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Analysis of Sinuosity and Temporal Shifting of Channel Belt of the Kaljani River in the Foothills of the Eastern Himalaya, Cooch Behar, West Bengal, India

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Abstract : *Changing nature of channel pattern and lateral shifting of rivers are common phenomena of the foothill of the Eastern Himalayas. The present study mainly concentrated on the assessment of changing nature of channel form and shifting of bank lines of the Kaljani River on a large temporal scale with advanced geospatial methods. The study also focussed on vulnerability assessment of the villages to the meander belt zone of Kaljani River for the period of 57 years (1962-2019). For the analysis of sinuous nature and lateral shift of the Kaljani river Sinuosity Index and Transect Method has been applied. Bank lines were delineated on toposheet and Landsat imageries and with the help of 12 cross-sections and after that lateral shift, migration rate and direction of the shift were also measured. From the result it is seen that increasing meander bend the lateral shift has an impact on the surrounding villages of Cooch Behar-II and Tufanganj-I blocks of Cooch Behar District.*

Key words: *Sinuosity Index, Lateral shifting, Meander belt, River Presence Frequency Approach.*

Introduction

Meandering river channels frequently shift their bank lines within their valleys confined within the vast alluvial flood plain of the Eastern Himalayas. They are naturally prone to shifting in response to variation of water and sediment discharge, tectonic instability, bank erosion, flood occurrences and human interferences (Lane and Richards 1997, Rinaldi 2003, Li et. al. 2007, Bierman and Montgomery 2014, Ghosh and Mistri 2015). The significance of quantification of changing nature of meandering rivers is not only limited in the arena of geomorphologists, soil scientists and hydrologists but also important for the environment planners to take precautions for the long-term river protection or developmental strategies (Dhar and Nandargi, 2000). The sinuous nature of the rivers, located in the foothills of The Eastern Himalaya, is also an important factor of channel dynamicity, which was assessed with the help of the Sinuosity Index. Friedkin (1945),

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Leopold and Wolman (1957), Schumm (1963), Brice (1964), Mueller (1968), and Friend and Sinha (1993) have given and refurbished the definition of Sinuosity Index. Application of multispectral satellite data of different time frames is a major breakthrough for identifying channel dynamics and bank line shift of the rivers which are now being focussed by several researchers (Yang et. al. 1999, Pati et. al. 2008, Sarma and Acharjee 2012, Gogoi and Goswami 2013, Chakraborty and Mukhopadhyay 2015, Dhari et. al. 2015, Oprah et. al. 2018, Mandal et.al 2018).

The Kaljani River after originating from Bhutan hills enters into the plain areas at Alipurduar District and flows through Alipurduar and Cooch Behar District. The reduced gradient of the river causes a sudden drop of huge sediments and flood deluge which ultimately results in a meandering process and consequent shifting of the river. Lateral shifting of the Kaljani river has resulted in erosion and deposition of sediment load which have far reaching impact on the agriculture-dependent livelihoods and land use patterns of the villages situated by the side of the river bank. Hence analysis of the vulnerable villages is also an important aspect of geomorphology (Dey and Mandal 2019, Mukherjee and Pal 2018, Thakur et. al. 2012). Thus appraisal of shifting behaviour of Kaljani River should be conducted to check those impacts on the economy of the district and better planning to prevent flood occurrences.

The present study aims to assess the changing sinuous nature of the Kaljani River and to quantify the bank lines shift of the river for the last 57 years. It will also show the affected villages of Cooch Behar district due to the oscillation of channel belts in different study periods.

Study Area

The Kaljani River is an important tributary of the Torsa River, which is a part of the lower Brahmaputra River system. It originates from the Dungenia Hill of Bhutan and debouches in the Torsa River near Deocharai village of Cooch Behar District, India. The reach of the Kaljani River under study extends from $89°34^{1}$ East to $89°34^{1}55^{11}$ East longitude and $26°16°55^{11}$ North to $26° 24^{1}46^{11}$ North latitude in Cooch Behar District of West Bengal (Fig. 1). The area belongs to the Tal region of eastern India and relief varies between 100- 60 Metres. The river stretch has a length of 27 Km and flows almost north to south in a sinuous pattern. The area is featured by numerous oxbow lakes, swamps, paleochannels, and meanders.

