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Channel Shifting Behaviour and Delineation of Channel Migration Zone: A Study on Nagar River of West Bengal, India

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Abstract: ***Channel shifting is very common aspect of the flood plain environment all over the world. Bank erosion is the immediate effect of channel shifting. A rapid rate of river bank line shifting is found in the study area. The changing character of land use is being accentuated due to river bank erosion or channel shifting. In this study, the changes in Land use and Land Cover (LULC) driven by bank erosion were studied using P.S map and Google Earth map. The present study is mainly oriented towards the morphometric measurement of river through temporal changes during 1937, 2019 P.S map and Google Earth map data. In this paper an attempt has been made to get the nature of shifting, direction of shifting, sinuosity of the river channel has also been calculated.***

Keywords: Channel migration, sinuosity, river reach, meander belt

1. Introduction

The water resource is closely related to the lives, livelihoods and development of human civilization is a well known fact. Every living element can survive without food for some times, but no one can survive without water. With the rapid growth of human population societal dependency on fresh water has been increasing worldwide. The economic base of a country, to a large extent, depends on the availability of fresh water due to its use in the purpose of irrigation and industries (Postel and Richter, 2003). The river Nagar of Uttar Dinajpur district is one of the important sources of fresh water for irrigation and domestic purpose to its surrounding region (K. Rudra, 2016). The Nagar river is a trans- boundary river that enters the country through Panchagarh district. Flowing southwest and then southward. The river defines the boundary between India and Bangladesh in various places on its course. The course of Nagar river is highly susceptible to migration and exhibit channel change over time. Migration of river channel associated with bank erosion of river Nagar is a common phenomenon which creates land ownership puzzle in its surrounding region. River plays a vital role in the economy of its basin and surrounding area also. Channel migration is dynamic and natural processes which have an adverse impact livelihood.

The lateral migration of river channels within flood plain regions and the bank erosion due to lateral shifting is a natural process (Leopold; 1964) but the growing intervention of a human being has made it semi natural. Migration of river channel organized within a corridor or region (Richard; 2005), so it sometimes create problems for those who living in this region. Sometimes many people have lost their homes, agricultural land, infrastructure, their livelihoods due to river channel migration and erosion (Islam and Rashid, 2011; Mann, 2003,). Fluctuation of channel widths over time because of short term imbalance between the rate of cut bank erosion and the rate of point bar sediment accumulation are responsible for variation in migration rate (Nanson and Hickin, 1983). Lateral shift of river channel also depends on the resistivity of the banks (Nanson and Hickin, 1984). Anthropogenic activities or natural disturbances can accelerate the rate of migration. For example, the clearing vegetation in flood plain can accelerate the rate of migration (Randle, 2014). Due to rapid and unsegregated human intervention on natural process, most of natural processes is now became semi natural. Many rivers all over the world such as Ganga, India (Singh, 1996; Roy and Sinha, 2005), Kosi, India (Wells and Dorr, 1987) and so many other rivers shows spatio- temporal shifting of channel (Pati, 2008). One of the crucial fact of lateral channel migration is an erosion of floodplain material along one bank and deposition of sediment along the other bank exactly matched (Leopold, 1964). There are several scientific methods for examination of channel change and channel migration, such as sedimentology, botanical, historical source planimetric survey, repeated cross profiling and terrestrial Photogrammetry (Lawler, 1993). There are many approaches from which the important method is 1) empirical approach 2) examination of maps for various sequential periods, and 3) fundamental modelling approach (Briaud 2002).

2. Objectives

The main objectives are as follows

1) To identify the river reaches
2) To delineate Historical Channel Migration Zone (HCMZ)
3) To explain the nature and magnitude of channel migration of Nagar river in the study area.
4) To explain the land use pattern in channel migration area.

3. Location of Study Area

Nagar river flows northeast to southwest and join with the Mahananda river at Pirganj (25˚07'36"N and 88˚03'46"E). The study area, 4.45 sq. km. consists of three villages (Bhopla, Daluakhari and Dhauta) of the Karandighi C.D. Block of Uttar Dinajpur, West Bengal. The study area is extented from 25˚51'30"N Latitude and 88˚06'41"E Longitude to 25˚47'53"N Lat and 88˚02'36"E Long. The total length of the river in the study area is about 1.5 km. Today as Barind and also physiographically these area coming under the plain region.

The summer is characterized by high temperature (30-38˚C) and with a relatively less diurnal range of temperature. The Temperature starts increase from March and May is the hottest month. The monsoon season starts in June with the coming of south – west monsoons and continues till the middle of September. During this season the region received the maximum amount of rainfall. The maximum rainfall of this season is 350mm. October and the first half of November constitutes the retreating monsoon season. Small amount of rainfall happens due to North East Monsoon. The cold or winter season starts from December and extends up to end of February.

The study area is located in Garo- Rajmahal Gap. The region forms part of the Ganga-Brahmaputra delta comprising Quaternary sediments deposited by the Ganga–Brahmaputra river system. Geomorphologicaly the area comprises active flood plain, older flood plain. The region contains some of the oldest as well as youngest of quaternary sediments within the Teesta and Mahananda interfluves.

A maximum portion of study area developed by continuous over the spilling of Nagar river. All the sediments of surrounding region comes under the course of Nagar river. Therefore, the entire land composed with thick fertile silt. The High level of soil moisture support good economic crop cultivation. As the study area comes under the Barind region composed of older alluvium.

