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Character and Cardinality of Channel Migration of Kalindri River, West Bengal, India

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Abstract

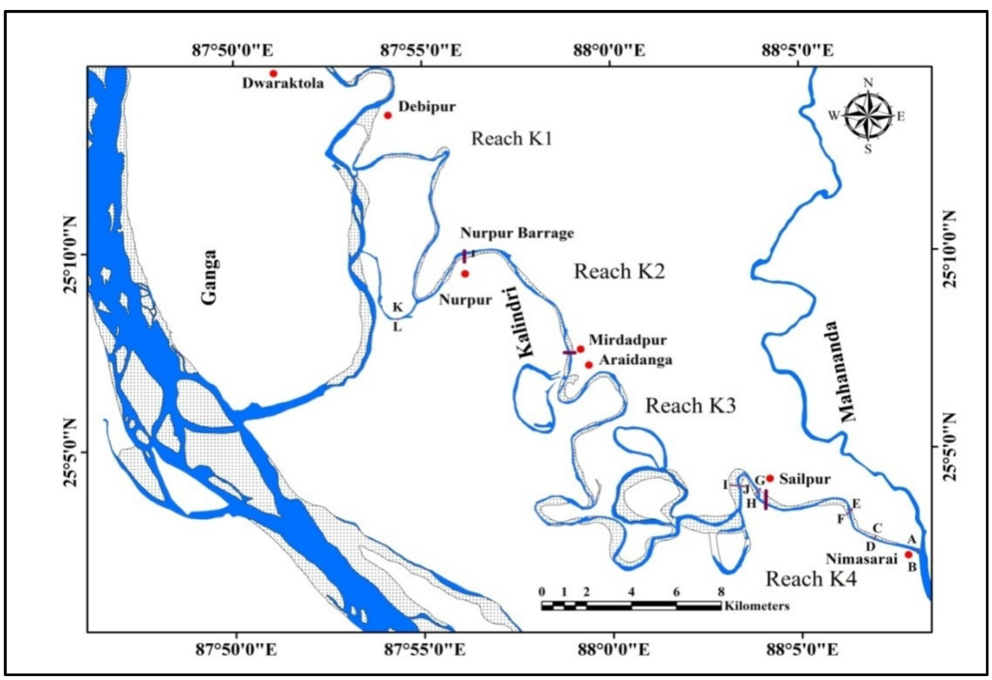
Kalindri River originates from River Phulhar at Najirpur (87⁰53′48″E and 25⁰08′13″) and joins Mahananda opposite the town of Old Malda after flowing south eastern direction of 54 km. The course of the Klindri highly migration prone and exhibits a complex fabric of channel change over time. Present paper will highlight on the nature and magnitude of channel migration in different reaches of the channel. A detail empirical survey has been conducted in different parts of course of Kalindri and various secondary data has been also used to prepare this paper.Phase wise map of the river has been prepared with the help of topo-sheets and Satellite images in GIS environment. To examine the reach wise magnitude of migration, polygon area method has been considered. The convenience of the work, entire channel has been sub divided into four reaches (K1, K2, K3and K4) based on some relevant parameters. The result displays that degree of sinuosity of the river increases from its previous course (1767) to present. The study suggests that the K3 reach is highly sinuous in nature (at SI = 3.16 in 2010). Rate of migration is recorded higher in phase-1(1924-1955) than phase-2 (1955-2010).In phase1 reach specific migration rate is higher (28.60 metre/year)in K4 than other reaches but phase-2 showing quite different result where K2 reach is highly migration prone than other reaches. The study suggests decreasing trend of rate of lateral migration with respect to its previous lateral migration history. This migratory nature is highly entangled with life and livelihood of the people lived there on.

Keywords: River channel migration, Lateral migration, Reach identification, Meandering and Migration rate.