Database and Methodology

For depicting historical changes of the sinuous nature of the Kaljani River, the toposheet of US Army corps and LANDSAT imageries of USGS was downloaded, compared and analysed. The toposheet was geo-referenced and converted into a digital form with UTM projection with the WGS 84 coordinate system. Thereafter the river was digitized and this was taken as the base year map. LANDSAT imageries were downloaded for the years (1992, 2007 and 2019) from the website of USGS Earth Explorer and processed. The next step was digitization and overlain of the active channel, secondary channel and their bank lines. The materials used for the study are enlisted in Table 1.

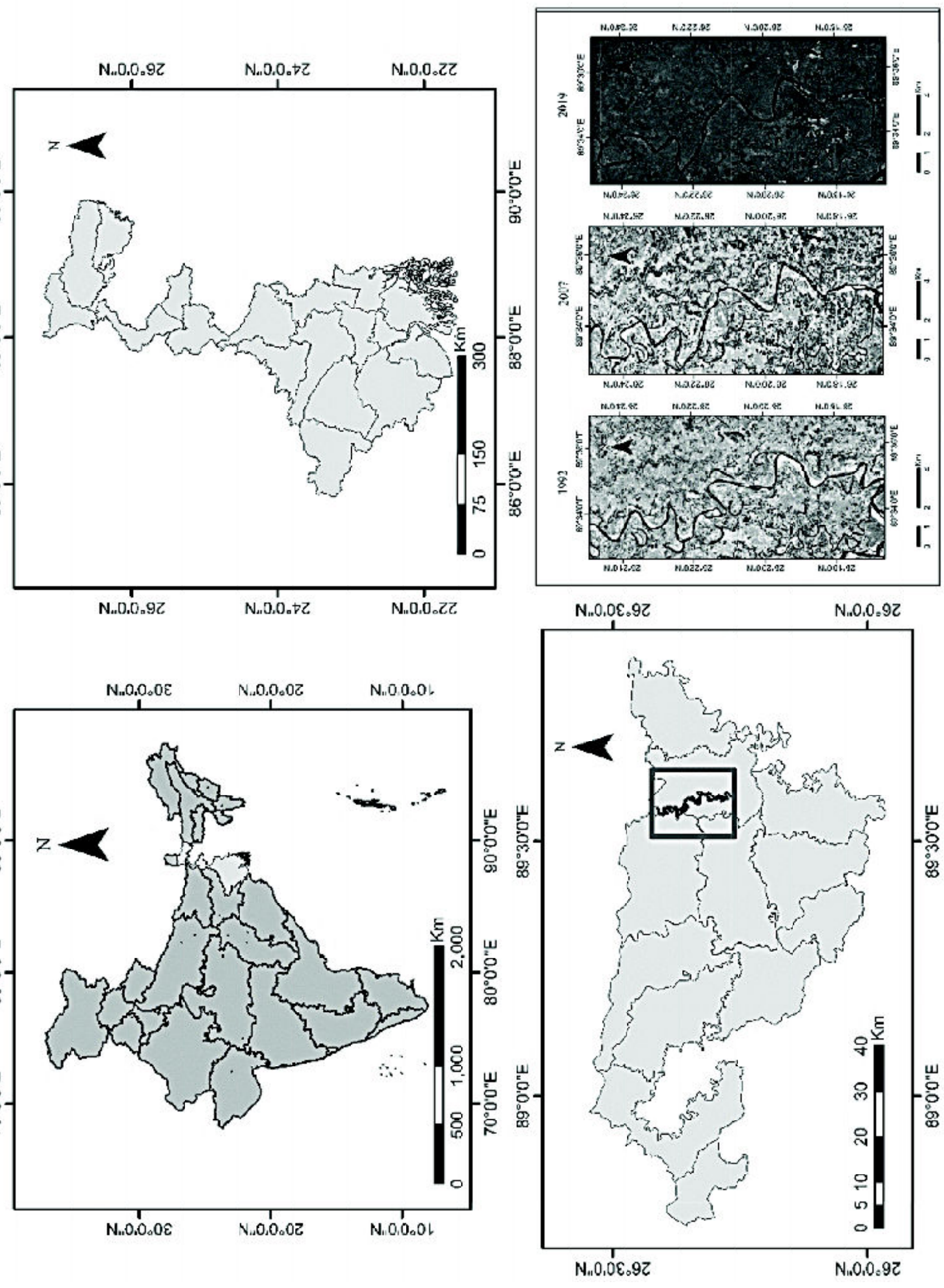

Fig.1: Location Map and flood plain area of the Kaljani River in different years

Source: Prepared from Landsat images

Table 1: The details of the Geospatial data used in the study

Data type	Satellite sensor/map no.	Survey year/ Acquisition date	Sources	Path/row	Scale/spatial resolution
Toposheet	G-45 L	1962	US Army corps		1:250000
LANDSAT 5	MSS	08/03/1992	USGS Earth Explorer	138/42	30 Metres
LANDSAT 5	MSS	18/03/2007	USGS Earth Explorer	138/42	30 Metres
LANDSAT 8	OLI/TIROS	20/04/2019	USGS Earth Explorer	138/42	30 Metres

Channel Sinuosity

To calculate the Sinuosity Index for different segments of the river mid-channel length and overall channel belt length were measured with the help of Arc GIS 10.3.1. from toposheet and LANDSAT imageries, after that Sinuosity Index (P), proposed by Friend and Sinha (1993) was applied [Eq.1]

$$P= L_{cmax}/ L_R$$

Where, P= sinuosity index; L_{cmax}= length of the midline of single-channel or midline of the widest channel of the reach; L_R= overall length of that reach.

After calculating the Sinuosity Index for every year, classification of the channel was done according to the scheme of Rust (1977).

Table 2: Classification of channel pattern (B.R. Rust, 1977)

Channel classification	Single-channel	Multiple channels
1. Low sinuosity (<1.5)	Straight	Braided