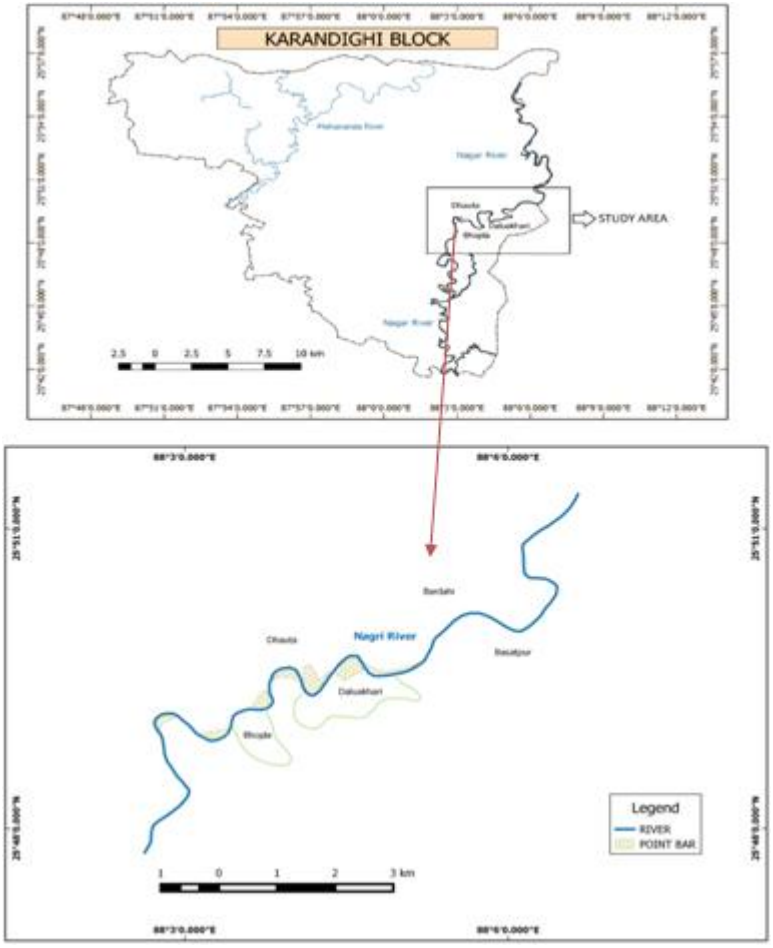


Figure 1: Study Area

4. Previous Research Work

Hydro-geomorphological evolution is very normal and natural process in a river basin (Das, 2013). In plain area river shifting is a common phenomenon. There are several studies related to this kind of phenomena. Sometimes river course migrated laterally such as the Kosi river shifts laterally over the Himalaya Foreland plain by continual minor cut offs and bank cutting and by episodic major shifts across watersheds (Sinha, 2009). The river channel migration through time and space is significant to many geomorphological and river management problems (Petts 1995; Milton et al., 1995; Hicking, 1983). Lateral shifting of river refers to the positional change of a river channel as a response to variations in water flow and sediment discharges and is always associated with bank erosion of the stream bed

or channel wall under turbulent flow conditions (Yang et al., 1999). Hicking (1974) observed the development of meanders in natural river courses and also did the reassess of river channel changes. Thakur et al (2011) studied the river channel changes of Ganga river upstream of Farakka barrage, in India using geospatial methods. Their study had been carried out to analyze the river bank erosion hazard due to morphometric change or River Ganga (Thakur et al., 2011). The previous work in this area (Banerjee, 1999; Parua, 1999, 2002; Rudra, 2005, 2010; Sen, 2010) had highlighted the problem of river bank erosion and its socioeconomic impacts on community living in this area. The study by Rudra (2005) used remote sensing images to maping eroded area and changes in river bank. The river bank erosion is also very prominent in Ganga-Padma rivers downstream of Farakka Barrage in the Murshidabad district of West Bengal (Banerjee, 1999; Rudra, 2005, 2010, Mukhopadhyay & Mukhopadhyay, 2007). River plays a vital role in the economy of its basin and surrounding area also. Ojeda et al (2007) tried to generate the economic value of the Yaqui River delta through Contingent valuation method.

5. Methodology and Database

1) Delineation of study area on the basis previous (1937) and present map (2019).
2) Identification of some problem of the study area.
3) Characterization of some socioeconomic parameters such as population density, population growth, worker category, literacy and economic activities etc.
4) After that the structural and semi structural survey schedule for the study has been prepared.

The cross profiles are made in different sites of the study area using Auto level. Along with profiles measurement of some other morphological parameters like wetted width, wetted depth, wetted perimeter, etc have been considered. And also assess the impact of shifting of river channel among the bank dwellers.

Methods for measuring channel migration are well explained in the many scientific literature (Shields, 2000; Urban and Rhoads, 2014).The magnitude and trend of migration to study area have been measured following various types of method.
First; Sinuosity Index (reach specific and different years wise) has been considered to measure the lateral trend of channel migration.

Sinuosity(S) deals with the meandering nature of the river. It is the ratio between actual length and straight length of the river.

Channel sinuosity = OL/EL (Schumm, 1963)
Where OL = observed path of stream and EL= expected straight path of a stream.

Plate 1: Field Study

Plate 2: Water depth measurment

Second; The migration rate has been calculated using the following equation (Giardino and Lee, 2011)

$$Rm= (A/L) / Y$$

Where Rm represents Migration rate A is the area of polygon; L is the length of centre line Time 1 for each polygon; (Fig; 2); and Y is the number of years between sequential channel centerlines (Hooke; 1987; MacDonald & Parker 1991).

Third: The migration consistency analysis has been thrown 79 (Fig: 3) fixed cross sections were made with reference to drainage of 1937 and 2019, considering base and present position of Nagar river. The cross sections were created at unequal distances and the section lines are almost perpendicular to the centerlines. These cross sections have been drowned on the basis of visual analysis of P.S Map image and Google earth image. The distance between the centerlines of two consecutive years has been calculated along those cross sections. After calculating migration distance migration rate also has been calculated through the calculated distance data. Distance of channel Migration has been measured through the help of following formula (Giardino and Lee)

$$Dm = T1 – T2$$

Where Dm is the distance of channel migration, and T1 and T2 are the time periods of successive channel migration.

The present study is based on both primary as well as secondary data.

5.1 Primary sources of data

Primary data have been collected directly from the field. A Cross section of the river has been drowned at different sites through the help of Auto level. The Cross section of the river has been drowned along the previous channel and recent channel. Which helps to understand the land use changes due to channel shift.

5.2 Secondary sources of data

Secondary data have been collected from different published sources. Various drainage maps have been collected from U.S Army maps, P.S maps, Google earth images, etc. Various other information such as Demographic, Occupational its data are collected from Census of India.

Table 1: Types and Sources of data

Data type	Source
Cross section of river	Primary Data
P.S map	Land and land reforms Dept of west Bengal.
Drainage Map	Google Earth Image, U.S Dept of State geographer Image landsat, 2019.

5.3 Historical Channel Migration Zone (HCMZ)

The methodology related to the delineation of Channel Migration Zone has been done through the help of previous year map and resent map. First of all the maps of various periods has been digitized in a GIS environment and overlapped. On the basis of overlapped images the highest limit of channel within both right and left bank has been identified. Through the help of highest limit of the river HCMZ has been identified.

