International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-09, Issue-03, June 2023

Application of Remote Sensing and GIS in the Assessment of River Meandering at Lower Kosi River Basin

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Abstract **The main objective of this study is to provide useful insights into the dynamics of the lateral river shifting in the lower Kosi River basin area. To do so, in this work, we analyzed the river meandering in the lower Kosi River Basin using remote sensing and GIS (Geographic Information System). This study focuses on the last 100 km length of the Kosi River in East Bihar, which is prone to frequent river meandering. We used Landsat images of the last 51 years (1972- 2023) downloaded from the United States Geological Survey server to track the movement and direction of the river channel's position and morphology. We focused on river sinuosity and lateral river shifting parameters to use them as an indicator of how much the river has shifted in a given time frame and utilized ArcMap10 GIS tools to measure these parameters. The results of this study can contribute to improved river management strategies (e.g., floodplain zoning, identifying the risk of huge riverbank erosion, land loss, and pointing out the zone of important construction projects along or across the river) in Eastern Bihar, and subsequently improving the human lives of this region.**

Keywords —GIS, Kosi River, Lateral Shift, Migration, River Meandering, Sinuosity

I. INTRODUCTION

Lateral migration of rivers is a natural process, which is prevalent in most of the rivers around the world [1, 2], and responsible for creating new habitats for aquatic plants and animals, and providing valuable nutrients for nearby agricultural lands [3]. On the other hand, it can also be a threat to the nearby communities by causing flooding and landslides [4]. Thus, it is clear that the lateral migration of rivers can impact our lives in both good and bad ways, which makes it extremely important to study this phenomenon. Through a systematic study of the lateral migration of rivers, a better understanding of how rivers behave over time and how they interact with their surrounding ecosystem can be achieved. Comprehensive knowledge of how the river changes its course over time not only helps us in better predicting and managing the risk of flooding [5] or evolution of new natural land-forms [6], but also in taking decisions on the design and construction of bridges, dams or other infrastructure projects that need to be built along or across the rivers [7]. It also helps us in understanding the complex interactions between water, sediment, and the underlying geological structure [8], which is essential for sustainable development. Additionally, research on river shifting can also provide insights into how human activities are affecting our rivers and the required actions for sustainability.

From the literature, it can be found that the research on river meandering and migration started in the 1930s. One of the first and foremost experimental studies was performed by [9] to assess different river shifting parameters like velocity, the direction of flow, sediment movement, and the relationship of meander belts with the width of the river at selected locations of Mississippi River. As experimental studies have proven to be extremely expensive in terms of time, cost, resources, and as well as physical labor, the research community became more and more interested in developing empirical relations between river morphology and the migration of the river. This eventually lead to a wide array of studies conducted between the 1950s and 1980s. Among these, one of the most notable ones is a study by [10], where he developed a consistent correlation between channel width, meander length, and radius of curvature of the Mississippi River. In the 1970s, the pattern of meander growth for Beatton River in Canada was formulated in terms of hydraulics by [11, 12]. With the

 DOI : 10.35291/2454-9150.2023.0138

advent of better computing resources, since the 1980s, people started to grow interest in developing numerical simulation models for studying the river meandering and shifting phenomenon. One of the pioneering works was performed by [13], where he established a two-dimensional stability model to derive a relation between meander wavelength and a number of braids. The mechanisms, morphological adjustment, and spatial propagation of meander cutoffs and formation of an oxbow lake in Bollin and Dane river floodplain were performed by [14].

For the last two decades, the use of remote sensing and geographic information system (GIS) technology to study river bank erosion and channel shifting from space has become extremely popular mainly due to two reasons: (i) time and cost-effectiveness and (ii) availability of a detailed and comprehensive understanding of how rivers change over time. The effectiveness of satellite remote sensing combined with GIS in exploring river relocation was demonstrated by [15] for the active Yellow River delta in China. The river dynamics of Brahmaputra River over a length of 620 km at Assam was investigated by [16] by overlaying Multi-date Landsat Multispectral Scanner(MSS), Thematic Mapper(TM), and Enhanced Thematic Mapper(ETM) images with each other. In a similar study, long-term spatio-temporal changes of Karnali Megafan were studied by [17] with the help of MSS, TM, and ETM Landsat data. Recently, the impact of global climate change on river meandering has gained a lot of attraction in the scientific community. In some recent studies, morphological responses of a river due to human and climate change were evaluated by [18] on the Hernad River in Hungary and [19] on the Pahang River in Malaysia.

