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<https://doi.org/10.47884/jweam.v2i2pp48-60>

Journal of Water Engg.
and Management

ISSN 2582 6298

Volume-02

Number- 02

Jr. of Water Engg. and Mgt.
2021, 2(2) : 48-60

Volume 02, No.-02

ISSN No.-2582 6298

JOURNAL OF WATER ENGINEERING AND MANAGEMENT



**JOURNAL OF WATER ENGINEERING
AND MANAGEMENT**
Hehal, Ranchi, 834005, Jharkhand, India



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Research Paper

Planform Dynamics of Kankai River using GIS and Remote Sensing

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ABSTRACT

The Kankai river is a rainfed perennial river of eastern Nepal and carries a large quantum of silt, and enters in Kishanganj of West Bengal, India. Recently, a bridge collapsed in a village in the Kishanganj district due to a rise in the water levels of the Kankai river. This paper presents a study of the dynamics of changes in channel planform and measurement of the erosion and accretion of the Kankai river in Bihar, India from 2000 to 2018. Spatial data were processed in GIS to determine the changes in sinuosity, centreline migration rates, and extent of erosion, and deposition of sediment. The maximum river shift was obtained as 800 to 1600 m and the minimum river shift varied from 6 to 70 m. With a sinuosity ratio for the whole reach of the river of 1.45, the Kankai river is considered a sinuous river and needs river training works at the erosion sites.

Keywords: Kankai river; channel planform dynamics; GIS; sinuosity index.

INTRODUCTION

When water flows downhill, it inherently contains energy which plays a greater role in landform evolution. The force of water erodes the soil and rock particles of the channel and transport them from one place to another. When water force becomes less effective, deposition takes place along its path. The shape of rivers and streams are affected by the process of erosion, deposition, and sediment transport mechanism. Due to erosion and sedimentation in the path of the river stream, the discharge, bed slope, flow depth and path, cross-section of the river change with time. In a river, erosion and deposition of channel beds and banks are important parameters for the study of fluvial geomorphology. Alluvial rivers are very dynamic due to which channel shape and flow pattern change rapidly. There are mainly three basic channel patterns that are identified in alluvial plain such as (1) Straight, (2) Meandering, and (3) Braided. The straight and meandering pattern of the river is measured by sinuosity. The sinuosity describes how the stream adjusts the slope of the channel with the slope of its valley. The braiding pattern of the river is characterized by many different ways among which the most common is the plain form index. On the outer part of the meander, where the bend is present, velocity is the highest at that place which causes erosion.

Such a study is not new but should be carried out for each river at a regular interval. Magner and Steffen (2000) investigated the stream morphological response to climate and land use in the Minnesota river basin in the United States. The larger drainage areas (> 100 square miles) appeared to have integrated the cumulative drainage

impact. Many studies have been conducted to determine the change in river course using GIS and remote sensing (Surian and Rinaldi, 2003; Magritskii et al., 2003; Ahmed et al., 2007; Fasolato et al., 2010; Blum et al., 2010; Lichter et al., 2010; Sumeghy and Kiss, 2012; Adityawan et al., 2014; Dai et al., 2015; Pregun, 2016; Cencetti et al., 2017; De Jong et al., 2018; Singh et al., 2018). The presence of geological structures like faults, folds and subsidence rates also affect the meandering pattern of rivers (Dar et al., 2019). For example, the Ebro river in Spain has shifted 7 km during the past 80 years owing to bank erosion (Ollero, 2010). Flodl and Hauer (2019) studied morphological regime conditions of bi-modal grain size rivers challenges and new insights for freshwater pearl mussel habitats in the Bohemian Massif at the location of Central Europe in Germany. With increasing flow velocities, the deposition of fine material was prevented, however, even larger grain sizes become mobile, and the danger of drift increases. Lin et al. (2020) investigated the decadal changes in the sediment budget and morphology in the tidal reach of the Yangtze River in China. The increase in the annual eroded mass of sediment in the reach was attributed to the decrease in the input annual sediment flux and the increase in the input annual water flux.

The Kankai River is one of the classes IIb type rainfed perennial river of eastern Nepal and originates from Nepal and carries a large quantum of silt. The river over floods during the monsoon and can overflow through the thousands of hectares of fertile plains of Jhapa in Nepal. Erosion of banks and inundation during rains caused problems for the residents of its catchment area. The protection works are being carried out with the assistance of the Government of India. The efficiency and workability of different water resource projects like irrigation, hydropower and domestic water supply projects are badly affected by the sediment problems (Raghubanshi, 2007). A change in the trend of water availability is expected to affect the future economy of the region critically. Previously, numerous studies have focused on the impacts of climate change on hydrological and other perspectives (Babel et al., 2013). Champak et al. (2020) evaluated the hydro-climatic variability and its possible impacts on groundwater in the Kankai River Basin in Eastern Nepal. The results were validated with the social survey data on climate change and the variability in spring discharge. It was observed that the groundwater in the region has been influenced by the changing climate and the condition may further be exaggerated by reduced recharge and increased evapotranspiration. Not much information is available on the river Kankai but recently a bridge collapsed and was washed away in Goabari village of Bihar's Kishanganj district due to a rise in the water levels of the Kankai river.