1) Different statistical methods such as central tendency, regression analysis have been used for migration rate analysis.
2) Maps of different periods have been prepared by QGIS software.
3) Historical Channel Migration Zone (HCMZ) has been delineated through the overlapped images and courses of Nagar of different periods.

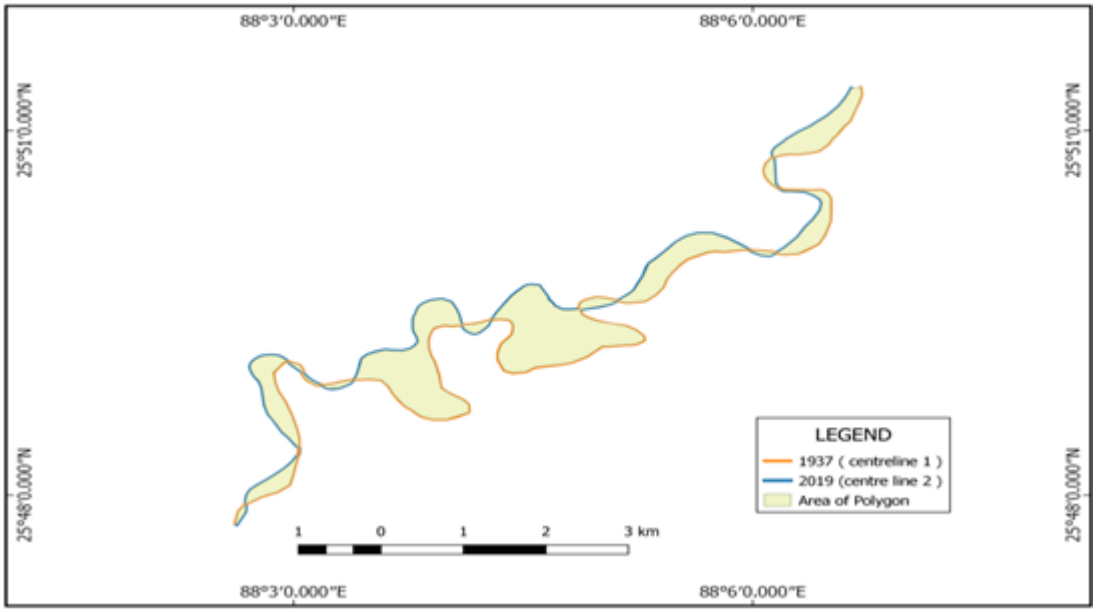


Figure 2: Polygon area between two successive centerlines (1937 and 2019)

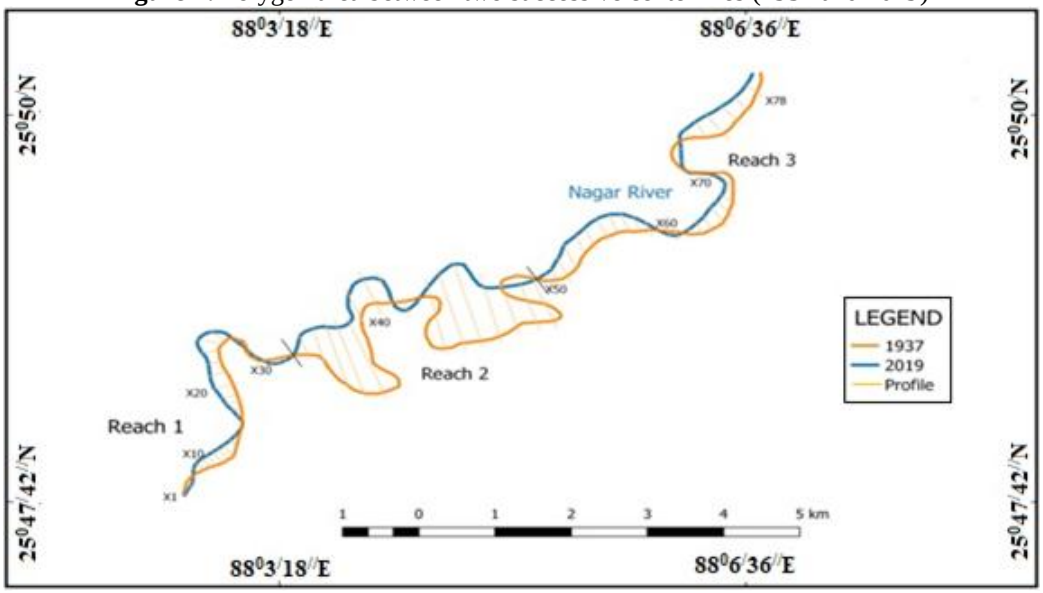
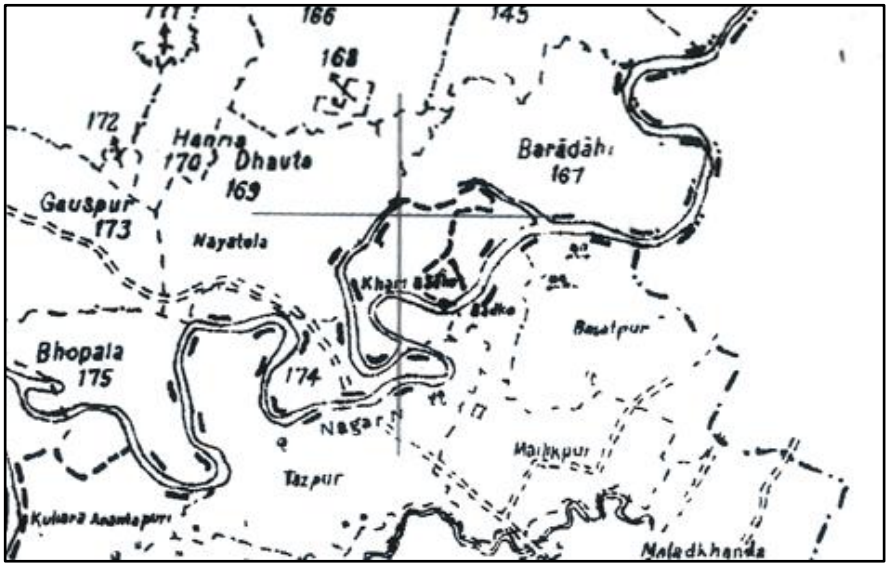


Figure 3: Section line over of courses of study area in Nagar River between two time periods for measurement of channel migration rate



Surveyed 1901-1905, PS-Karandighi

5.4 Identified reaches of Nagar River and their characteristics

The entire study area divided within three river reaches (Figure: 4). Brief description of reaches has been given below. Reach identification on the base of sinuosity of course.