Introduction

Introduction and Objectives: The lateral migration of river channels within flood plain regions and the bank erosion due to lateral shifting is a natural process[1-6] but growing intervention of human being has made it semi natural. Lateral migration of river is always associated with bank erosion of the stream bed or channel wall due turbulent flow condition of water[7]. Migration of river channel organized within a corridor or region[8], so it sometimes creates problems to those who living in this region. Sometimes, many people have lost their homes, agricultural land, infrastructure, their livelihoods due to the river channel migration and erosion[9-12]. Alluvial courses are very migration sensitive and if hydrology, sediments, active tectonics etc. Changes they easily readjust themselves. Lateral migration of sinuous alluvial river channel sometimes creates conflicts between bank erosion and human activities near riverbanks[13]. Some study suggests that active channel migration also helps to maintain riparian ecosystem[14,15]. Measurable soil properties, natural bank geometry (e.g. channel width, meander length, meander wavelength, amplitude, radius of curvature, arc angle and sinuosity), discharges of various frequencies[16-18], distribution of riparian vegetation, and vertical and horizontal heterogeneity of floodplain soils[19] etc are some responsible factors for Channel migration. Fluctuation of channel widths over time because of a 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[20]. Lateral shift of river channel also depends on the resistivity of the banks[21]. Distributions of various sized deposits in flood plains and their cohesiveness are also having some impacts on river channel shifting[22]. Anthropogenic activities or natural disturbances can accelerate the rate of channel migration. For example, the clearing vegetation in flood plain can accelerate the rate of migration[23]. There is a close relationship between plants growing within the river corridor and fluvial processes[24]. Due to rapid and unsegregated human intervention on natural processes, most of the natural process is now become semi natural. Many river all over the world such as Ganga, India[25-28], Kosi, India[28,29] Gandok river, India[28,30], Meghna river, Bangladesh[31] and so many other rivers shows spatio-temporal shifting of channel[28]. Systematic temporal adjustment of river is termed as Channel movement which can occur in both vertically and horizontally[32]. One of the crucial fact of lateral channel migration is erosion of floodplain material along one bank and deposition of sediment along other bank exactly matched[1].Bank erosion at each point along the channel is almost proportional to the near-bank perturbation of velocity[33]. The predictions of migration rates based on short-term observation for individual bends are highly suspect as the migration of channel cannot occur continuously within any single bends[21]. Examination of information related to depletion of the terrestrial environment on the outside of meander bends, or essentially overlay the channel outline from multiple, consecutive years and note changes introduced to the channel is one of the simplest way to monitor the channel migration[34,35]. Many scholar has been described the phenomena of river meandering and lateral channel migration. Ikeda suggests that channel migration patterns are highly influenced by the distribution of thick fine-grained cohesive deposits in flood plains[22]. Nelson and Smith in their study presents a predictive model for velocity, surface elevation, and boundary shear stress fields in natural meander bends[36]. Johannesson and Parker developed a mathematical model for the calculation of flow field and bed topography in curved channels with an erodible bed[37]. In his study Ellis-Sugai recommends that the lateral channel migration and bank erosion are natural behaviour of river, through these processes side channels and meander bends are developed, sand flood plains are formed, point bars are deposited[34]. Lancaster and Bras suggests a new method for analysis of meandering channel bends using platform sinuosity[38]. Monitoring meander migration pattern using channel platform and vegetation cover data extracted from maps and aerial photography is one of the simplest methods for examination of phenomena of channel migration[39]. One can easily predict the meandering channel migration character and migration rate of river trough the help of historical orthophotos[40]. Hickin examined the problem of interpreting of meander growth from the surface configuration of flood plains and also reviewed some good literatures related to river channel change[41,42]. There are several scientific methods for examination of channel change and channel migration such as sedimentological evidence, botanical evidence, historical sources planimetric survey, repeated cross profiling, erosion pins, and terrestrial photogrammetry[43]. Through the method of flume tests and risk analysis meander migration rate also can be predicted[44]. Among various approaches, with specific focus on the magnitude of channel movement there are three commonly used approaches for prediction meander migration. These methods are i. empirical approach, ii. extrapolation approach or examination of maps for various sequential periods, and iii. fundamental modelling approach[45]. For scientific planning methodical framework suggested by Rapp and Abbe is very useful for delineation of Channel Migration Zone[32].Kalindri River, a distributary of river Phulhar, exhibits a complex fabric of channel change over time. Present paper will highlight on the nature and magnitude of channel migration in different reaches of the channel and how it can be explained.

About Study Area: The Course of river Kalindri and associated old courses has been selected as study area for this paper. This river has historically experienced a long course of evolution. According to Sengupta, Kalindri river is known as a distributary of the eastern branch of the river Ganga[46].According to Sengupta and Lambron, Phular was a branch of river Mahananda and lower part of this river was considered as Kalindri[46,47]. Carter in his settlement report has described the course of river Kalindri in the District of Malda as it is existed in 1935: “The Kalindri has always been connected with the Ganges by navigable Channel, down which the flood water of Ganges passes”[48]. According to filed visit October 2014 and May 2015 the river Kalindri a branch of River Phulher which is bifurcated from Phulher at Najirpur ($87^{0}53^{'}48^{"}$E and $25^{0}08^{'}13$") in Malda district (Figure-1).It is flowing mainly south east and join Mahananda River at Nimasari Ghat ($88^{0}8^{'}07^{"}$ E and $25^{0}02^{'}42^{"}$N).