2. High sinuosity (>1.5)	meandering	Anastomosing

Also, for calculating the Sinuosity index for overall river reach, the method of S.A. Schumm (1977) has been applied-

Sinuosity Index (SI)= O_L/E_L

Where, O_L is the observed path of a river and E_L is the expected straight path of that river.

Quantification of Channel Shifting

Channel shifting can be quantified using two methods (Rapp and Abbe 2003), they are –

1. Polygon and 2. Transects Method

For the present study, the Transects Method has been applied. This method consists of the determination of base year and identification of the active channel for that year; division of the floodplain into transects which are equidistant; overlaying of bank lines of active channels of different years and flood plain transects and measurement of migration distance and migration rate from that overlay.

Vulnerability of the Villages to Channel Shifting

River Presence Frequency Approach (RPFA) has been applied to show the villages which are vulnerable to the past incident of channel shifting. This method is based on the number of channel appearances on the villages and the total number of the year (Mukherjee and Pal 2017, Dey and Mandal 2018) [Eq. 2]

$$RPFA = \Sigma\ RPn/N$$

RPn is the number of presence of the river and N is the total number of years considered for the study.

Results and Discussion

Change in the Sinuosity from 1962-2019

In 1962, the calculated Sinuosity Index (SI) for the Kaljani river was 1.68 (Table 3) indicating that the river was meandering at that time. In 1992, the Sinuosity Index increased to 1.82, and in some segments Sinuosity Index (P) attained a value of more than 2. After 15 years from 1992, the Sinuosity Index decreased to 1.79, due to bifurcating of the single-channel river into multiple channels by point bars in some segments, although from the overall viewpoint channel remained meandering. In the next 12 years (2007-2019), again the Sinuosity Index decreases to 1.76 but from segment-wise study it is clear that in the upper portion the Sinuosity Index is as high as 2.