5.5 Reach 1

Reach 1 extends from 88˚ 2' 58.55" E and 25˚ 49' 8.03"N downstream for approximately 3.035 Km, to a point 88˚ 2' 38.76"E and 25˚ 47' 49.56"N. Sinuosity (ratio of channel length to valley length) of the river in this reach is 1.69 (2019) and 1.52 (1937). In 2019 the sinuosity is higher than the reach 2 and reaches 3.

5.6 Reach 2 (STUDY AREA)

Reach 2 extends from 88˚ 5' 7.08" E and 25˚ 49' 37.2" N downstream for approximately 4.553 Km, to a point 88˚ 2' 58.55" E and 25˚ 49' 8.03" N. The sinuosity index value is 1.46(2019) and 2.45 (1927). In 2019 the sinuosity is relatively higher than reach 3 but lower than reach 1.

5.7 Reach 3

Reach 3 extends from 88˚ 6' 41.4" E and 25˚ 51' 24.47" N downstream for approximately 5.715 Km, to 88˚ 5' 7.08" E and 25˚ 49' 37.2" N. In 2019 the sinuosity value 1.38 which is relatively lower than other two reaches. From these three reaches Reach 2 is the main field study area. Cross section reading and others purposive field work done in Reach 2. Other two reach identified as to compare with Reach 2.

Table 2: Reach 2(the study area) of Nagar River and their characteristics

Reach ID	Location	Length (Km)	Straight length (Km)	Characteristics		
				Sinuosity index	Morphology	Riparian character
Reach 2	Near Bhopla, Daluakhari and Dhauta	5.0	3.42	1.46	High migrated area	Settlement, Agricultural land, point bar etc.

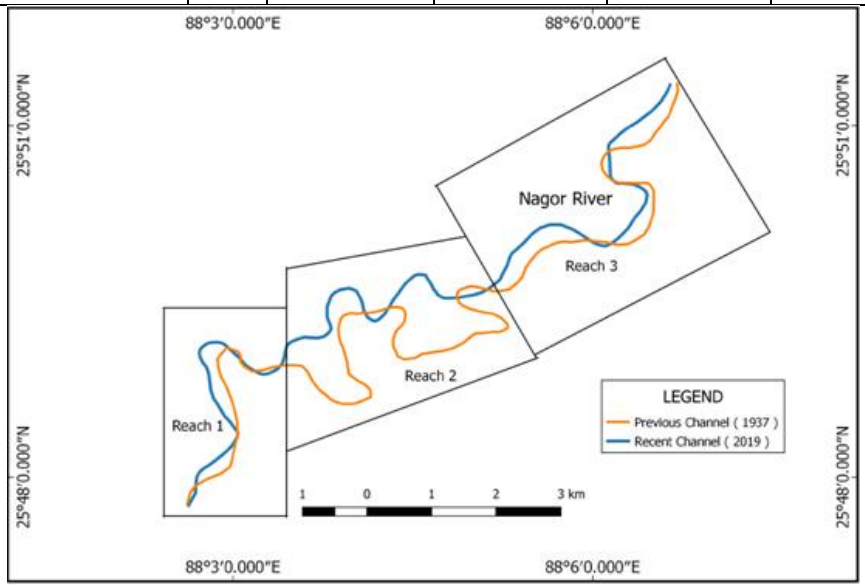


Figure 4: River Reaches of Nagar River

5.8 Channel Change Detection and Analysis

5.8.1 Lateral migration based on area method

Table; 3 displays migration rates statistics between the years 1937 to 2019 measured. The total study divided into three reaches (Reach 1, Reach 2 & Reach 3). The average migration rate is 0.44 m/year, 1.48 m/year & 0.824 m/year near Reach 1, Reach 2 & Reach 3 respectively. That means over the time period the migration rate is higher near Reach 2, then Reach 3 & Reach 1 respectively. Total 3.953 square Km. area in the study area was affected by River migration during period 1937 to 2019. Where almost 2.365 square Km. the area was affected in Reach 2, which is more than other two Reach. That means in study area (Reach 2) the migration rate statistically is very high since 1937 to 2019

Table 3: Migration rate statistics (Calculated following the polygon area method).

	Migration Rate (metre /year) (1937-2019)		
	Reach 1	Reach 2	Reach 3
Mean	0.44	1.48	0.824
Median	0.28	1.33	0.76
Standard Deviation	0.33	1	0.461
Co-efficient of variation	75.14 %	67.57 %	55.95%

5.9 Lateral migration based on sinuosity

Table no-4 displays meandering character by sinuosity index values within the two time periods. The sinuosity index value ranges from 1.87 to 1.53 during 1937 to 2019. In the study area the total length of Nagar river is 18885.864 m in 1937 whereas it is 15469.048 m in 2019. That means the length of the stream is higher in 1937 than 2019. The general trend shows that Sinuosity of river Nagar decreases from 1937 to present.

5.9.1 Reach specific lateral migration on the basis of Sinuosity

The reach wise migration rate also varied between two successive years. In 1937 the sinuosity index value in Reach 2 is relatively higher than other two reach. That mean in 1937 higher rate of meandering in Reach 2, which indicate the higher rate of migration. Other hand in 2019 the sinuosity index value in Reach 1 is relatively higher than other.

But magnitude of sinuosity in 2019 relatively lower than previous year. In Reach 1 and Reach 3 the sinuosity index value is almost same in both years, but near Reach 2 these values are high fluctuated.

Table 4: Trend of sinuosity index since 1937 to 2019

Reaches	1937	2019	Remark
R1	1.52	1.69	More sinuous
R2	2.45	1.46	Channel become straight and cut-off formed
R3	1.48	1.38	Relatively stable

5.9.2 Trend of sinuosity at different reaches

Table no-4 represents the trend of Sinuosity Index in different reaches in different time period. Two reaches showing the negative change of sinuosity except reach 1. It means over the time period the sinuosity decreases in the study area. Rate of change in reach 1 showing the positive change.

5.10 Reach specific migration consistency analysis

Table: 4 displays the reach wise summary statistics of migration rate. According to these tables in reach 1 the migration rate was almost 1.35m/year, then in reach 3 the migration rate was almost 2.52m/year and to reach 2 the migration rate was almost 8.88m/year. Reach 2 that mean the main study area exhibits the higher rates of migration than others two reach.