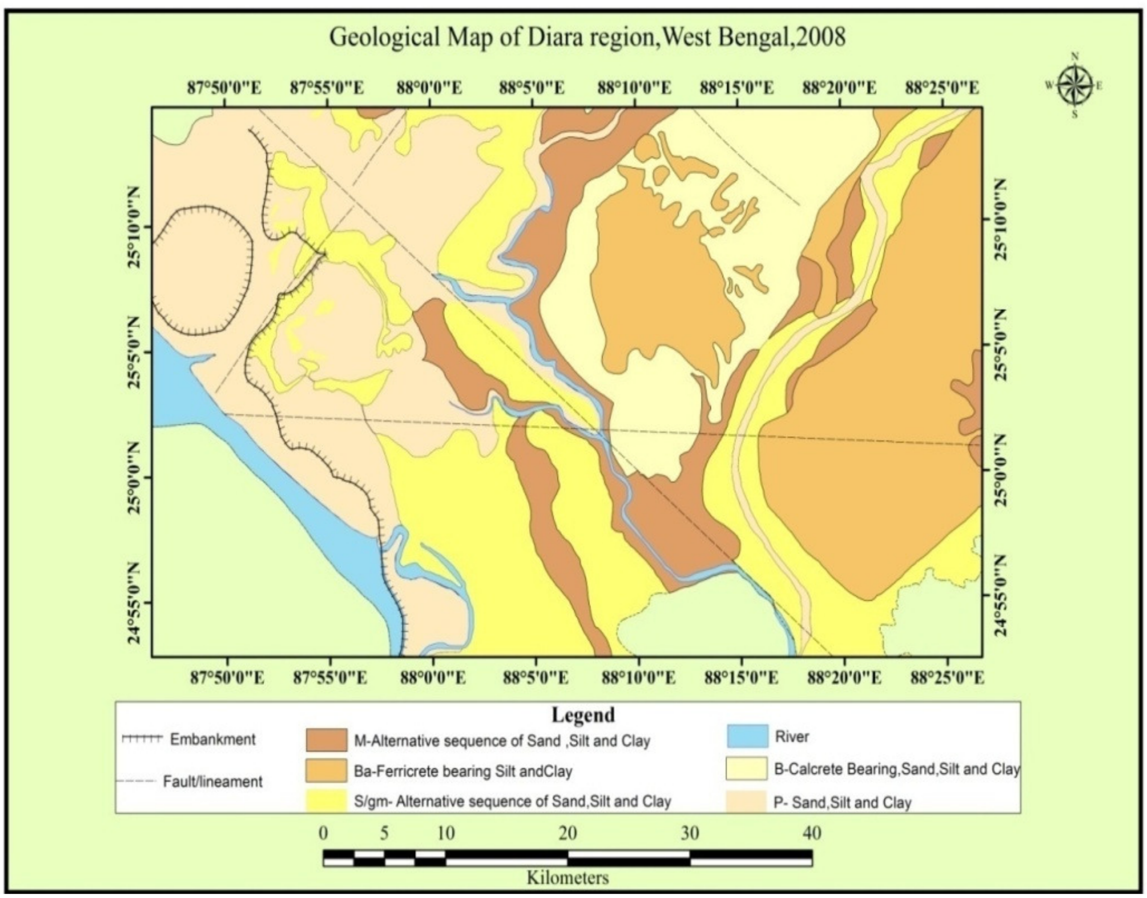
Source: Topo-sheet, Survey of India

Figure-1
The Course of River Kalindri, 1974

The northern portion of this river has been known as 'Tal' land and the southern portion called 'Diara'. Diara region is the most fertile and the most populous area of the district. This river basin is also known for its glorious history,a reference is found in the Ramacharita by Sandhyakara Nandi of the River Kalindri in which it has been stated that Madanapala defeated his enemy on the bank of the Kalindri river [46]. According to the GSI report the maximum portion of study area composed by Entisol (This is a very diverse group of soils with one thing in common, little profile development) and Inceptisol. Both of the soil is made of by alternative deposit of sand, silt and clay (Figure 2). Diara region composed with new alluvium where as the Barind region composed by old alluvium. According to G.S.I report 2008 the entire area divided within four distinct regions, these are i Upland, ii Active flood plain, iii. Inactive flood plain and iv. Restricted flood plain. The upland which is found in the eastern portion of the study area is basically formed by Older Alluvium of Pleistocene age.