In the Indian subcontinent, Kosi is one of the most important rivers due to its huge impact on a large number of people in the Indian state of Bihar, and the neighboring country of Nepal. This river is historically extremely susceptible to the lateral migration phenomenon. From the literature [20–23], it can be seen that the river has shifted by 112 km towards the west from Purnea to Supaul in Bihar in approximately 200 years, and in doing so it has also washed out a huge area of approximately 7680 sq. km. In the years of 2008 and 2009, devastating floods in Kosi not only caused the river bank shifting and landslide but also caused significant damage to crops, property, livestock, etc. [24, 25]. The dense population density of Bihar has also exacerbated the adverse effects of Kosi river migration, which has directly affected the overall economy of the state quite significantly. This necessitates a comprehensive assessment of the lateral migration and meandering behavior of the Kosi River in the plains of Bihar. But, to the authors' knowledge, in the literature, only a couple of studies exist focusing on the upper Kosi River basin in Nepal. In a recent work by [26], sediment flux through the Kosi river basin was estimated and its significance for river avulsion and inundation risk was identified. In another work, Flow Duration Curves (FDCs) and Flood Frequency Analysis (FFA) techniques were used by [27] to make a first-order sediment-discharge relationship at the Kosi river basin in Nepal.

It is important to note that the Kosi River dynamics in Nepal and Bihar differ significantly in terms of topography, climate, and human activities. While, the Kosi River in Nepal is characterized by high-gradient channels, frequent landslides and debris flows, and contributions from glacial streams[28]; the Kosi River in Bihar is characterized by a low-gradient channel, nourished by rainwater, periodic floods, and significant human modifications to the river's morphology and hydrology. Also, as mentioned earlier, Kosi River migration has a significant impact on infrastructure, agriculture, and communities in the Bihar region. These reasons demand a separate study on Kosi river migration for Bihar, as it can significantly help in the development of effective management strategies to manage the impacts of river migration and enhance the resilience of communities in the region.

Despite the fact that such studies will be helpful in better planning flood protection works, ecosystem studies, and identifying new construction zone in Bihar, to the authors' knowledge no such study exists on lateral migration of the Kosi River in Bihar. In order to address that issue, in this work we have studied the lateral migration of the Kosi River for a length of 100 km in Bihar. To do so, we used the Landsat images of the Kosi River study area over a time period of 51 years from 1972 to 2023. To analyze the GIS data, we used one of the most popular techniques in the research community, which is split the center-line technique. The rest of this paper is organized as follows: in Section 2, we describe the study area, slope, and Landsat image; in Section 3, we discuss the method to identify the long-term evolution and center-line migration of Kosi River; in Section 4, we present the shifting of the Kosi River center-line in various time intervals; and finally in Section 5, we conclude with a summary and closing remarks.

II. Study Area, Data and Data Pre-Processing

In this section, we first discuss the details of the study area and its morphological properties. Next, we present the details of the Landsat image data for the selected study area, and various features associated with it.

Kosi River is one of the most important rivers originating from the central Himalayas. Its catchment area covers some parts of Nepal and East Bihar in India. Kosi is a combination of three rivers named Sun Kosi, Arun Kosi,

 DOI : 10.35291/2454-9150.2023.0138

ISSN : 2454-9150 Vol-09, Issue-03, June 2023

and Tamur Kosi; which meet at Tribeni in Nepal and then flow under the name of Kosi. After originating from the central Himalayas, it passes through a 10 km deep canyon and reaches a plain region at Chatra in Nepal. Next, it flows 42 km through a sandy alluvial plain in Nepal and reaches the border of India in North Bihar. Subsequently, it flows for 260 km and joins the river Ganges at Kursela in Bihar. In this work, we have selected a 100 km stretch of the Kosi River in the eastern part of Bihar (86°40′E to 87°20′E and 25°40′N to 25°27′N) as our study area. The slope of the Kosi River changes significantly over the course of its flow: at the initial stage, the Kosi River has a slope of 1.5 m/km, but then it reduces to 0.95 m/km when it reaches to alluvial plainland at Chatra. By the time it reaches our selected study area, the Kosi River catchment becomes almost flat, and finally, at the outfall at Kursela, the slope changes to 0.03 m/km. This information highlights the noticeable changes in the slope of Kosi from Nepal to Bihar and corroborates the need for special attention to the selected study area. The entire Kosi River catchment and sub-catchment area and our selected study area are shown in Figure 1.

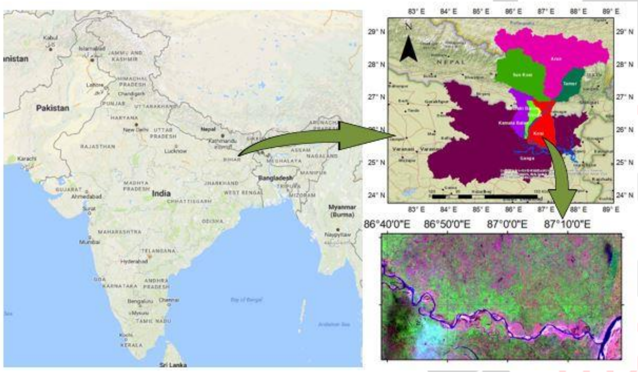

Figure 1: This image showing the catchment and sub-catchment of Kosi River in India and designated area of focus for this research

In this study, we have used ArcMap10 for extracting geographic details, rectification, processing, spatial referencing, measurement, overlay, and analysis of the Landsat images of the study area (downloaded from the United States Geological Survey USGS server, Earth Explorer: https://earthexplorer.usgs.gov/). A total number of six satellite images over a span of 51 years (for the years 1972, 1988, 1992, 2002, 2013, and 2023) were considered in the present study. This dataset was chosen from the non-monsoon months to avoid the cloud cover of Multispectral Scanner (MSS), Thematic Mapper (TM), Operational Land Imager (OLI), and Thermal Infrared Sensor (TIRS) sensors; which were processed accordingly to get a single multi-band image using ArcGIS. Since one Landsat image did not capture the entire study area, a mosaic image (prepared by combining two different satellite images for the same time duration) was used for the study. The details of the Landsat images are presented in Table 1.