Table 5: Reach specific summary of migration rates along different section lines.

	Migration Rate (metre /year) (1937-2019)			
	Reach 1	Reach 2 (Study area)	Reach 3	Total
Mean	1.35	8.88	2.52	3.81
Median	0.91	8.05	3.32	2.95
Standard Deviation	1.1	4.17	0.92	3.75
Co-efficient of variation	81.48%	53.04%	36.57%	98.42%

5.11 Historical Channel Migration Zone (HCMZ)

Areas affected by channel migration, the movement of a river or stream channel across its valley bottom, are called Channel Migration Zones. Channel migration zone (CMZ) means the area along a river within which the channel can be reasonably predicted to migrated over time. One of the integral parts of the study is a delineation of Historical Channel Migration Zone (HCMZ). A common starting point for mapping channel shifting and delineating channel migration zones is a collection of archival records to document change in location from historic to contemporary periods. To demarcate HCMZ first and foremost drainage map of different years has been collected. Though a period of 100 years often is identified as an appropriate timeframe (Bolton and Shellberge, 2001) but due to of the historic image, the historical maps from 1937 to 2019 (82 years) have utilized to map the Historical Channel Migration Zone (see figure: 6).

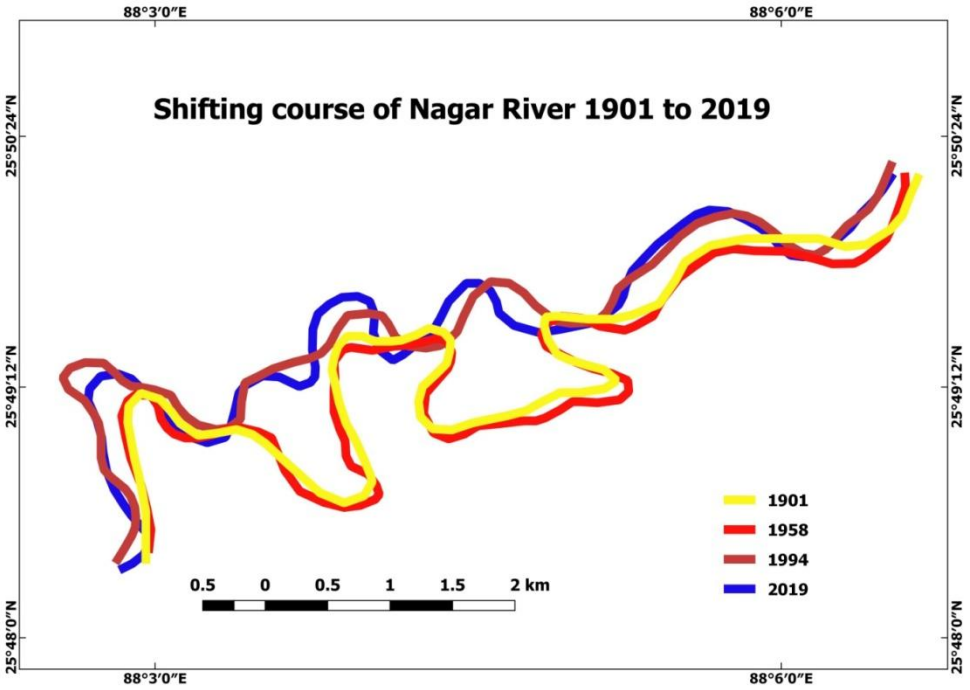


Figure 5: Overly view of Courses of Nagar River of different years

From the above discussion, it is clear that the Historical Migration Zone is based on a composite area defined by channel location 1937 and 2019 (Figure: 5).The resulting area reflects the zone of channel occupation over an 82 year timeframe. Over the given time period, rivers occupy a corridor area which width is dependent on rates of channel shift. The reach 2 *i.e.* the study area showing massive shifting of course and extent of shifting corridor is more than others two reaches.

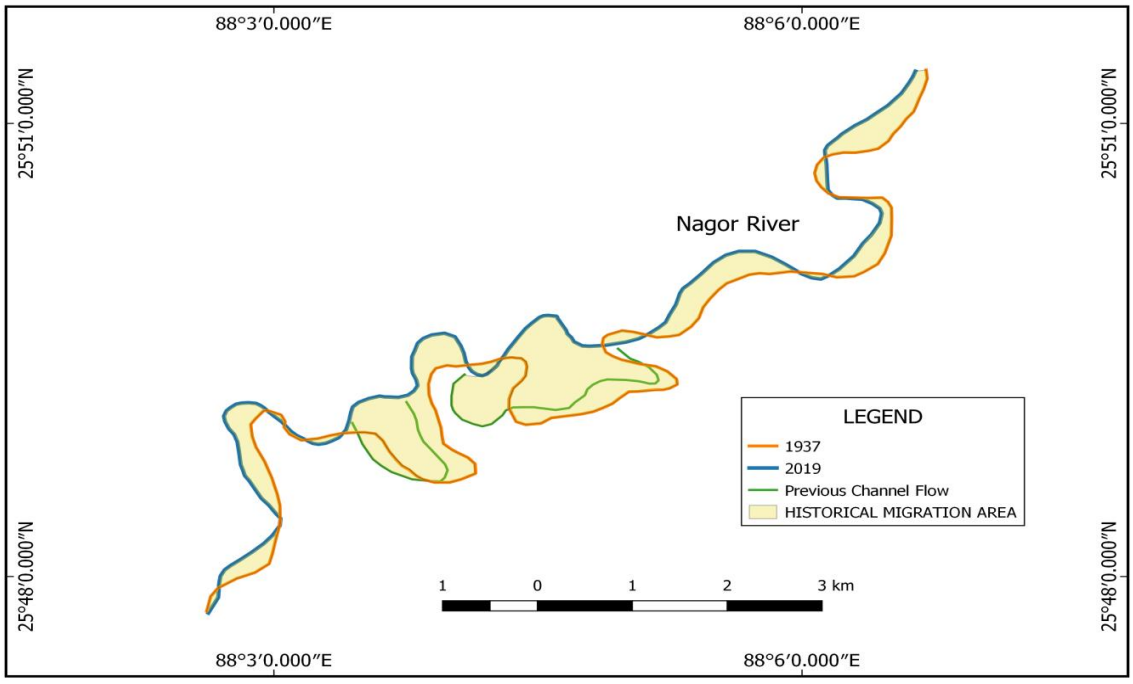


Figure 6: Historical Channel Migration Zone (HCMZ)

Figure: 6 represents the historical channel migration zones of Nagar river. The green coloured region within this figure indicates the Inactive Channel Migration Zone. And the light brown coloured portion within the map represents Active Channel Migration Zone. That means the study area of Nagar river is more active than others surrounding area. And in study area the magnitude and shifting tendency of channel migration is more than its surrounding area.