To analyze and visualize the morphological characteristics and changes in the river, remote sensing and GIS technique are of great help. This technique can help in understanding the effect of morphological changes in man-made and natural features. The river originates in Nepal and passes through the Kishanganj district in Bihar. The river causes to increase in the possibility of flooding. Change of course of a river is responsible for erosion and deposition and every year people are migrants to other places and many lands are wasted. In the present study, an attempt was made to study the shifting of river courses and changes in its plan for the years 2000, 2006, 2012, and 2018 concerning the year 2018 at each 2 km interval. The main aim of the study is to measure the erosion and accretion in the river using geospatial techniques over a long period (2006-2018). The bank erosion or deposition in terms of erosion length and erosion area at every 30 km interval were also investigated.

MATERIAL AND METHODS

Study Area Description

Kankai river basin is located in the eastern part of Nepal bordering India on two sides. It lies between 26.46° - 27.10° N and 87.819° - 88.00° E. The catchment area of the Kankai River basin is 1284 km^2 . The upper part of the Kankai basin spreads in a hilly region with steep slopes while the lowermost part of the basin lies in flat plains with mild slopes. The entire basin area is dominated by forest and cropland. Kankai river is located in the eastern part of Bihar and it enters Tegharia of Kishanganj district and finally meets the Mahananda river. It is an entirely landlocked district of Bihar and very rich in water resources, both the ground and the surface water resource. The location map of the study area is shown in Fig. 1.