Features	Year		
	1972	1988	1992
Spacecraft ID	Landsat 1	Landsat 5	Landsat 5
Sensor ID	MSS	TM	TM
Acquisition date	07/11/1972	23/01/1988	06/03/1992
WRS Path	150	140	139-140
WRS Row	42	42	42
Resolution (m)	80	30	30
Features	Year		
	2002	2013	2023
Spacecraft ID	Landsat 7	Landsat 8	Landsat 9
Sensor ID	ETM	OLI/TIRS	OLI/TIRS
Acquisition date	10/03/2002	10/04/2013	05/04/2023
WRS Path	150	140	139-140
WRS Row	42	42	42
Resolution (m)	30	30	30

Table 1: Features of Landsat Images obtained from USGS (https://earthexplorer.usgs.gov/) in our study area for the years (a) 1972, (b) 1988, (c) 1992, (d) 2002, (e0 2013, and (f) 2023

III. METHODOLOGY

In this section, we discuss a couple of useful metrics to assess river meandering. Among various parameters, we mainly focus on three of them: the sinuosity parameter, the lateral river shifting, and the active meander zone. In the literature, sinuosity is defined as the ratio of the actual length of a river channel to the straight-line distance between its endpoints. It is an important parameter to assess the plan-form dynamics of a river because it provides valuable information about the shape and behavior of a river. It also represents the interplay between various geomorphic and hydrologic processes that shape the river channel. Meandering rivers tend to be more dynamic and have a higher potential for erosion and deposition, as well as habitat creation, than straight rivers. Rivers with higher sinuosity also tend to have a higher diversity of habitats and greater ecological productivity. A river with high sinuosity, i.e., a meandering river, has a longer channel length than a straight river of the same length. This indicates that the river channel is constantly changing its position, creating meanders and bends as it flows. In contrast, a river with low sinuosity, that is a straight river, has a shorter channel length than a meandering river of the same length. Therefore, sinuosity is an important metric for assessing the health and functioning of river ecosystems and can be used to identify areas of the river that are most susceptible to change or degradation. By analyzing changes in sinuosity over time, river managers and scientists can gain insights into the natural and anthropogenic drivers of river channel evolution and make informed decisions about river management and restoration.

 DOI : 10.35291/2454-9150.2023.0138

On the other hand, lateral river shifting is a dynamic process by which a river changes its course horizontally, moving sideways across its floodplain over time. It is a natural phenomenon that occurs due to various factors including erosion, sediment deposition, and changes in the river's flow patterns. It can affect land use, property boundaries, and the stability of riverbanks. Thus, it is important to understand and monitor these changes to mitigate potential risks associated with riverine ecosystems and human settlements located near rivers.

To assess the sinuosity and lateral river shifting we have to generate a number of shape files in the GIS platform. A shape file is a popular geospatial vector data format used in GIS software, ArcGIS. It consists of a collection of files that store different types of information about geographic features, such as points, lines, and polygons. A shapefile typically includes three files with the same name but different extensions: .shp - the main file that stores the geometry of the features; .shx - an index file that allows for faster searching of the features; and .dbf - a database file that stores attributes associated with each feature. Shapefiles can be used to represent different types of geographic features such as rivers and can be used for analysis, visualization, and mapping. They are widely used in the GIS community because of their simplicity, versatility, and compatibility with various software applications. To calculate the sinuosity, we followed the following steps:

• Shapefiles were generated for the Kosi River centerline for every single Landsat image (corresponding to each year we considered) (see Figure 2), and the length of the river was calculated with the help of ArcMap 10 (see Table 2).

• For the year 1972, the entire study area of the Kosi River was split into segments of equal lengths (10 km each).

• Next, at each split point, split lines are generated in the direction perpendicular to the river centerline, which will intersect the rest of the river centerline shapefiles generated for the years 1988, 1992, 2002, 2013, and 2023 (see Figure 3).

• To calculate the river sinuosity, the centerline length of each segment and the straight-line distance of the meander belt for each segment were calculated with the help of ArcMap 10.

• The sinuosity for every segment was calculated by using the following equation: $P = L_c/L_s$, where P denotes sinuosity, L_c is the length of the centerline of the river segment, and L_s denotes the straight-line distance of the river segment.

