrease with the increase in the bankfull discharge.

$$S_0 = 0.012 Q_{bf}^{-0.44} \quad (4.1)$$

Lane (1957) also proposed threshold equations of braiding but in addition to Leopald he proposed equation for meandering channel also. The criteria adopted by Lane was slightly different to that of Leopold. Lane proposed threshold equations for meandering from a straight river and braiding from a meandering river by using mean annual discharge Q

$$S_0 = 7 * 10^{-4} * Q^{-0.25} \quad \text{meandering threshold} \quad (4.2)$$

$$S_0 = 0.004 Q^{-0.25} \quad \text{braiding threshold} \quad (4.3)$$

Henderson (1963) and Ferguson (1987) introduced the participation of sediment size d_{50} in mm along with mean annual discharge Q in defining the threshold of braiding from meandering. The equations given by Lane and Leopaldo are generalized equations. Sediment plays an important role in determining braiding. So Henderson firstly considered the sediment size and showed that the slope increases with increase in the size of sediment. It means the braiding will be more if the sediment size is bigger. Later Ferguson also proposed the equation with some addition .Henderson (Equation 4) and Ferguson (Equation 5) suggested the following equations, respectively.

$$S_0 = 2 * 10^{-4} Q^{-0.44} d_{50}^{1.15} \quad (4.4)$$

$$S_0 = 4.9 * 10^{-3} d_{50}^{0.52} Q^{0.21} \quad (4.5)$$

Where, d_{50}=size of sediment

4.2.2.2 Pattern of Kosi River

We use the data of slope and discharge of two stations of Barahkshetra and Birpur to find the pattern of the river between these two stations. The distance between the two region is 42 km. The above three equations are used to calculate the pattern. These two stations are selected due to availability of data at these stations.

We apply the above equations alternately and try to know the pattern of the river from each equations.

Table 4.1: Braiding Threshold by Equation 4.1

Station	Barahkshetra	Birpur
Slope (S)	0.00175	0.00041
Mean annual discharge (Q_m)	9925 m^3/s	9183 m^3/s
Bankfull discharge (Q_{bf})	8023 m^3/s	7458 m^3/s
Braiding Threshold (S_0) (By Equation 4.1)	0.000229	0.000391

So it can be seen that S>So at both locations. So the river is braided type by this method in the region from Barahkshetra to Birpur.

Now we apply the third equation which is proposed by Lane to show that the river is braiding type in the region.

Table 4.2: Braiding threshold by equation 4.3

Station	Barahkshetra	Birpur
Slope (S)	0.00175	0.00041
Mean annual discharge (Q_m)	9925 m^3/s	9183 m^3/s
Bankfull discharge (Q_{bf})	8023 m^3/s	7458 m^3/s
Braiding Threshold (S_0) (By Equation 4.3)	0.00041	0.000408

Again by eq 4.3, it can be seen that S>So at both locations. So the river is braided type by this method in the region from Barahkshetra to Birpur. We are not using the fourth and fifth equations due to unavailability of data of sediment size in the area. But the study by above method is sufficient to know that the river is of braiding pattern in the region. The braiding pattern of the river is observed by both the methods which indicates that that the river upstream of barrage is separated by by small islands called braid bars.

This work is based on the existing braiding indicators to find the level of braiding .The study area is selected from Barahkshetra to Birpur and the data related to this are collected and analysed and calculations are done based on the existing equations.

4.2.3 Braiding Intensity Calculation Method

After finding that the pattern of the river kosi is of braiding type, we will now calculate the intensity of braiding by different methods. Several researcher have proposed the different indices to calculate the intensity of braiding based on different characteristics. The different indices used by the researcher is based on several characteristics such as bar dimension, channel length, and number of channel. The main parameters which are required for braiding are length of bars, mid channel length, centre line, and total number of active channels in a cross section. But none of the indices uses all the parameter, every indices use one or two parameters.

Brice (1964) have used the parameters length of sandbars and length of centre line to calculate the braiding index. He studied the channel pattern of Loup river in Nebrasaka. The braiding index equation proposed by Brice is given by

$$BI = \frac{2b}{c} \qquad (4.6)$$

Where b is the length of sandbars and c is the length of centre line.