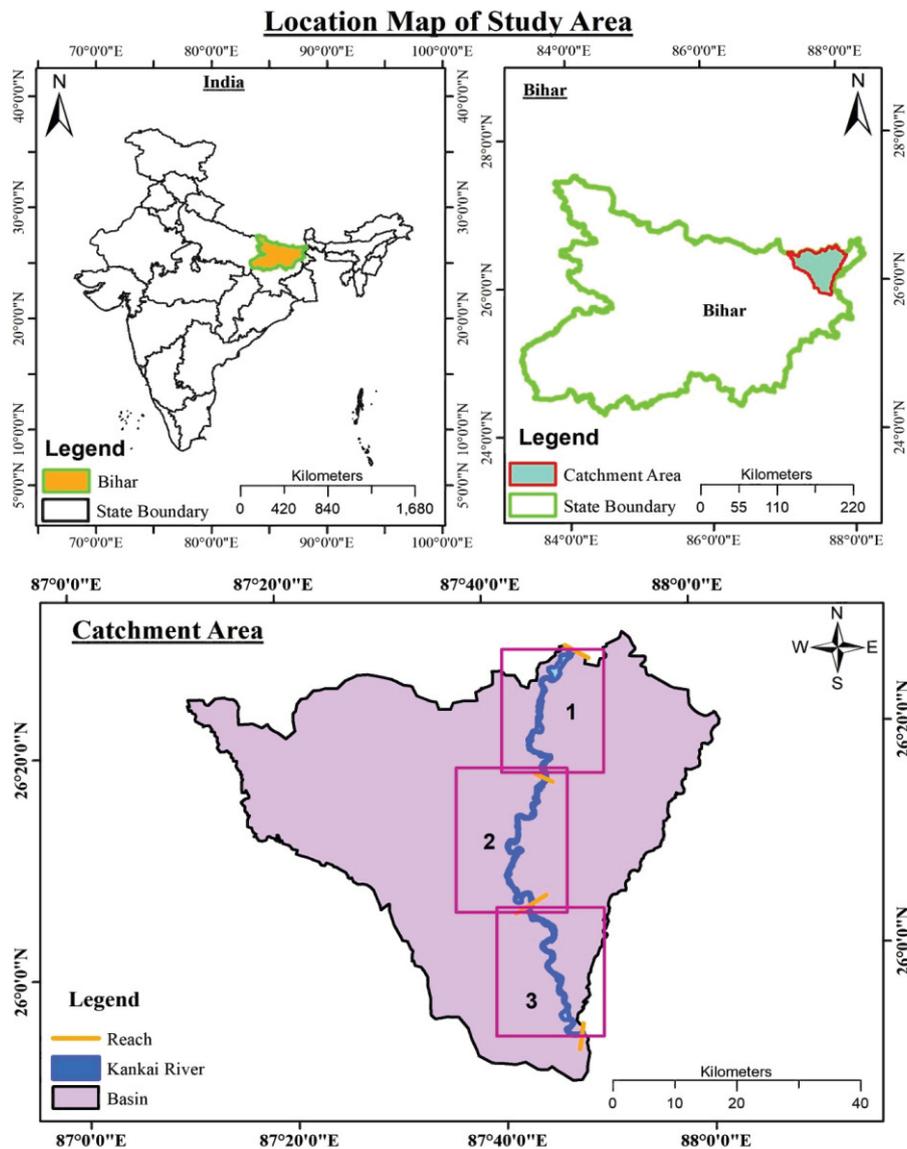


Fig. 1. Location map of study area

Methodology

With the help of temporal satellite imageries, morphometric changes of the river were studied over a specific period. Based on the spectral signature of the objects, different band ratio classifies the image in different unique colours. Arc-GIS 10.3 was used for the preparation of various spatial inputs. Satellite data LISS-I, LISS-II, LISS-III, and Landsat OLI sensors for different dates relevant to 2000, 2006, 2012, and 2018 were obtained from USGS (Table 1). All the layers were processed in a layer stack which yielded a single multi-band image. The individual images related to the study area were processed, and mosaic and colour balancing to generate a colour balanced single image, which covers the full basin of the river course, were performed. Bank lines of the year 2000, 2006, 2012, and 2018 were digitized from satellite imageries and all the digital maps were geo-referenced with the same projection in UTM 1984 zone.

Table 1. Details of remote sensing digital Data for study shifting of the river

Data	Data sources	Year	Resolution
IRS LISS-I	USGS Website	2000	72.50 m
IRS LISS-II	USGS Website	2006	36.25 m
IRS LISS-III	USGS Website	2012	23.50 m
Landsat OLI	USGS Website	2018	30 m

Determination of Bankline Shifting, Erosion, and Deposition

The displacement of river bank material is caused by hydraulic action which is related to near-bank velocity conditions (Odgaard 1987; Hasegawa 1989). A river tries to maintain its course unless it is disturbed by diastrophic movements, natural calamities like floods, landslides, or human activity. A change in discharge, sediment load size, and slopes may disturb the river's equilibrium state, resulting in aggradations or degradation of the river. The total chainage of the river was subdivided into 3 reaches of 30 km length each (Fig. 2). Reach 1 starts from the Singhimari and ends at Laucha in Kishanganj district, Bihar. In this reach, flow is fast due to the high elevation and therefore, high erosion is expected. The river has deviated into 2 streams at the Kanchanbari Istamarar. Reach 2 starts from the Tegharia located at 87° 44'17.09" E and 26° 3'43.02" N, and passes different locations such as Satmari, Bochagari, Nisndara, Khutti, Ghosainpur, Majkuri, Kesarra, Kabaia, Balia, Nau Nankar Sirar, Siswa, Asiani, and finally reach the end location at Ghordhup. The Reach 3 starts from Bardiha at geographically located 87° 47'49.63" E and 25° 52'25.89" N and finally reach the Benibari. The area is considered as eroded where the bankline goes to the outer side of the river with respect to the previous year bankline and it has been denoted by the (-) sign. The area is considered as deposition where the bankline goes to the inner side of the river concerning the previous year bankline and it is denoted by (+) sign (Fig. 3). Critical zones were identified based on the maximum erosion of a particular location. A possible sand mining area was identified based on maximum deposition year by year in river reaches.

Sinuosity Index

The sinuosity index of a river is defined as a ratio of the length of the river along the thalweg line to the actual distance between the start and endpoints of the river (Crosato, 2008). The thalweg line depends upon the hydrography of the river (Eziashi, 1999). The sinuosity index later was modified by Friend and Sinha (1993) and can be estimated by the ratio of the centerline length of a major channel to the horizontal distance between the start and endpoints in the analysed reach of the river. Rivers with a sinuosity index of less than 1.5 are referred to as sinuous, whereas rivers with a sinuosity index greater than 1.5 are termed meandering (Singh, 2005). Friend and Sinha (1993) defined the sinuosity parameter as given hereunder:

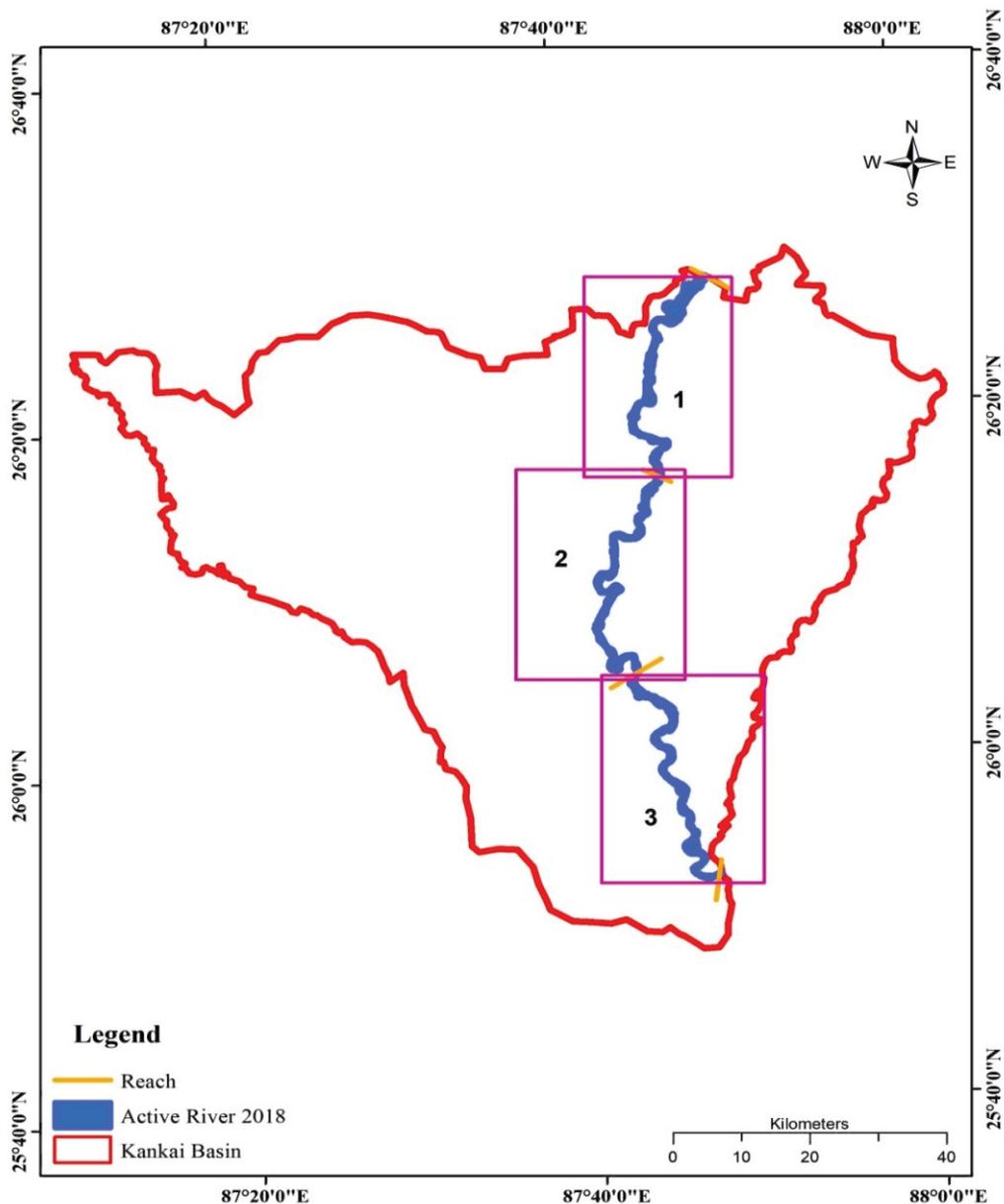


Fig. 2. Division of Kankai river into 3 reaches

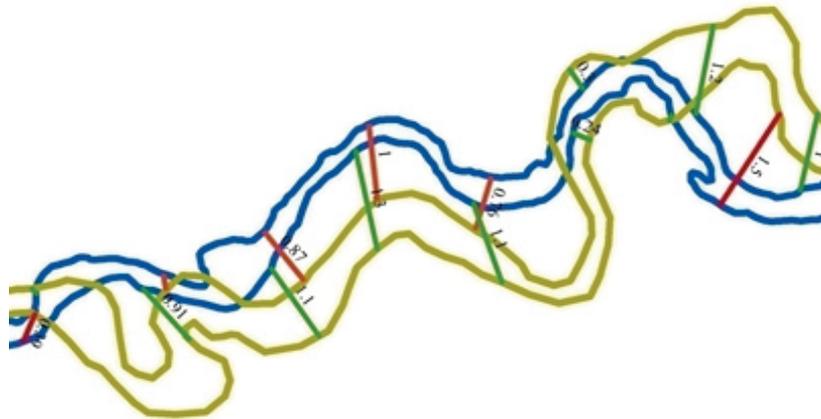


Fig. 3. Determination of bankline shifting

$$P = \frac{L_{c \max}}{L_R} \quad (1)$$

Where, $L_{c \max}$ is the observed path of a river and L_R is the straight-line distance. It is a dimensionless quantity and calculated as actual path length divided by the shortest path length of the curve. It varies from 1 to infinity. The river, having a sinuosity ratio of less than 1.5, refers to straight or sinuous and the river is meandering having a sinuosity ratio of 1.5 or above. Critical zones are identified based on the maximum erosion of a particular location. Channel migration is the geo-morphological process of lateral movement of the alluvial river across the floodplain. This process is a combination of erosion and deposition. Channel change is largely affected by sediment transport. As the streamflow enters the river, the centrifugal force developed by the bend creates helicoidal flow, a corkscrew-like pattern of flow, which causes the hydraulic action on the opposing bank.

RESULTS AND DISCUSSION

Sinuosity Index

Sinuosity index determined for all three reaches are shown in Tables 2, 3, 4, and 5 for the years 2000, 2006, 2012, and 2018. The sinuosity index in reach 3 is relatively higher than the other reaches. As the average value of the sinuosity ratio for the whole reach of the river is 1.45, therefore, the Kankai river shall be considered as the sinuous river as per the classification laid by Leopold and Wolman (1957).