Year	Length (Km)
1972	104
1988	92
1992	97
2002	91
2013	81
2023	78

Table 2: Length of Kosi River in our study area obtained from Landsat Images using ArcMap10 tool at different times over the last 51 years

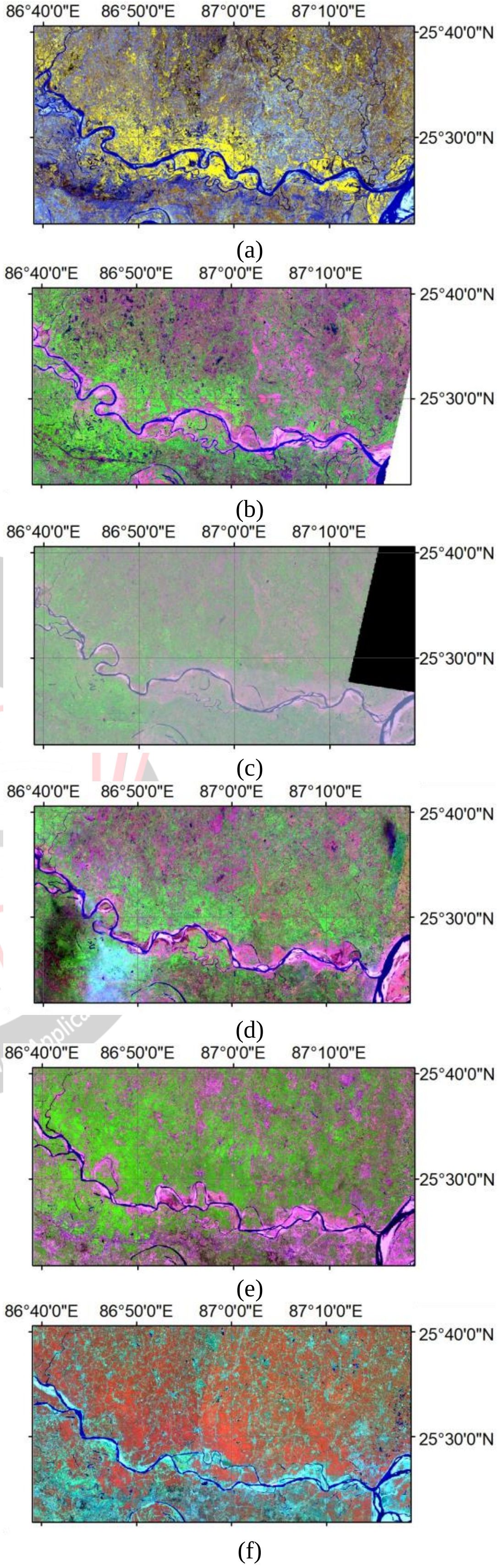

Figure 2: Landsat images of the Kosi River in our study area for the years (a) 1972, (b) 1988, (c) 1992, (d) 2002, (e) 2013, and (f) 2023

We can assess river shifting in two ways: polygons

 DOI : 10.35291/2454-9150.2023.0138

ISSN : 2454-9150 Vol-09, Issue-03, June 2023

technique and split the centerline technique [29]. In this work, split the centerline technique was used, and to do so the steps followed are explained below:

• Shapefiles were generated for the Kosi River centerline for every single Landsat image (corresponding to each year we considered) (see Figure 2).