Rust (1978) have used the parameters length of sandbars and length of the widest channel to study the braiding of the river. Rust suggested the following equation to calculate braiding

$$B = \frac{b}{M} \qquad (4.7)$$

Where b is length of sandbar and M is the length of widest channel

Mosley (1981) used the length of mid channels and length of widest channel parameter to calculate the braiding and suggested the following equation

$$B = \frac{s}{m} \qquad (4.\ 8)$$

Where s is length of mid channel and M is Length of widest channel

Friend and Sinha (1993) upgradaed the equation used by Mosley and used the same parameter which was used by Mosley. His equation is only a addition in Mosley equation

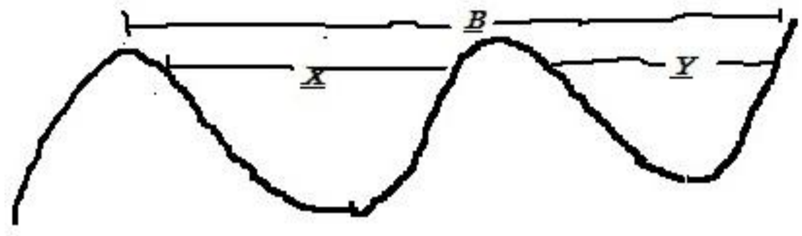
$$B = \frac{s-m}{m} \qquad (4.9)$$

Sharma (2004) used Plan Form Index (PFI) to calculate the degree of braiding in the Brahmputra river reach. It uses flow top width of mid channels, overall width of channel and number of braided channels. He also proposed Flow Geometry Index and Cross slope ratio to calculate degree of braiding of highly braided river. Here we only study about the PFI.

The formula to calculate PFI is given by the equation:

$$PFI = \frac{T}{B} * \frac{100}{N} \qquad (4.10)$$

Where T is flow top width B is overall width of channel and N is the number of braided channel.



Here T =X+Y

Fig 4.1 : Figure showing top and overall width of channel

The following threshold values are provided for a wider range of classification of the braiding pattern

Highly Braided	PFI<3
Moderately Braided	20 > PFI>3
Low Braided	PFI>20

L.Saikia (2018) used a new index to calculate braiding intensity in Brahmputra river. In this index he used number of mid channel bars, fraction of area covered by sandbars and maximum width of channel, by using these factors he proposed the following equation

$$B = X * \mathrm{N} * \frac{\mathrm{W}}{\mathrm{L}} \qquad (4.11)$$

Where X is fraction of area covered by bars, N is number of mid channel bars W is width of channel and L is length of reach

4.3 Methodology

The method used in this study is to extraction of relevant information from the GIS data source and then put the data in the above equations. The equations given in above section are used to calculate the braiding index of the two years that is of 2005 and 2016. The parameters required in these equations such as length of sandbar, centerline length, length of widest channel, mid channel length and flow top width are obtained from the available geoprocessed Landsat 5 image of the study area. The study area is divided into four reach of 10 km and then these four reaches are divided into four sub reach to make the extraction of information process easier. The coordinates of each of the region of both side of river and also of the sub region are selected so that there will not be a mismatch of region while calculating the length from two data of different year. The georeferenced Landsat images are processed in Arc GIS 10.4 software to obtain relevant parameters required to calculate the braiding intensities and planform index. These obtained values are than put in the above equations and the result obtained by the equations are compared to get the required result.

5. RESULTS AND DISCUSSION

5.1 Introduction

In this chapter we will obtain the results by using the data and the equations which are already discussed in the previous chapters. The results obtained for the year 2005 and 2016 will then compared to know the evolution in the morphology of the river Kosi. The chapter gives a detail about result obtained while processing the satellite images of two different years of the river. This chapter contains detail explanation of the observation which requires to fulfill the objective of this study.

5.2 Observsation

5.2.1 Braiding Intensity of Kosi in 2005

A Landsat 5 geo referenced image of the river is obtained from USGS Earth Explorer website is used to obtain the parameters such as length of Sandbar (b), length of Centerline (C), length of widest (main) channel, flow top width (T), and overall width of the channel. The river area upto 40 km upstream of barrage have been selected and the 40 km length is divided into four reach.
The latitude and longitude of the right bank of selected reaches in moving from upstream to downstream are given below.