Change Detection in Bankline in Different Reach

A drastic change has been observed on the river in this reach at a different downstream location at 2 km intervals. We considered the year 2018 as the base year. The maximum channel changes of 1836.21 m in this reach were observed for the year 2000 at a distance of 8 km at Lohargarha and the minimum centreline shifted of 7.78 m occurred at a distance of 2 km from the source at Singhimari. In 2006, the maximum channel changes of 1310 m were noted at a distance of 28 km from the source at the location of Bansbari and minimum centreline shifted was

observed as 67.79 m occurred at a distance of 8 km at Lohargarha. Similarly, for the year 2012, the maximum centerline shift was found to be 558 m at Bhelagurhi, a place 16 km away from the source, and the minimum centerline shift was noted as 6.9 m at Dargah Kanchanbari. The initial and final view of the Kankai river bank lines is shown in Fig. 4 and Fig. 5. In reach 2, some changes were observed on the river in this reach at the different downstream locations of 2 km intervals. The maximum channel changes of 832 m were observed in 2000 at a distance of 50 km from the source and the minimum centreline was shifted by 24.13 m at a distance of 42 km at the location of Singhimari. In 2006, the maximum change in channel path was observed as 773.40 m at a distance of 58 km from the source at the location of Sirar, and the minimum centreline shift was noted as 51.94 m at 60 km from the source. For the year 2012, the maximum centerline was shifted (130.8 m) at Kabaia at a distance of 52 km and the minimum centerline shift (2.75 m) was found at Kesarra (Fig. 6 and 7). In reach 3, shifting of the right bank due to erosion is less than deposition in left bank indicates the shrinking of river bed near Mangalpur at a distance of 72 km from source and channel shift towards the west direction (Fig. 8 and 9).