Table 3: Sinuosity Index according to Schumm

Year	Sinuosity Index
1962	1.68
1992	1.82
2007	1.79
2019	1.76

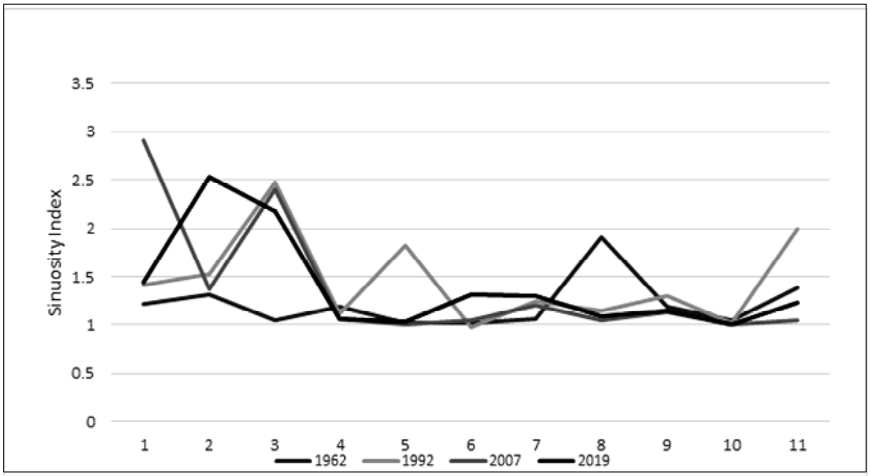

Fig.2: Sinuosity Index of different segments for Kaljani River (Source: Prepared from Landsat images)

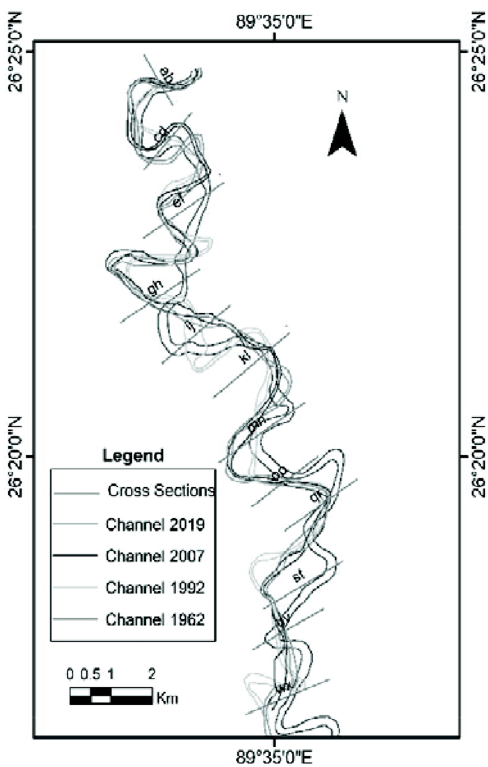

Fig.3 Shifting of the Kaljani River (1962-2019) with cross-sections (Source: Prepared from Landsat images)

Whereas near the confluence point with the Torsa River it is as low as 1, which is indicative of a straight channel pattern.

Lateral Shifting of Kaljani River (1962-2019)

For analysing the spatiotemporal lateral shift of the Kaljani River, 12 cross-sections have been drawn to cover the entire reach of the aforesaid river (Fig. 3). The active channel in 1962 was taken as the base year and this channel was overlaid on channels of different years (1992, 2007, and 2019). The study period was divided into three-time spans, these are – **1.** The first phase (1962-1992) consisted of 30 years, **2.** The second phase (1962-2007) covered 45 years and **3.** The last phase (1962-2019) comprised 57 years. Thereafter the distance of lateral shift and migration rates were calculated on each cross-section (Fig. 4 and Table 4).