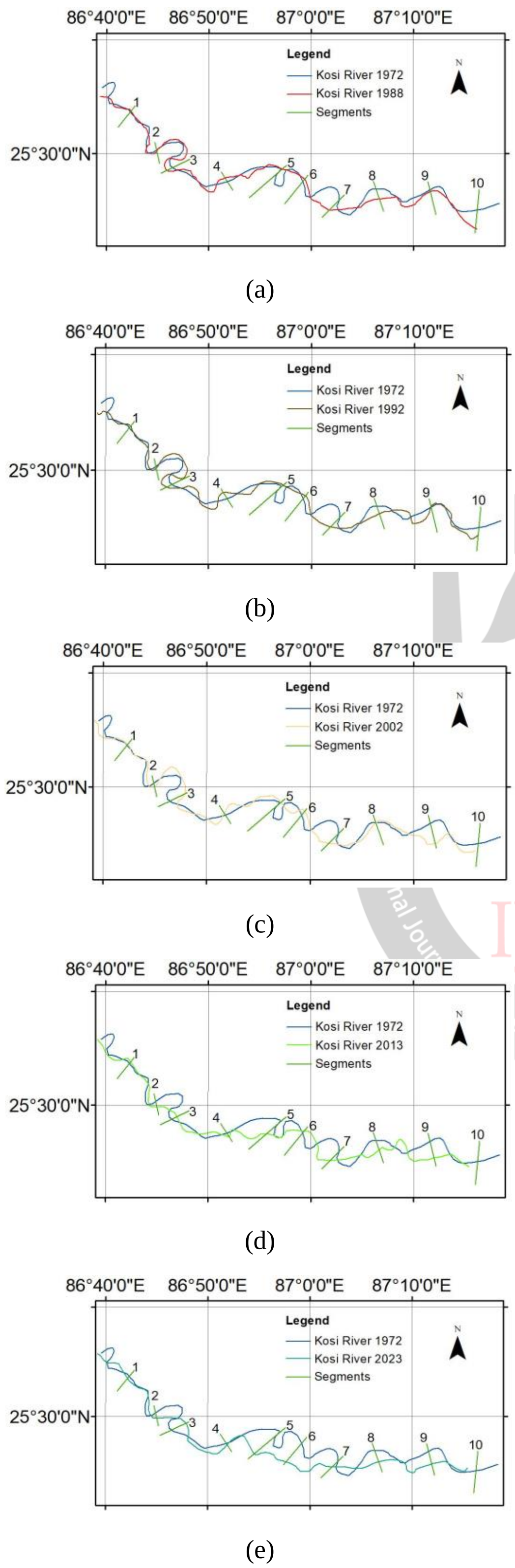

Figure 3: Centerline and Split line shapefile for the years 1972, 1988, 1992, 2002, 2013, 2023

• The next step of the analysis is selecting the initial river path. To do so, the shapefile for the Landsat image corresponding to 1972 was selected.

• Next, the initial river centerline shapefile has to be split into a number of segments. To do so, the entire length of the river in the selected study area was divided into multiple segments of equal lengths (10 km).

• Next, at each split point, split lines are generated in the direction perpendicular to the initial river centerline, which will intersect the rest of the river centerline shapefiles generated for the years 1988, 1992, 2002, 2013, and 2023 (see Figure 3).

• Subsequently, the shapefiles of the center line of the river for all years and the split line have to be overlaid in ArcGIS.

• Finally, for all the different years considered in our study, the lateral shift has to be calculated. To do so, the migration distance, i.e., the difference between the previous study year's river path and the shifted river path along split lines is calculated in ArcGIS.

After we compute the lateral river shifting and the sinuosity of Kosi, another important parameter for river meandering is the active meander zone. It refers to a stretch of a river or stream where the channel has a high degree of meandering or curving, and where the meandering is still actively occurring. In such a zone, the river's flow is continuously eroding the outer banks of the meanders while depositing sediment on the inner banks, causing the meanders to slowly migrate downstream over time. On one side, these zones are natural habitats for many aquatic species, and on the other side, they can also pose a risk to human infrastructure such as bridges and levees if they are not properly managed. Therefore, understanding and managing active meander zones is important for both ecological and human safety reasons. The active meander zones of Kosi River in our study area were delineated by overlapping all river center line shape files obtained for the years 1972, 1988, 1992, 2002, 2013, and 2023 (see Figure 4).

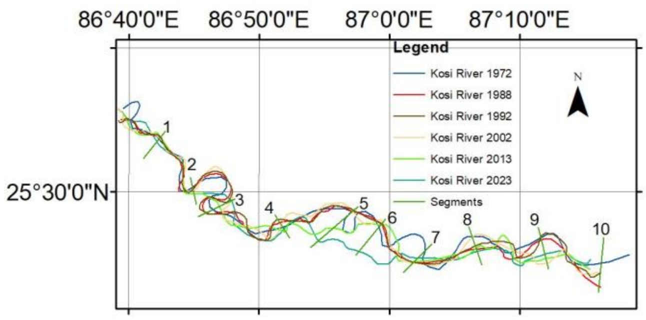

Figure 4: Delineation of active meander zone of Kosi River in 51-year study period

Now, as we have introduced a number of metrics that can be utilized to measure the lateral migration of the Kosi River, we move on to the next section to discuss the

DOI : 10.35291/2454-9150.2023.0138

findings from our current work.

IV. Results and Discussion

In this section, we will focus on our findings for mainly three areas:

• Sinuosity of the Kosi River in each segment (created by split lines) for every time period (e.g., 1972-1988, 1988-1992, etc.)

• How much the river has shifted laterally at any given time interval (e.g., 2002-2013, 2013-2023, etc.)

• The active meandering zone of the Kosi River in the last 51 years (i.e., 1972-2023)

As mentioned earlier, the image processing analysis on the relevant data (i.e., the Landsat images) was done using ArcGIS.

SINUOSITY OF THE KOSI RIVER

In Figure 5, we plot the sinuosity of the Kosi River for different years in each segment of the study area. The most important observations from this figure are summarized below:

• There is a progressive increase in the sinuosity of the river in segment 3 for the years 1972-1992, but from 2002 it starts to decrease and finally in 2013 and 2023, it became very close to 1. This has resulted in the significant meandering of the river in that particular region for the first few decades, and finally, around 2013, the cutoff happened, and an oxbow lake was created. The yearly progression of events has been well captured in the Landsat images shown in Figure 2.

• Similar series of events took place for segment 6. In this case, though the sinuosity of the river started to decrease after 1972, and an oxbow lake was created in 1988. This has also been well captured in the Landsat images shown in Figure 2.