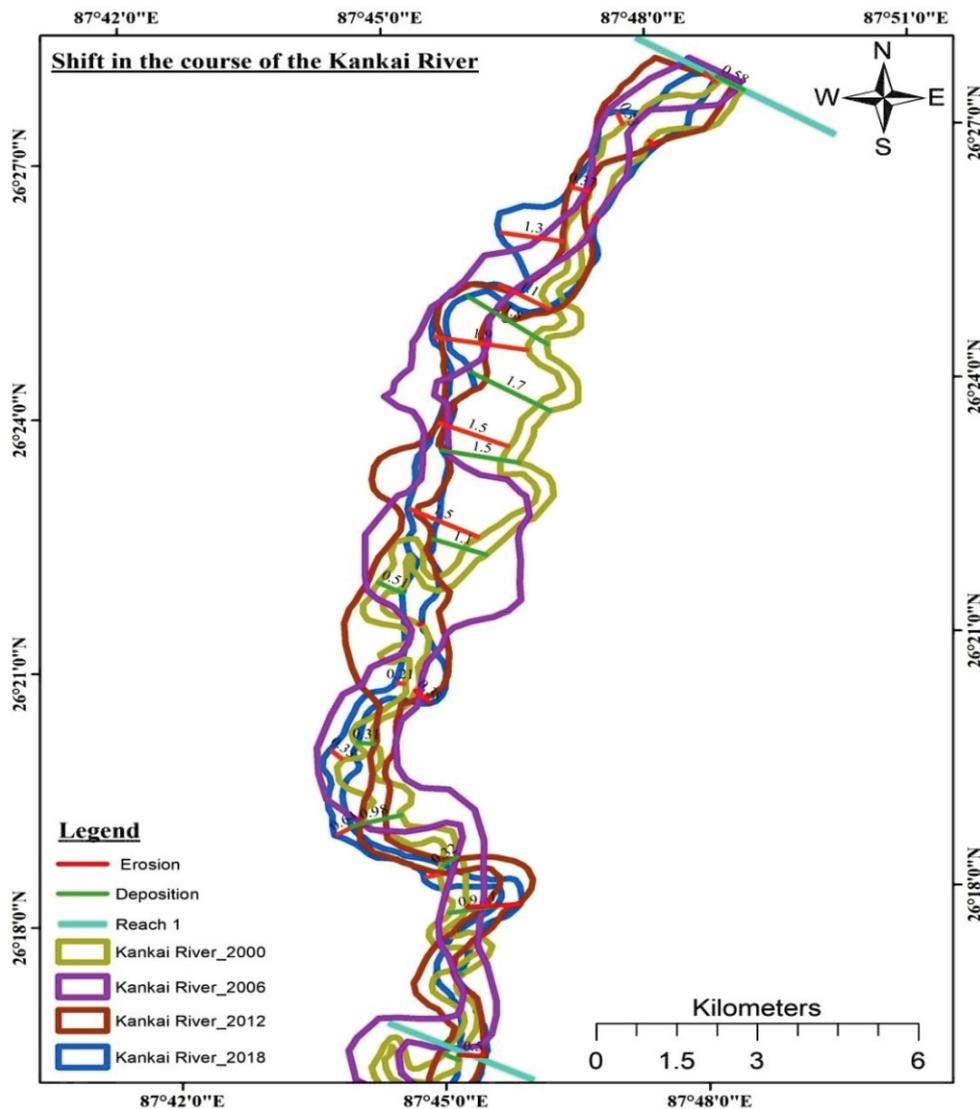


Fig. 4. Shift in the course of the Kankai river in reach 1

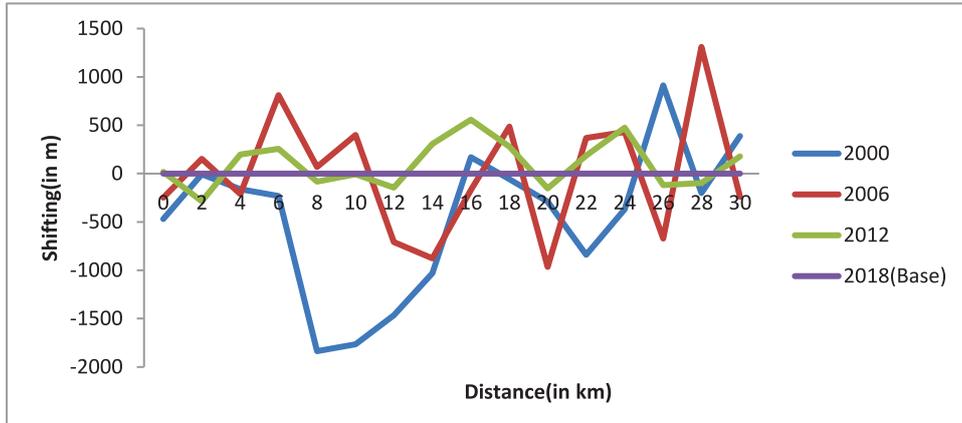


Fig. 5. River centre line shifting in reach 1

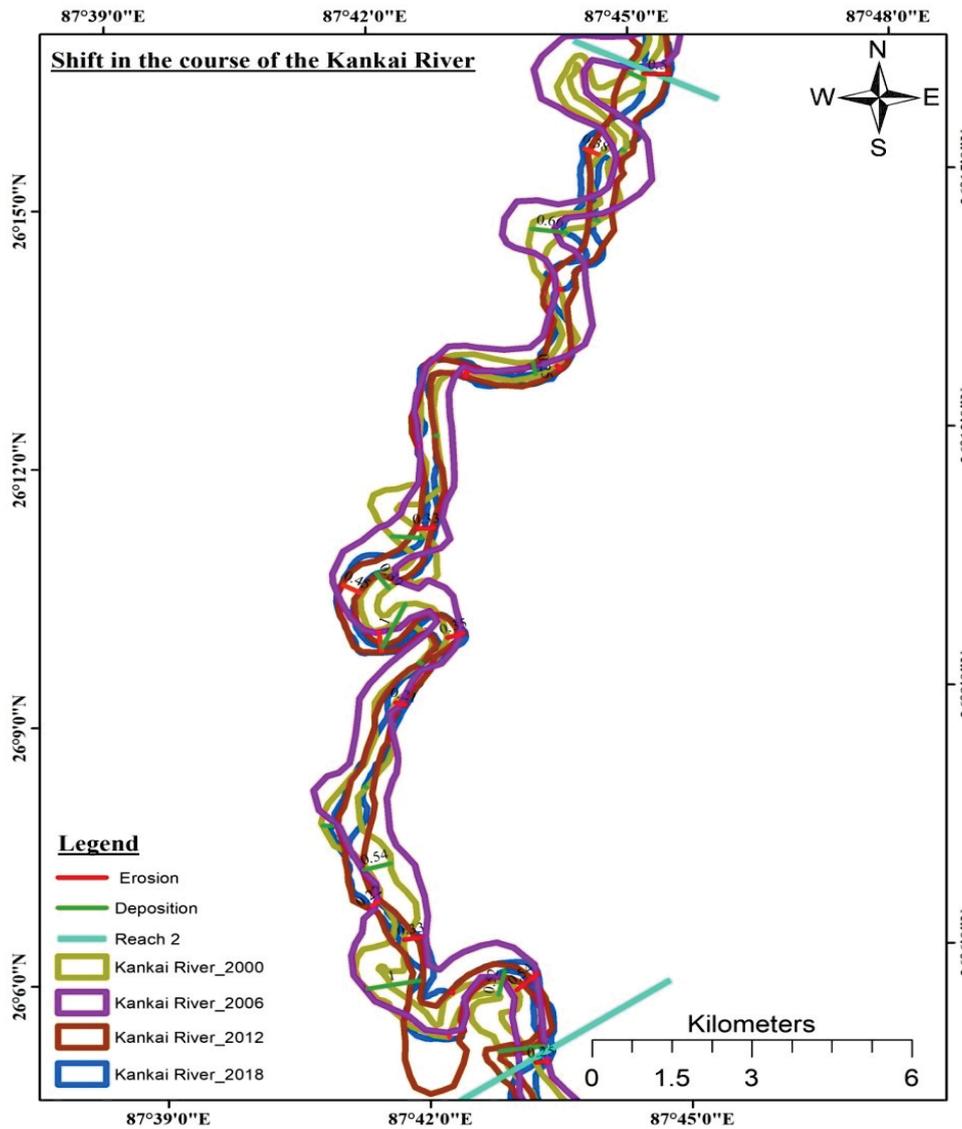


Fig. 6. Shift in the course of the Kankai river at reach 2

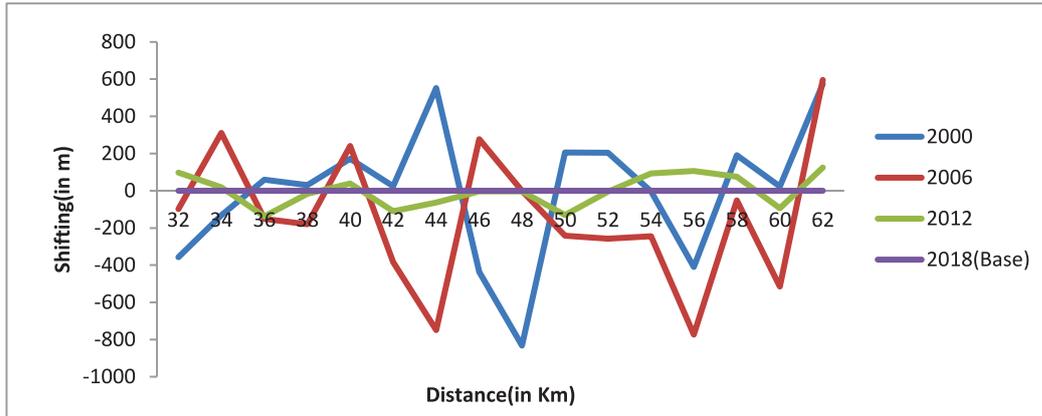


Fig. 7. River centre line shifting in reach 2

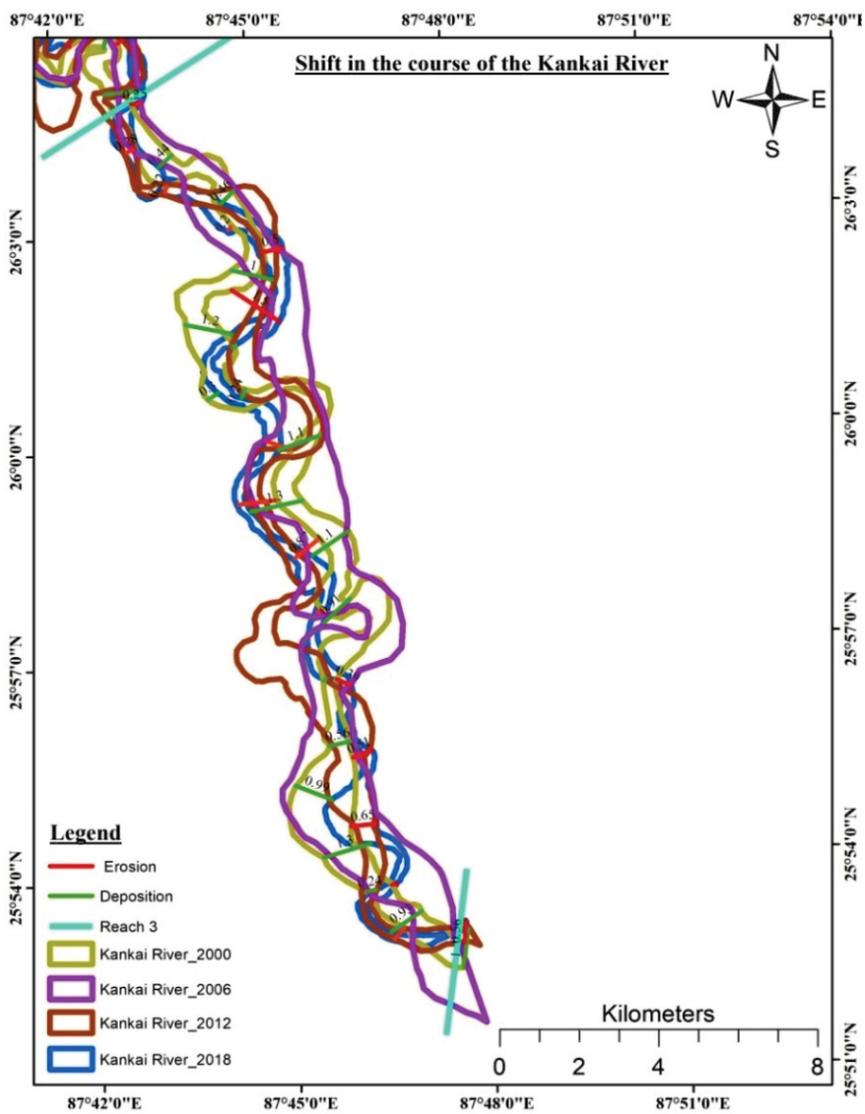


Fig. 8. Shift in the course of the Kankai river at reach 3

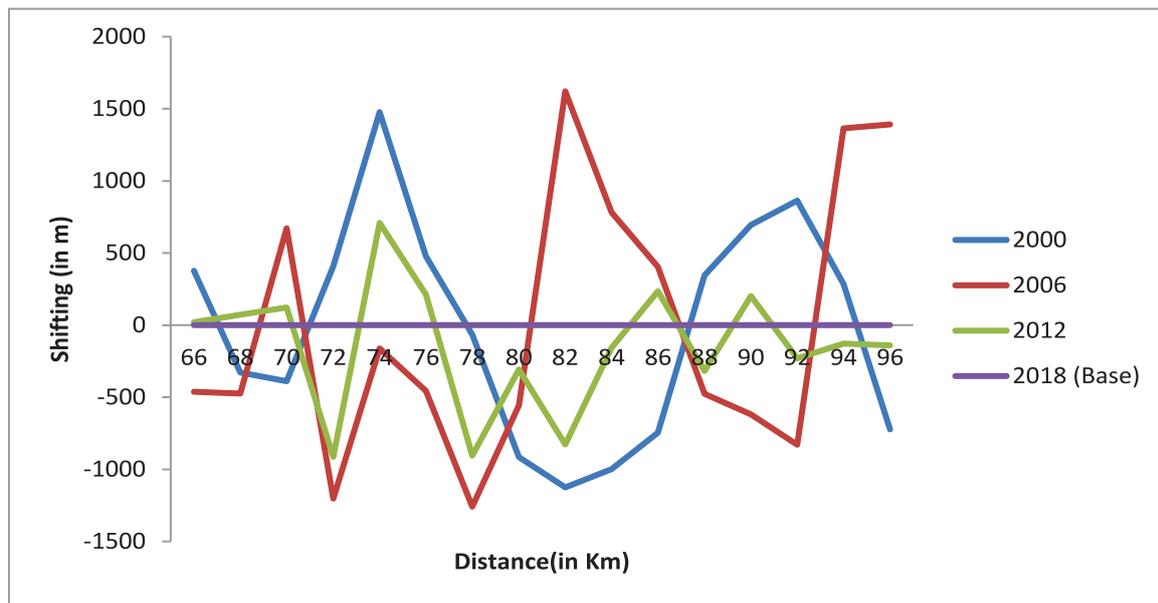


Fig. 9. River centre line shifting in reach 3

Erosion and Deposition

The area-wise erosion and deposition both in the left and right bank of the Kankai river along the reaches were determined. The left bank changes its state of deposition to erosion for the initial distance of 10 km and then the rate of deposition increased up to 18 km. The right bank was observed to be shifted inward indicating more deposition rate. In reach-1, both the left and right banks showed erosion. At Korobari, the right bank showed more deposition. Maximum erosion was found at Kanchanbari and