In the first phase i.e. 1962 to 1992, maximum shifting can be observed on ef, mn, and st cross-sections. After measuring migration distances on every cross-section, it is evident that in that period the river shifted westwards. The average migration for this period was 1.01 Km. and the average migration rate was 16.88 metres/year.

The second phase indicates the varied nature of river shifting, because on ef, ij, kl, mn and uv cross-sections river shifted migrated eastward, whereas in other cross-sections river kept its previous westward trend. ef, mn, and st cross-sections faced a higher amount of lateral migration in this phase. The average migration rate for the period was 14.03 metres/year.

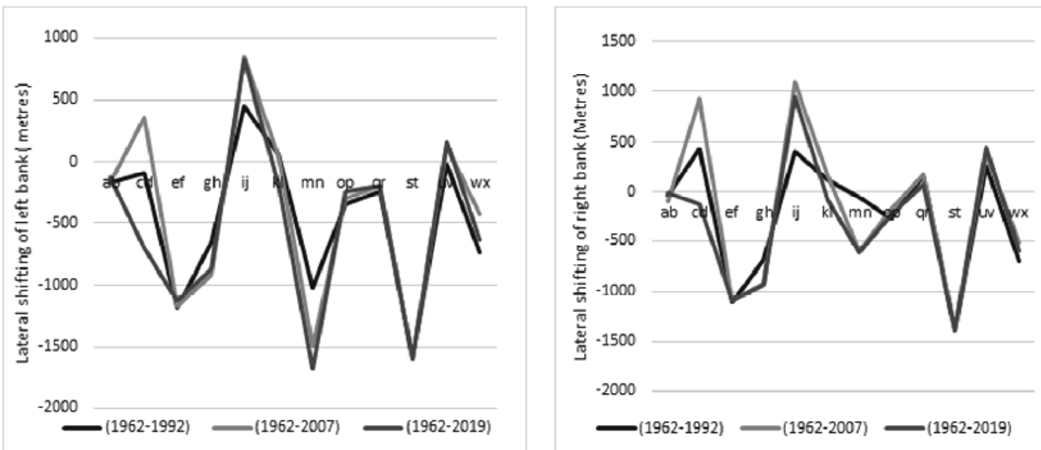

Fig. 4: Lateral shift of left and right bank of the Kaljani River (Source: Calculated and prepared from Landsat images)

In the third or last phase, the amount of average shift was 1.26 km and the average migration rate was 10.88 metres/year. Also, in this period, the river kept its westward migration trend except on ij and uv sections.

Lateral shifting was more consistent for the period of 1962 to 1992, whereas maximum CV was measured during 1962-2019 (Table 5). Both the second and third phases experienced the negative values of kurtosis which indicate the discrete uniform distribution of channel shifting. The values of Kurtosis show a platy-kurtic pattern. As the values of skewness are positive, they indicate the normal distribution of values in datasets. (Table 5)

Table 4: Migration rate for the Kaljani River

Cross Sections	Migration Rate (m/y)		
	1962-1992	1962-2007	1962-2019
ab	3.63	2.95	1.26
cd	8.59	14.33	7.36
ef	39.29	25.10	19.44
gh	22.08	20.28	15.69
ij	15.12	21.40	15.47
kl	2.91	2.24	2.37
mn	17.94	23.32	20.09
op	10.16	5.36	4.27
qr	6.61	4.16	2.39
st	49.44	33.14	26.15
uv	4.63	5.70	5.30
wx	23.96	10.33	10.88

Source: Calculated by author from Landsat images along the cross-lines

Table 5: Descriptive Statistics of lateral shift of the Kaljani River (1962-2019)