The maximum portion of the region is a part of active flood plain which is formed by immature, loosely compacted newer alluvium with higher moisture content[49]. According to Purkait[50] ground water flow is very slow in the study region as the hydraulic gradient is very low and there are so many of cut-off Channels, meander belts and ox-bow lakes which showing the evidences of previous channel change of various rivers. One of the important features of this area is dominance of mango trees than other species of vegetation. According to supervise classification based on Landsat image almost 18252.7 hectares land is under mango orchard. Almost 8531.91 hectares land is occupied by water bodies. Settlement covers near about 15360.8 hectares of land and 21641.8 hectares of land under agricultural activities.

Materials: A detail empirical survey has been conducted in different parts of course of Kalindri River and associated old courses for measuring of depth, width, velocity (where applicable), suspended and dissolved load, bank material, bed material etc. From entire present river course, 6 sites have been surveyed as shown in fig1. Toposheets of Survey of India (1924, 1971-72), Renells' Drainage map[51], U.S Army maps (1955,1982), Landsat 5 images (2005), google image (2015), cadastral map of Revenue survey, Govt. of West Bengal (1951) have been used to prepare the base map of different periods (The specific details of Primary data, R.S data and maps used in this study listed in Table-1).



Source: Quarternary Geology and Geomorphology map of North Bengal,GSI report 2008

Figure-2
Geological Map of Diara Region, 2008

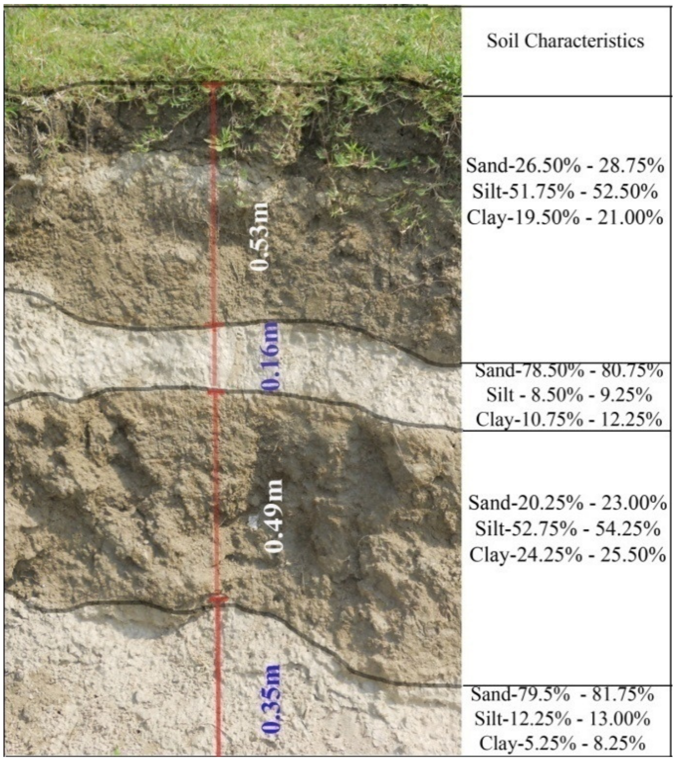


Figure-3
Soil Profile at right bank of river, Nimasari Ghat, 2015

Figure-4
Signature of Meandering of Kalindri,Madia Ghat,201

Table-1
Types and Sources of data

Data Type	Source
Depth, Velocity, Bank materials, Bed material, Sediment load, Seasonal change of water level	Primary (empirical measurement)
Secondary Base Map	Survey of India toposheets (78 $\frac{c}{4}$,1972 and 72 $\frac{0}{16}$ 1974) and Google Earth Image
Geological Map of Diara Region	Quadrangle maps of Geological Survey of India, GSI Report, 2008
Geomorphological Map,2008	Quarternary Geology and Geomorphology map of North Bengal,GSI report 2008
Geohydrology Map,1983	Hydrogeology of da District ,CGWB report 1983, Hydrological Atlas of west Bengal ,CGWB report 1988
Geotechnical Characteristics and Natural hazard Map,1955	Geotechnical Map of india ,GSI, I955,GSI report
Drainage Map of J.Rennel (1767)	Rennell, J. (1781)
Drainage Map of 1855 based on revenue survey map	Revenue Survey Map(1855)
Drainage Map,1924	Survey of India Toposheet
Drainage Map,1955	U.S.Army
Drainage Map,1961	U.S Army map(sheet no NG 45-11)
Drainage Map,1977	Landsat image, Path/Row-139,43,1977
Drainage Map Map-1982	U.S Army
Land use Map Kalindri river and surroundings of Diara region,West Bengal, 2005	Landsat image, Path/Row-139,43,2005
Drainage Map,2010	Google Earth Image,2010