the last location of reach-1 showed deposition. In reach-2, at Tegharia, the left bank and right bank shifted maximum and after 2 km from the source, the river showed minimum shifting. Kesarra was found to have maximum erosion due to the removal of the sediments from those areas. In reach-3, shifting in all places was found maximum at the distance of 74 km at Mangalpur. The total deposition was found higher in reach 2 and 3, however, erosion was the dominant hydrological process in reach 1. This may be attributed to the higher and steep elevation in reach 1. River training works may be required to be undertaken in reach 1.

CONCLUSIONS

Kankai River faces frequent planform changes in its lower reaches due to floods. The topography and the floods are powerful agents to bring changes in the river morphology. This paper presents a channel planform dynamic of Kankai river from 2000 to 2018. The maximum river shifting was observed as 1836.21 m at Lohargarha in the year 2000 and the minimum river shift was found to be 6.9 m at Dargah Kanchanbari in the year 2012 in reach 1. In reach 2, the maximum river shifting is 832 m at Kesarra showed the maximum shift in river course as 832 m in the year 2000 and the minimum river shift was noted as 8.27 m at Kesarra in the year 2012. Similarly, in reach 3, the maximum river shift took place in 2006 and the minimum river shift was observed as 68.66 m in 2012. As the

average value of the sinuosity ratio for the whole reach of the river is 1.45, therefore, the Kankai river shall be considered as a sinuous river. The outcomes of this study shall form a base in river training works, and understanding and predicting the future dynamics of the rivers. Future effects of erosion and deposition may be prevented by adapting scientific bank protection measures and efficient planning of the adjacent settlements. The identification, nature and trend of the geological structures, like faults, folds and geology supported with detailed field validation should form the future course of the work on the topic. However, spatial as well as positional accuracy varies with the different data sets used in this study.

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