Table 5.1: Lat and Long of four reaches on right bank of river

Reach	Latitude	Longitude
Reach 1	26.830 26.760	87.129 87.0775
Reach 2	26.760 26.68	87.0775 87.0266
Reach 3	26.68 26.61	87.0266 86.97
Reach 4	26.61 26.570	86.97 86.914

The latitude and longitude of the left bank of selected reaches in moving from upstream to downstream are

Table 5.2: Lat and Long of four reaches on left bank of river

Reach	Latitude	Longitude
Reach 1	26.822 26.758	87.151 87.124
Reach 2	26.758 26.673	87.124 87.064
Reach 3	26.673 26.603	87.064 87.013
Reach 4	26.603 26.530	87.013 86.942

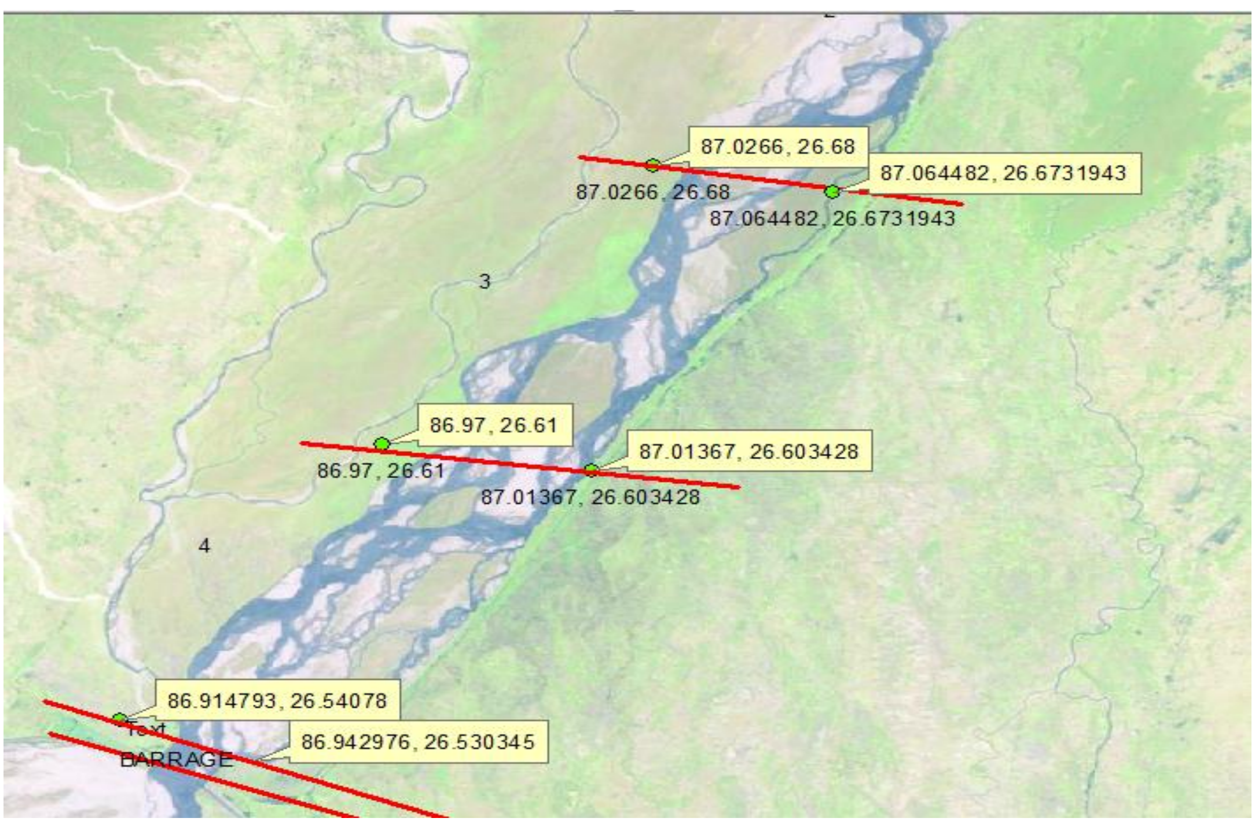


Fig 5.1: Map showing reach 3 and 4 with coordinates

The different parameter like length of sandbar, length of centerline, flow top width, length of widest main channel and flow top width used to calculate the braiding are obtained for the year 2005 and are given below.