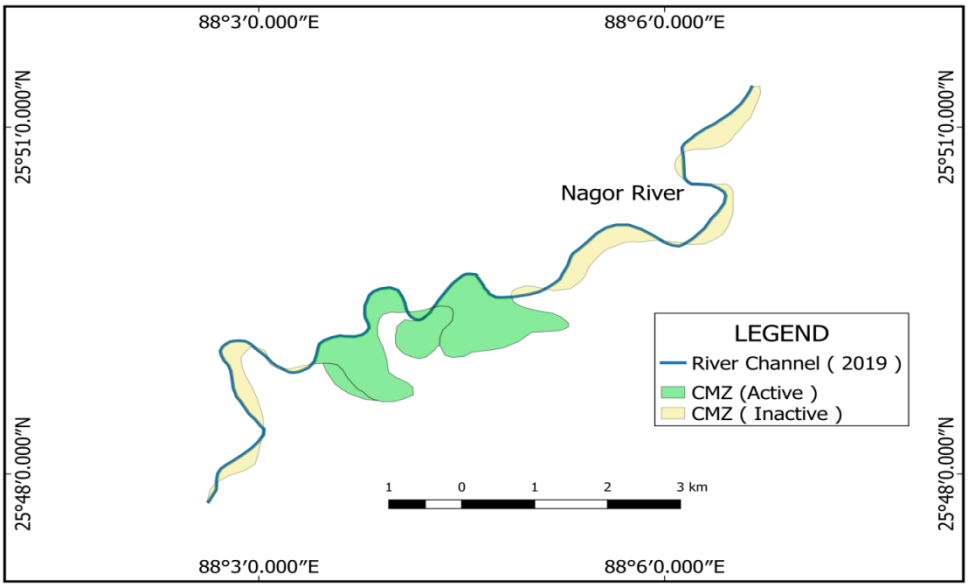


Figure 7: Present river within HCMZ

Figure: 7 represent a panoramic view of the present river within a Historical Channel Migration Zone. If we would like to draw presents Channel Migration Zone it will be reshaped to some extent, disconnected part will be avoided. If it is done the width of the migration corridor will be narrowed down. It is one of the major effects of discharge lowering.

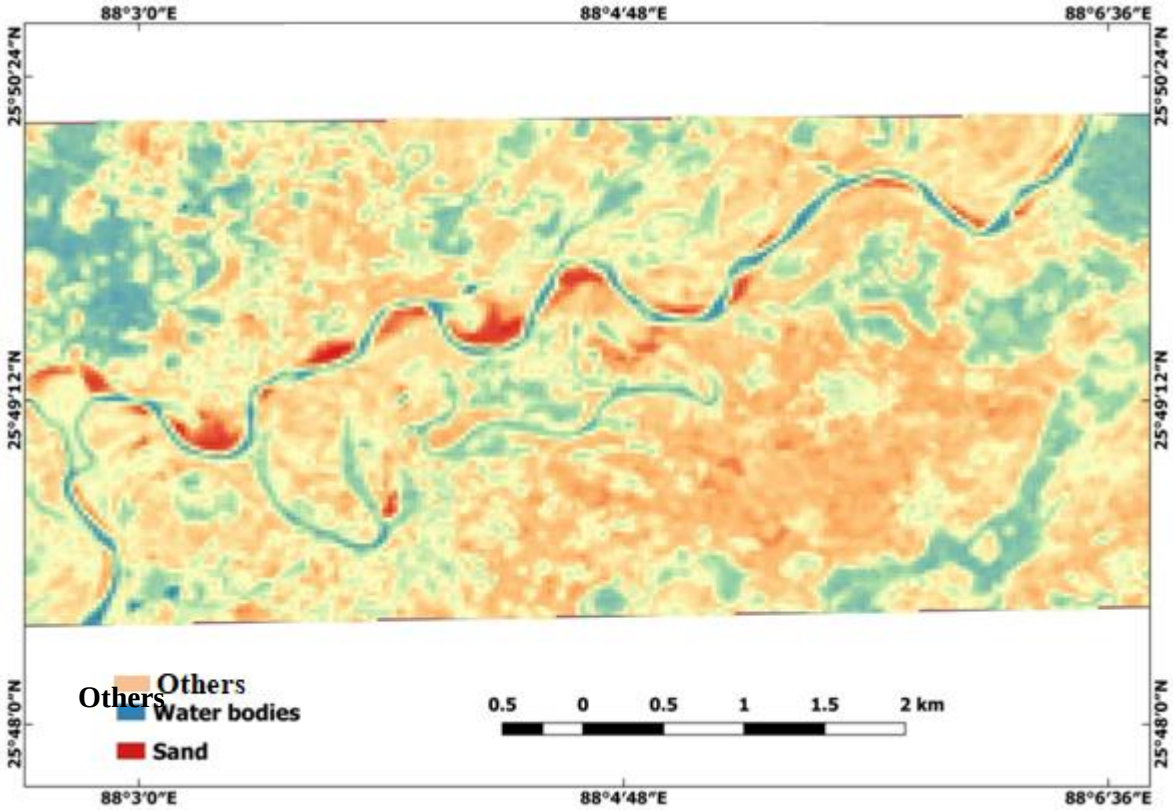


Figure 8: Showing the river channel in 1994 by using Landsat image

5.12 Analysis of cross profile along the channel migration zone

The land use pattern in the channel migration zone is very important. The land use between previous channel course and recent channel course dynamically change due to channel migration. There different reason for channel migration. Channel migration of a region, impact on their population status, occupational status, economic status etc.