Time span	Average Shift (km)	Median	SD	CV	Kurtosis	Skewness
1962-1992	1.01	0.95	0.87	0.77	0.98	1.26
1962-2007	1.26	1.11	0.93	0.87	-1.13	0.44
1962-2019	1.24	1.04	0.95	0.90	-1.07	0.48

SD stands for Standard Deviation and CV for Co-efficient of variation

Source: Calculated by author

Delineation of Meander Belt and Vulnerability of villages

Channel belt means the areas where the river is active in different study periods. For delineating active channels of the Kaljani River, it was traced by drawing polygons on a GIS platform. The polygons were overlaid and merged to get the final meander belt. As channel migration has a significant impact on land use, the channel belt was delineated to identify the villages and Gram panchayat areas which were susceptible to lateral shift.

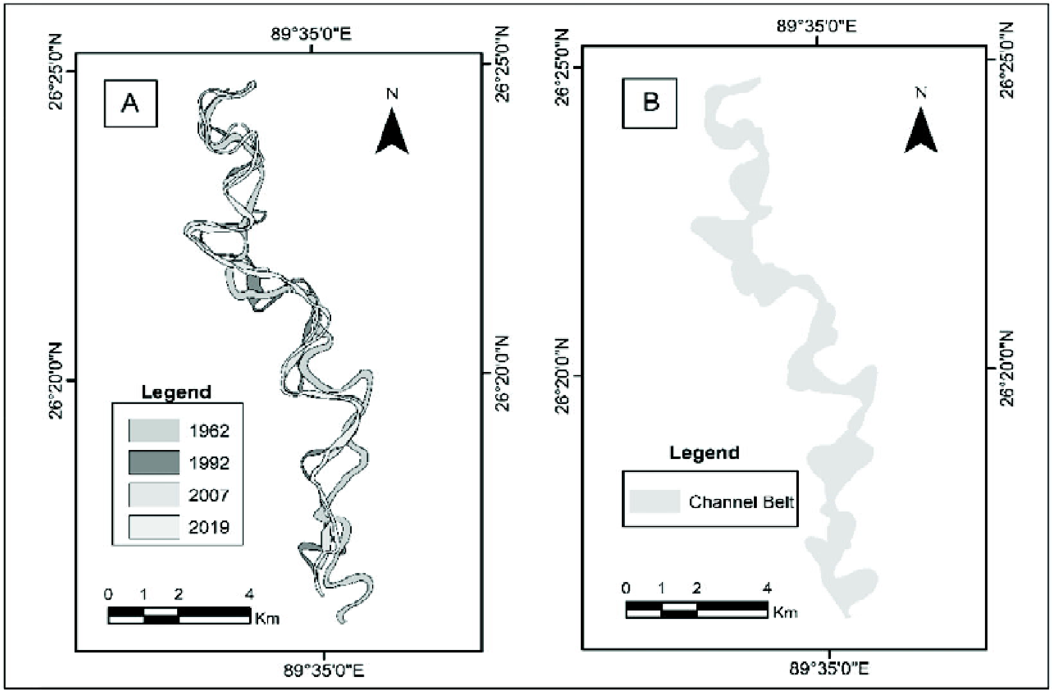

Fig. 5: A. Channel belts of the Kaljani River in different years and **B**. Meander belt of the Kaljani River (Source: Prepared from Landsat images)

According to the result of the RPFA method, 9 villages of Natabari-I and II, Chilakhana-I, 3 villages of Baneswar and Ambari Gram panchayats in Tufanganj-I and Cooch Behar-II blocks are very highly affected by the past change of channel position. Only one village of Maruganj Gram panchayat falls under the highly affected area. Balarampur-I and Maruganj gram panchayats have a moderate impact of lateral shifting, whereas Chilakhana-II-gram panchayat has far less impact on the Kaljani River.

Conclusion

The present study aimed to delineate active channel belts for the span of 57 years (1962-2019) of Kaljani River and also to demarcate vulnerable areas to past channel shifts. Toposheet and multi-temporal satellite data were used to measure channel shift and migration rate of the river.