• For the rest of the study area, the river remains almost straight and stable throughout the last 51 years, thus not creating new landforms or oxbow lakes. A detailed future study on the formation of oxbow lakes and new landforms in segments 2 and 6 is crucial to understand their implications on the river ecosystem, management, and restoration in those areas, which will affect the lives of thousands of people living there.

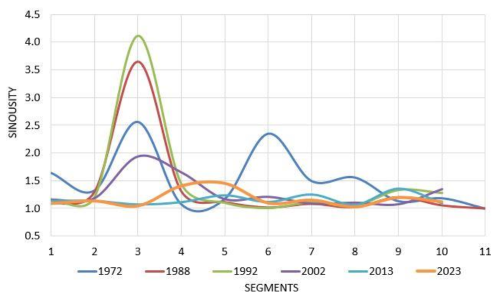

Fig. 5: Sinuosity of the Kosi River for different years in each segment of the study area

LATERAL SHIFTING OF KOSI RIVER

Here, we will discuss the findings on the lateral shifting of the Kosi River from our study. The lateral river shifting parameters (per time interval) of the river (in our study area) in the last 51 years is shown in Figure 6.

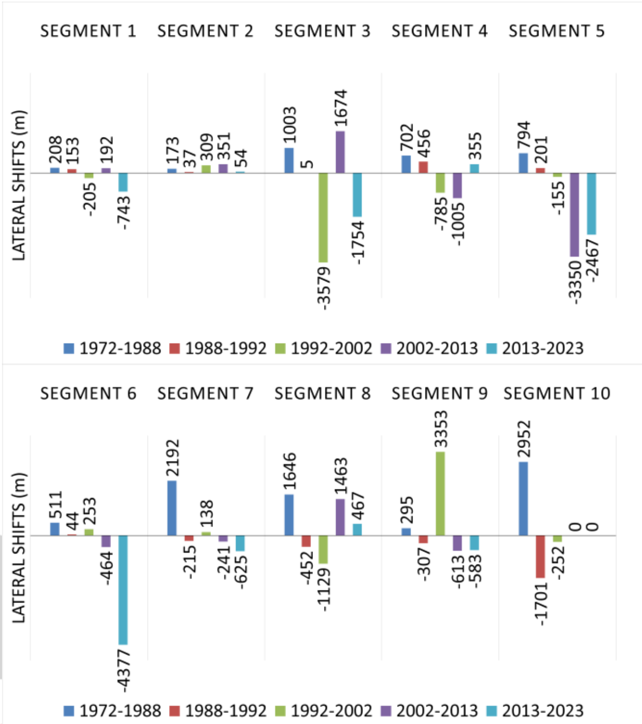

Fig. 6: Lateral shift (m) in the Kosi River (in our study area) per time interval

The most important observations from the above figure are summarized below:

• The first two segments clearly didn't experience a considerable amount of lateral shift in the path of Kosi River in the last 51 years. Another interesting observation is that in segment 2, the river channel never changed its direction which is good from a stability point of view. That indicates, in these regions, the river channel is mostly stable, and the habitat in the nearby area is not under immediate risk of huge riverbank erosion, or land loss.

• It is clear that segment 3 is highly susceptible to the instability of channel migration. The fact is also corroborated by the sinuosity data presented in Figure 5. This region experienced a high lateral shift as well as a change in the direction of flow in almost all the time intervals considered in our study. That shows this region will need further attention from the risk management team, as the human settlement in this area has a higher chance of getting adversely affected by the river.

• Segments 5-6 (the sinuosity parameter for segment 6 is also very high as seen from Figure 5), and 9-10 have experienced similar lateral shifts of the river (like segment 3) in the last 51 years; whereas segments 4, and 7-8 although have not experienced an extremely high amount of lateral shift in any given time interval, they have gone through significant change in the river flow direction.

DOI : 10.35291/2454-9150.2023.0138

These observations again drive us to the decision that we should carefully assess the landform, and geomorphology of these areas before undertaking an important construction project, and periodically monitor the Kosi River path in these regions.

Finally, in Figure 7, we have also plotted the active meander zone width at each segment in the last 51 years. This figure also highlights the fact that segments 3, 5-6, and 9-10 are among the most susceptible regions to river shifting. These regions have a significantly higher risk of undergoing rapid land loss/ landform, as well as affecting thousands of human lives.