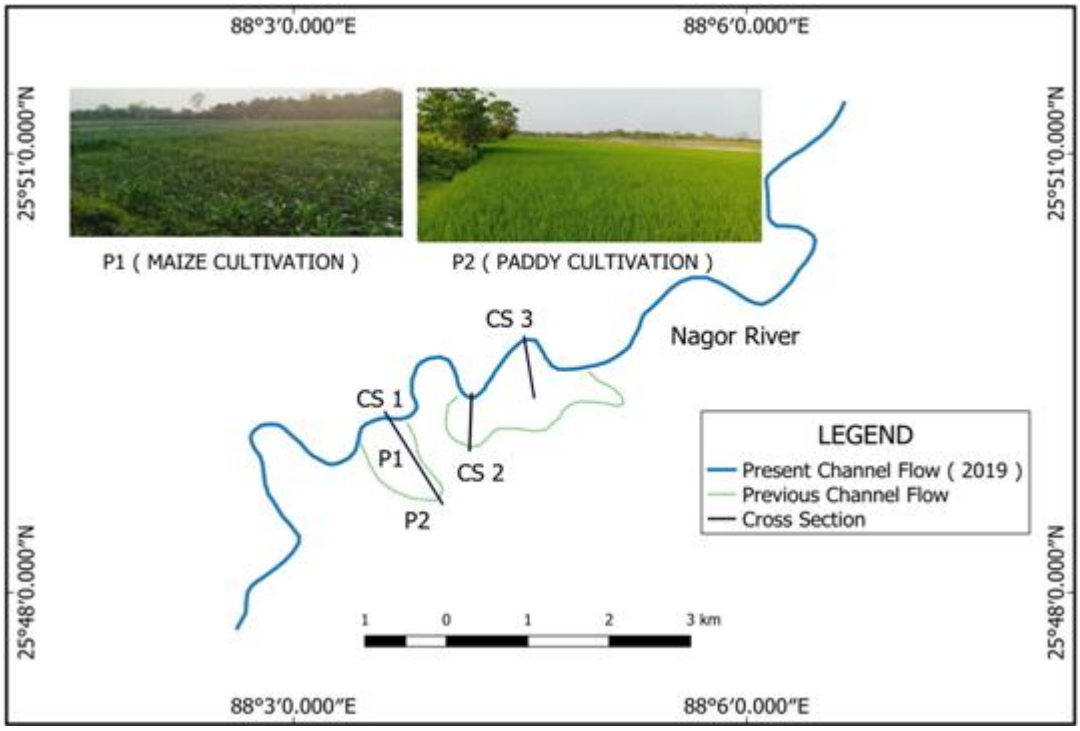


Figure 8: Three selective cross section

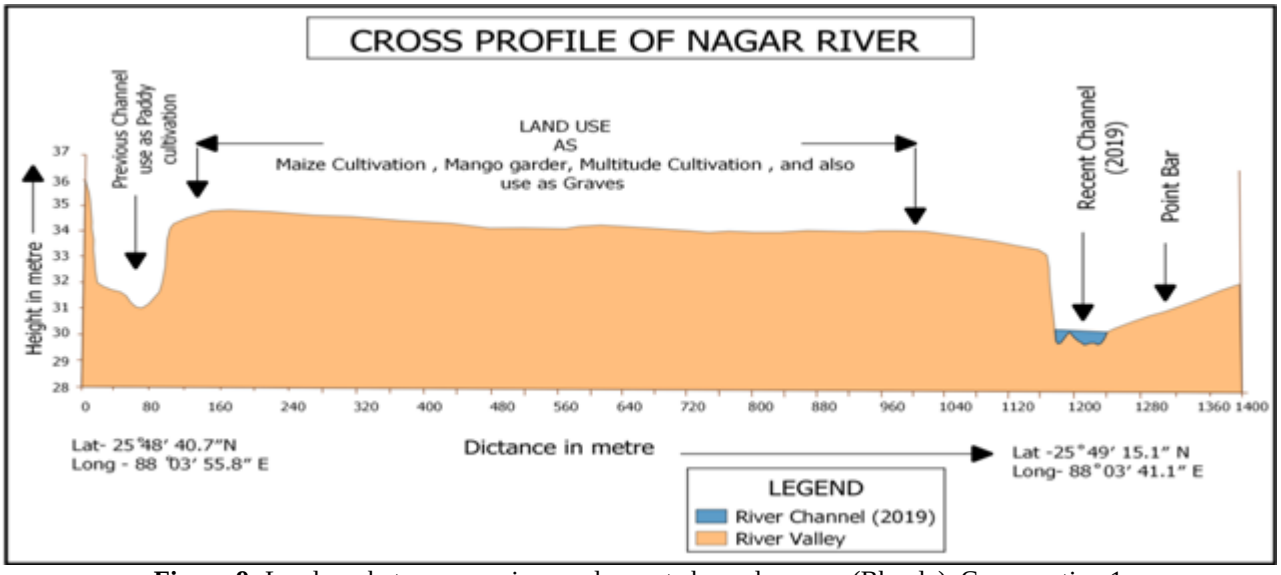


Figure 9: Land use between previous and recent channel course. (Bhopla), Cross section 1

There are three cross sections drawn in the study area along Nagar river to explain the land use of this region. If we see the cross section 1 (Figure 9) than the total about 1060 meter distance covered between the previous channel (1937) and recent channel (2019). Due to these shifting of the river the land use of these regions changed. In present time in these regions the land use as maize cultivation, mango garden, multitude cultivation and also use as Graves. These cross sections drown along the Bhopla village. And most settlements of these regions appear left bank side previous channel and right bank side recent channel. And between these two courses of channel the land use cultivation of different crop. Maize, paddy, mango tree garden etc are cultivated in these regions.

As the main economy of these region based on the agriculture, so the total economy of these study area changes due to channel migration.

5.12.1 Impact of channel migration on land use

1) The middle zone between previous channel and recent channel use, as maize cultivation, mango garden and also use as Graves.
2) And in previous channel use, as paddy cultivation.
3) It is also seen in the study area that the settlement shifted their position due to channel shifting.

This all changes to be observed in the study area (Fig: 9) and these change effects on their economic development, population structure etc.