In 1962, the river had a meandering channel pattern with a sinuosity index of 1.68 but in a later period, the river length of the meander bends was increased. As a result, the Sinuosity Index increased to 1.82 in 1992. In the later period, the value of the Sinuosity Index decreased slightly because of the straightening of some segments and in some places point bars divided the river

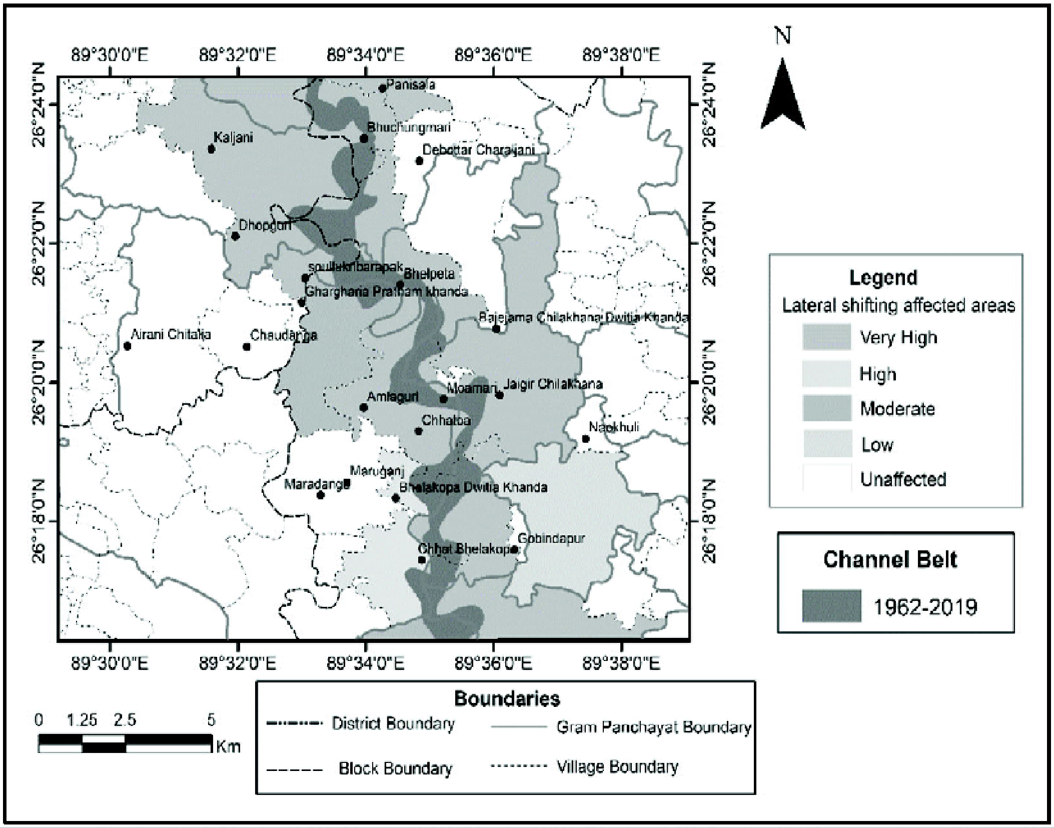

Fig. 6: Vulnerable villages to meander belt due to channel shifting during 1962-2019 (Source: Prepared by author from the cross-lines)

into multiple channels. From the analysis of the changing trend of Sinuosity Index, it can be assumed that in the next few years the river can bifurcate into many channels to get a braided form or simply take a straight path by chute formation.

In the three periods of analysis, the river kept the trend of westward shifting of both banks except in some portions of central and northern parts. Meander Belt Delineation and River Presence Frequency Approach were applied to estimate susceptible areas of channel migration. According to the results, 12 vulnerable villages of different gram panchayats were demarcated which will be fruitful for further planning of bank stabilization and flood protection strategies.

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