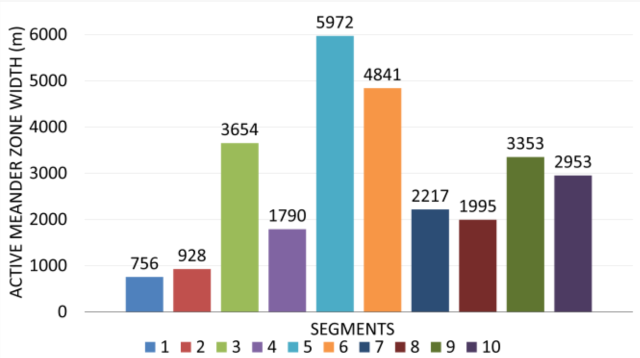

Fig. 7: Active meander zone width for each segment in the last 51 -year

Identifying the lateral migration and meandering of the Kosi River is important for effective flood management, infrastructure planning, environmental impact assessments, ecological conservation, and socio-economic development in the region. It allows for informed decision-making, ensuring the sustainable and resilient management of the river system while balancing human needs and environmental considerations. The findings of the lateral shift parameter study make it obvious how important it is to perform a comprehensive study on the lateral migration and meandering of the Kosi River in this lower basin area, as well as possibly extending it to the other regions of Eastern Bihar in India.

V. CONCLUSIONS

The aim of this study was to provide useful insights into the dynamics of the lateral river shifting in the lower Kosi River basin area. To achieve that, in this work, we analyzed the river meandering in the lower Kosi River Basin using remote sensing and GIS. By utilizing satellite images and integrating them with GIS tools, we were able to accurately analyze and monitor the spatial and temporal changes in the river channel's position and morphology. The key takeaway points from this study are as follows:

• For almost the entire length of the Kosi River in our study area, significant lateral movement and change in flow direction were observed. This indicates that the river channel in this region is highly unstable, and the river bank is susceptible to continuous changes (landform or land loss).

• We also observed that the maximum active meander zone width of the Kosi River in our study reached up to a maximum of 5972 m (almost 6 km) in the last 51 years. This indicates that there is a high probability of the river being laterally shifted by about 6 km (it can be even more) in the future. So, we will recommend leaving at least 5-6 km as a buffer zone on both sides of the river in this area for any kind of important permanent construction.

• We noticed that whenever the sinuosity of the river exceeded 2.4, the river forms an oxbow lake and starts to again flow in a straight path. This indicates that if in any given time frame, the sinuosity is reaching around 2.4, special attention should be paid to those regions, as the risk of creating a new landform would be very high.

• The remote sensing and GIS techniques employed in this study offered several advantages: including the ability to obtain accurate and timely spatial information and the capacity for large-scale analysis. As it helped us in getting a comprehensive understanding of the river meandering process in the lower Kosi River basin, we think it also has huge potential in enabling informed decision-making and facilitating the sustainable development of the region.

We would like to conclude by highlighting again that the assessment of river meandering in the lower Kosi River basin helped us understand the magnitude, direction, and frequency of meandering, which are crucial factors for effective river management. The use of remote sensing and GIS technologies offers several advantages, including the ability to acquire data over large areas, cost-effectiveness, and the ability to monitor changes over time. It provides a valuable tool for long-term monitoring, trend analysis, and prediction of river meandering, allowing for proactive management and planning. It is important to note that the application of remote sensing and GIS in the assessment of river meandering also has its limitations. Factors such as cloud cover, sensor resolution, and the availability of historical data can affect the accuracy and reliability of the analysis. Additionally, field validation and ground truthing are essential to ensure the accuracy of the remote sensing data and the interpretation of the results.

The results of the study can contribute to the development of strategies for floodplain zoning, erosion control, and sustainable land use planning, thus ultimately minimizing the environmental and socio-economic risks associated with river meandering. So, we should continue monitoring and analyzing to track any future changes in river meandering of the Kosi River in India. Regular updates and assessments will contribute to the adaptive management of the lower Kosi River Basin (and possibly extending it to the rest of the Kosi River in India), ensuring the implementation of appropriate measures to mitigate risks and promote sustainable use of the river system.

DOI : 10.35291/2454-9150.2023.0138

REFERENCES

[1] Li, L., Lu, X., Chen, Z.: River channel change during the last 50 years in the middle Yangtze River, the Jianli reach. Geomorphology 85(3-4), 185–196 (2007)

[2] Naim, M.N.H., Hredoy, M.S.N.: Simulation of channel dynamics of the Padma river considering seasonal variations: A GIS and statistical approach. Environmental Challenges 4, 100169 (2021)

[3] Kafle, K.R., Khanala, S.N., Dahalb, R.K.: Impacts of long-term floodinduced sedimentation on agricultural land: case study of the 2008 Koshi flood in eastern Nepal. Kathmandu Univ J Sci Eng Technol 14 (2020)

[4] Panhalkar, S., Jarag, A.P.: Flood risk assessment of Panchganga River (Kolhapur district, Maharashtra) using GIS-based multicriteria decision technique. Current Science, 785–793 (2017)

[5] Donovan, M., Belmont, P.: Timescale dependence in river channel migration measurements. Earth Surface Processes and Landforms 44(8), 1530–1541 (2019)

[6] Nayak, J.: Sediment management of the Kosi River basin in Nepal. IAHS Publ (1996)

[7] Agnihotri, A.K., Ohri, A., Mishra, S.: Channel planform dynamics of lower Ramganga River, Ganga basin, GIS and remote sensing analyses. Geocarto International 35(9), 934–953 (2020)

[8] S. Chen, B. Mulgrew, and P. M. Grant, "A clustering technique for digital communications channel equalization using radial basis function networks," *IJREAM Trans. Neural Networks*, vol. 4, pp. 570–578, Jul. 1993.