Table 5.3: Parameters of river in 2005 to calculate braiding

Reach	b	c	M	T	B
1	6.7	8.2	8.68	1.42	2.42
2	8.30	7.87	6.89	0.91	3.73
3	7.83	8.24	9.82	1.05	3.6
4	11.52	10.68	10.43	0.89	3.72

Here b = length of sandbar(km); c = centerline length of river(km); M = Length of widest main channel(km); T = Flow top width(km) ; B= Overall width of channel(km)

Now we use the equations 4.6, 4.7, and 4.9 given by Brice (1964) Rust (1978) and Sharma (2004) mentioned in chapter 3 to find the braiding intensity by three different methods in the year 2005.

Table 5.4: Braiding Intensity in four reach in 2005

Reach	Brice BI=2b/c	Rust BI=b/M	Sharma PFI=T/B *100/N
Reach 1	1.59	0.77	29.3
Reach 2	2.10	1.29	3.48
Reach 3	1.90	0.79	14.58
Reach 4	2.15	1.10	3.98

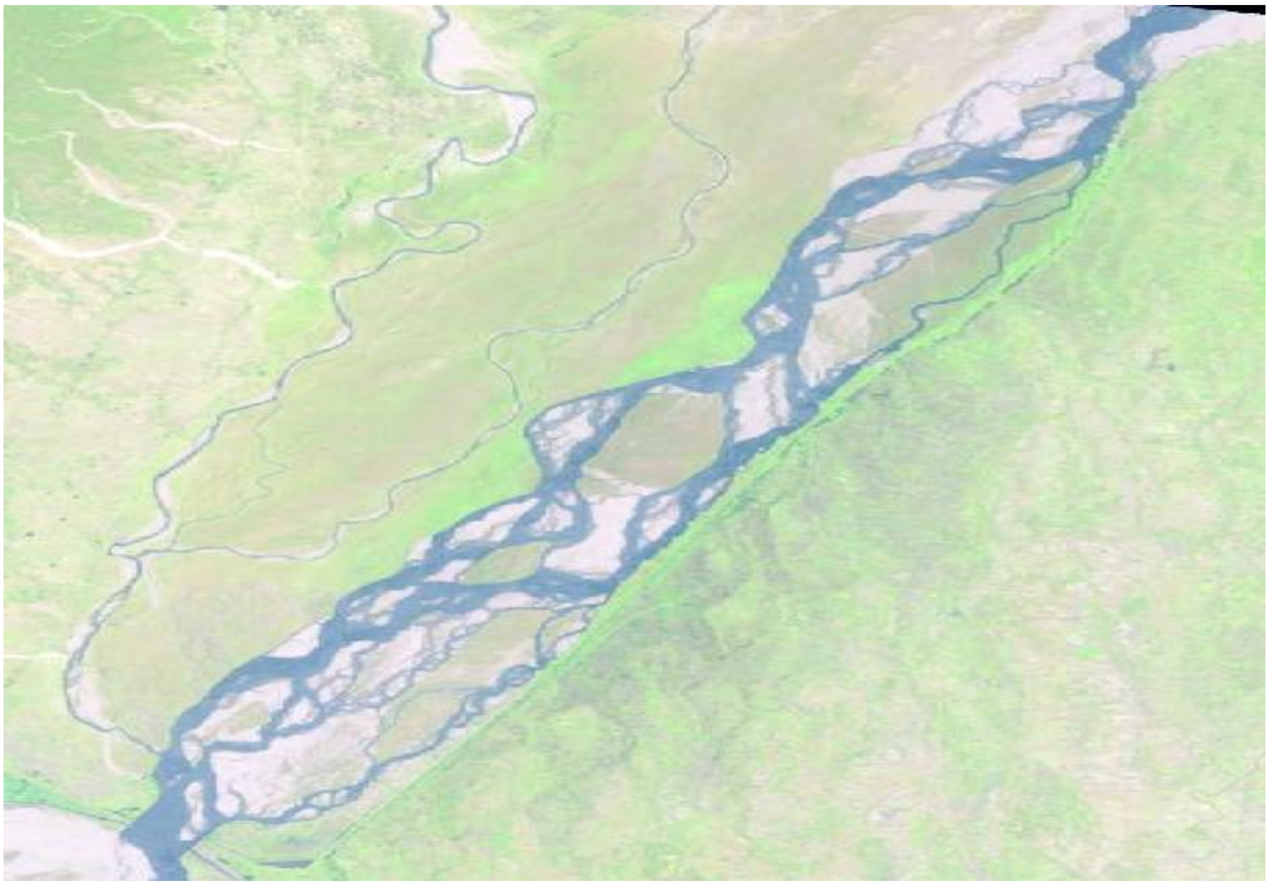


Fig 5.2 : Landsat image of Kosi in 2005

5.2.2 Braiding Intensity of Kosi in 2016

Different parameters of all the four reach ,which is required to calculate the braiding intensity of the river Kosi in the year 2016 are obtained through Landsat image of year 2016 are given below in the table