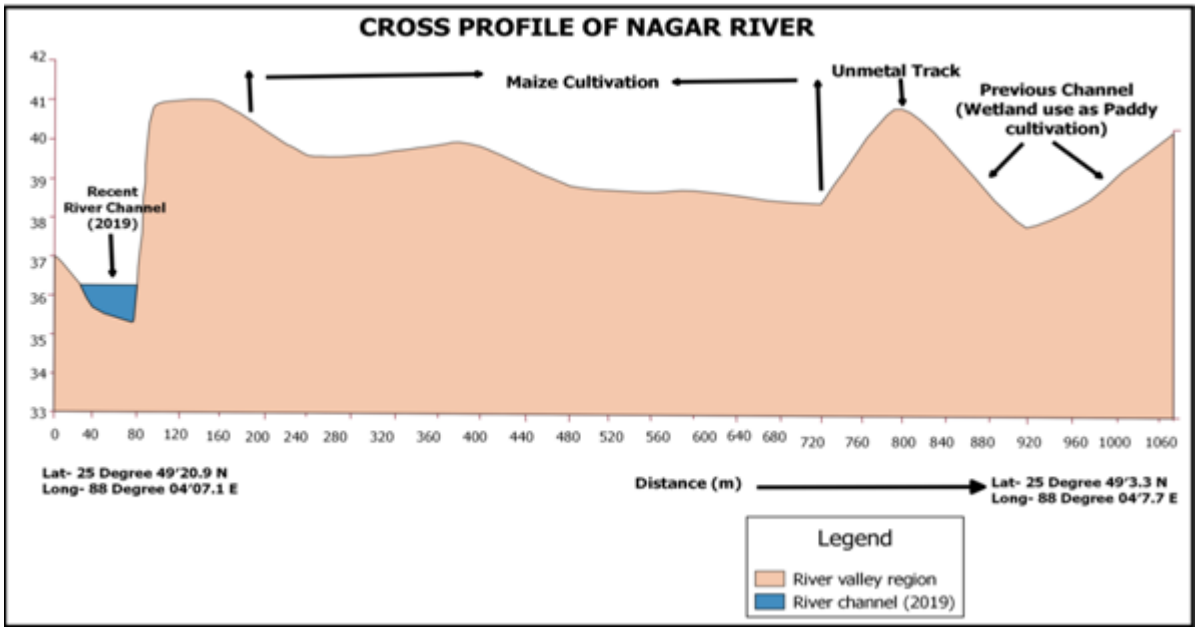


Figure 10: land use between previous and recent channel (Daluakhari) Cross section 2

Another important cross section (Fig: 10) in the study area expresses various type land use pattern change due to channel migration from 1937 to 2019. Maize cultivation, unmetal track is to be found between previous channel and recent channel. And the wetted previous channel use, as paddy cultivation. As the agriculture is the main economic activity, the land use as cultivation of various crops.

Table 6: Land use along the cross section

Cross section	Location	Length of cross section in meter	Land use pattern along the cross section
Cross section 1	Bhopla (lat 25˚ 48' 40.7" N Long 88˚ 03' 55.8" E TO Lat 25˚ 49' 15.1" N Long 88˚ 03' 41.1" E)	1400	Mize cultivation, mango garden, multitude cultivation and use as graves.
Cross section 2	Daluakhari (lat 25˚ 49' 20.9"N Long 88˚ 04' 07.1" E TO Lat 25˚ 49' 3.3" N Long 88˚ 04' 7.7" E)	1090	Maize cultivation, paddy cultivation and construction of unmetal road.
Cross section 3	Daluakhari (Lat 25˚ 49'38.5 "N Long 88˚04' 21.6" E TO Lat 25˚ 49' 22.0" N Long 88˚ 04' 30.5" E)	626	Point bar, settlement, and paddy cultivation.

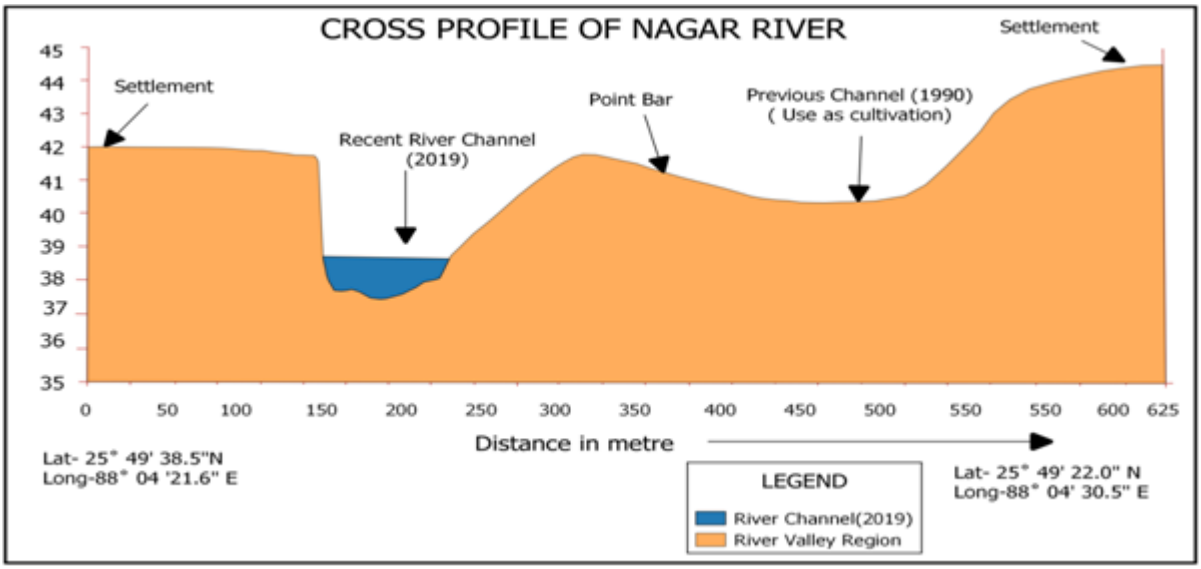


Figure 11: Land use between previous channel and recent channel (Daluakhari) Cross section 3

Another cross section (Fig: 11) along the Nagar river exhibits the channel migration in 29 years (from 1990 to 2019). And these change exhibit the various changes in land use such as point bar formation between previous channel (1990) and recent channel (2019). And it is also found that the settlement shift from right bank side to left bank side due to channel migration. In previous channel course the land use as cultivation of maize, paddy etc.

Key Findings

1) Sinuosity of channel decreases from 1.87 to 1.53(from 1937 to 2019).
2) The rate of change of channel shifting/migration is 3.81m/year from 1937 to 2019.

6 Conclusion

The Present study has proved that how many areas was affected by channel migration or channel shifting. With the help of past data (P.S map, 1937) and present data (Landsat Satellite Images) analysis indicates that the river Nagar has changed its channel from highly meandering to sinuous. And it is also found that a vast area was affected by channel migration in the study area. The land use also changed due to channel migration, the affected flood area used as agriculture activity. Their main economy based on cultivation, and due to these fertile affected areas is suitable for crop production. It is also found that the settlement of these regions shifted from endangered side of bank to another bank side.

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