[9] R. W. Lucky, "Automatic equalization for digital communication," *Bell Syst. Tech. J.*, vol. 44, no. 4, pp. 547–588, Apr. 1965.

[10] S. P. Bingulac, "On the compatibility of adaptive controllers (Published Conference Proceedings style)," in *Proc. 4th Annu. Allerton Conf. Circuits and Systems Theory*, New York, 1994, pp. 8–16.

[11] G. R. Faulhaber, "Design of service systems with priority reservation," in *Conf. Rec. 1995 IJREAM Int. Conf. Communications*, pp. 3–8.

[12] W. D. Doyle, "Magnetization reversal in films with biaxial anisotropy," in *1987 Proc. INTERMAG Conf.*, pp. 2.2-1–2.2-6.

[13] G. W. Juette and L. E. Zeffanella, "Radio noise currents n short sections on bundle conductors (Presented Conference Paper style)," presented at the IJREAM Summer power Meeting, Dallas, TX, Jun. 22–27, 1990, Paper 90 SM 690-0 PWRS.

[14] J. G. Kreifeldt, "An analysis of surface-detected EMG as an amplitude-modulated noise," presented at the 1989 Int. Conf. Medicine and Biological Engineering, Chicago, IL.

[15] J. Williams, "Narrow-band analyzer (Thesis or Dissertation style)," Ph.D. dissertation, Dept. Elect. Eng., Harvard Univ., Cambridge, MA, 1993.

[16] Archana, S., RD, G., Nayan, S.: RS-GIS based assessment of river dynamics of Brahmaputra River in India. Journal of Water Resource and Protection 2012 (2012)

[17] Rakhal, B., Adhikari, T.R., Sharma, S., Ghimire, G.R.: Assessment of channel shifting of Karnali Megafan in Nepal using remote sensing and GIS. Annals of GIS 27(2), 177–188 (2021)

[18] Kiss, T., Blanka, V.: River channel response to climate-and human induced hydrological changes: Case study on the meandering Hern´ad River, Hungary. Geomorphology 175, 115–125 (2012)

[19] Kamarudin, M.K.A., Toriman, M.E., Rosli, M.H., Juahir, H., Aziz, N.A.A., Azid, A., Zainuddin, S.F.M., Sulaiman, W.N.A.: Analysis of meander evolution studies on effect from land use and climate change at the upstream reach of the Pahang River, Malaysia. Mitigation and Adaptation Strategies for Global Change 20, 1319–1334 (2015)

[20] Agarwal, R., Bhoj, R.: Evolution of Kosi river fan, India: structural implications and geomorphic significance. International Journal of Remote Sensing 13(10), 1891–1901 (1992)

[21] Chakraborty, T., Kar, R., Ghosh, P., Basu, S.: Kosi megafan: Historical records, geomorphology and the recent avulsion of the Kosi River. Quaternary International 227(2), 143–160 (2010)

[22] Burele, S.A., Sharma, N., Ahmad, Z., Gupta, I.D.: Numerical simulation optimization for channelization of River Kosi. International Journal of Scientific Engineering and Technology 1155(3), 1149–1155 (2014)

[23] Omar, P.J., Rai, S.P., Tiwari, H.: Study of morphological changes and socio-economic impact assessment: a case study of Koshi River. Arabian Journal of Geosciences 15(17), 1426 (2022)

[24] Mishra, K., Sinha, R., Jain, V., Nepal, S., Uddin, K.: Towards the assessment of sediment connectivity in a large Himalayan river basin. Science of the Total Environment 661, 251–265 (2019)

[25] Kumar, N., Jha, R.: Morphometric analysis of Kosi River Basin, Bihar, India using remote sensing and GIS techniques. Climate Change Impacts on Water Resources: Hydraulics, Water Resources and Coastal Engineering, 469–481 (2021)

[26] Sharma, T.P.P., Zhang, J., Koju, U.A., Zhang, S., Bai, Y., Suwal, M.K.: Review of flood disaster studies in Nepal: A remote sensing perspective. International journal of disaster risk reduction 34, 18–27 (2019)

[27] Sinha, R., Gupta, A., Mishra, K., Tripathi, S., Nepal, S., Wahid, S., Swarnkar, S.: Basin-scale hydrology and sediment dynamics of the Kosi river in the Himalayan foreland. Journal of Hydrology 570, 156–166 (2019)

[28] Sinha, R., Sripriyanka, K., Jain, V., Mukul, M.: Avulsion threshold and planform dynamics of the Kosi River in north Bihar (India) and Nepal: A GIS framework. Geomorphology 216, 157–170 (2014)

[29] Rapp, C.F., Abbe, T.B.: A framework for delineating channel migration zones. Technical report (2003)

 DOI : 10.35291/2454-9150.2023.0138