Table 5.5 : Parameters of river in 2016 to calculate braiding

Reach	b	c	M	T	B
1	7.78	8.85	9.77	0.89	1.85
2	14.09	8.2	9.80	0.82	3.95
3	12.83	8.30	11.1	0.95	4.05
4	13.52	10	11.0	0.93	4.21

Here b = length of sandbar(km); c = centerline length of river(km); M = Length of widest main channel(km); T = Flow top width(km) ; B= Overall width of channel(km)

Now we use the equations 4.6, 4.7, and 4.9 given by Brice (1964) Rust (1978) and Sharma (2004) mentioned in chapter 3 to find the braiding intensity by three different methods in the year 2016.

Table 5.6: Braiding Intensity in four reach in 2016

Reach	Brice BI=2b/c	Rust BI=b/M	Sharma PFI=T/B *100/N
Reach 1	1.75	0.79	24.05
Reach 2	3.43	1.43	2.96
Reach 3	3.10	1.15	2.83
Reach 4	2.70	1.22	3.15

5.2.3 Comparison of Braiding in 2005 & 2016

Braiding intensity in the year 2005 and 2016 have been calculated by three different methods, now braiding intensity of the years are compared to know the change in the braiding pattern in this eleven year period.

Table 6.1: Comparison of braiding intensity

Reach	Brice(BI)		Rust(BI)		Sharma(PFI)	
	2005	2016	2005	2016	2005	2016
Reach 1	1.59	1.75	0.77	0.79	29.03	24.05
Reach 2	2.10	3.43	1.29	1.53	3.48	2.96
Reach 3	1.90	3.10	0.79	1.15	14.58	2.83
Reach 4	2.15	2.70	1.10	1.22	3.98	3.15

In the table we can clearly observe the increase in braiding intensity (BI) and decrease in Planiform Index (PFI). The decreasing value of PFI is an indication to higher degree of braiding, while the increase in the BI value indicates for higher braiding. We can see the increasing braiding intensity for all the four reaches. The braiding in reach 1 is low braided while in the reach 2 & 3 it is highly braided in 2016 but moderately braided in 2005 and in reach four it is moderately braided in both the year but it also shows increasing trends.

6.CONCLUSION

As discussed in the above chapters, the increase in the braiding intensity and decrease in the planiform index in the year 2016 as compared to year 2005 is a clear sign that the Kosi river from Barahkshetra to Kosi barrage show increase in the braiding level. The braiding intensity of river increase in all the four reach as can be seen in the table 5.7. The increase for the reach 1 & reach 4 is minimum while for the reach 3 & 4 it is maximum. The change in the braiding of the river causes the morphological change. This increase in the braiding of river upstream of barrage is due to increase in sandbar length, mid channel length, and widening of the river. Widening of river resulted in huge loss of land area. The reaches which are low braided in the year 2005 becomes moderately or high braided in 2016.

This paper compared the results obtained by the existing braiding indicators and tried its best to include all the parameters required to know about the braiding intensity of the river. Each method only include one or two parameters to calculate braiding, so the three methods have been used to obtain the more accurate result. All the three methods shows the increase in the braiding intensity of the river. The range of PFI values divide the region into high, low and moderately braided reach

Highly Braided	PFI<3
Moderately Braided	20 > PFI>3
Low Braided	PFI>20

By using PFI value obtained above we can divide the reach into low, high and moderately braided in 2005 and 2016.

Table 5.8: Change in braiding of river

Reach	**2005**	**2016**
1	Low braided	Low braided
2	Moderately braided	High braided
3	Moderately braided	High braided
4	Moderately braided	Moderately braided

In Table 5.7 we can see that there is high variation of braiding intensity for the regions 2 and 3 compared to the region 1 and 4 by both the method. This indicates that the braiding intensity have been increased heavily for the region 2 and 3 but slightly for the region 1 and 4. This gives the clear idea that the high morphological change occurred in the region 2 and 3.

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