Methodology

Data collection methods: Primary data has been collected directly from field by field survey method. Six cross section sites has been selected as shown in Figure-1.Selection of the sites has been done on the parameters such as erosion, deposition and stability, scour formation etc. Dumpy level survey has been followed for measurement of depth, width etc. Soil and Water sample has been collected for measuring the texture of soil, suspended sediment load, and dissolved sediment load and water quality. Water velocity has been measured with the help of current meter. Bank material has been test has been done following the ribbon test method. Latitude, longitude and altitudinal data has been collected with the help of GPS.

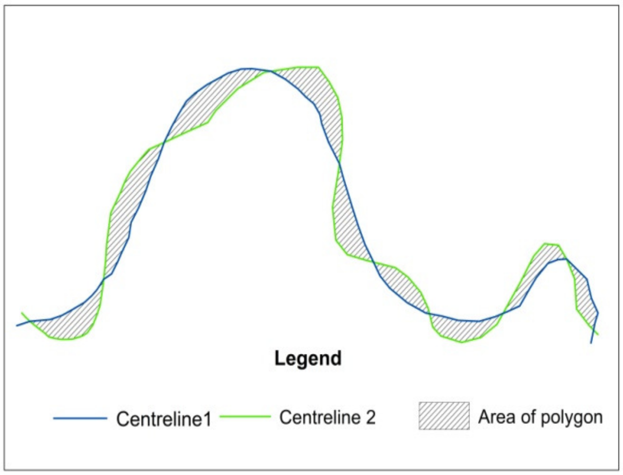


Figure 5
Polygon area between two successive centrelines

Data analysis methods: Methods for Reach Identification: A reach is a length of stream or valley used as a unit of study[52]. Reach breaks are generally determined using factors such as changes soil group, gradient, or pattern, the presence of geologic structure or man-made constraints. For delineating reach in this work, some parameters such as migration character, sinuosity, bank materials and soil character have been selected.

Methods for Measuring Channel Migration: Methods for measuring channel migration are well explained in the many scientific literature[53,54]. Magnitude and trend of migration of the study has been measured following various types of methods, first and foremost Sinuosity Index (reach specific and different years wise) has been considered to measure the lateral trend of channel migration. The methodology for measuring total cannel migration between years is similar to that presented in shields[53] and Hughes[55, 56].

The migration rate has been calculated using the following equation[56,57,58] -

$$Rm = \frac{A}{L} \Big/ Y$$

Where: Rm represents Migration rate *A* is the area of the polygon; *L* is the length of centre line Time 1 for each polygon (Figure-5); and *y* is the number of years between sequential channel centrelines[55-57]. For migration consistency analysis183 (Figure-21) fixed cross-sections were made with references to drainage of 1924 and 1955, considering base and present position of Kalindri River. The cross-sections were created at unequal distances and the section lines are almost perpendicular to the centrelines, giving more emphasis on morphometric changes of river. These cross-sections have been drawn on the basis of visual analysis of temporal remote sensing images, Google earth images and the cross section lines are denser where the degree of morphometric changes are higher than other region. The distance between the centrelines 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[56]-

$$Dm = T1 – T2$$

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

For showing directionality of migration distance wise shifting of channel (right ward or left ward) in reference to previous selected year done. Length of channel of 1955 has been measured in reference to 1924 both in left and right side. Similar thing has done 2010 in reference to 1955.

Data presentation methods: All the hard copy of map scanned and converted into digital format to use on GIS platform. The secondary maps were registered with the UTM projection (India) and converted into vector data. GCP is collected using GPS for geo-referencing the present study area. Previous maps were registered based on the past hard copy maps available from different sources. Those map already possessed coordinates. After vectorization of all the maps selected, overlay operation has been done to produce relative trend of stream migration. Entire GIS based work is done on Arc Gis (version 10.1) environment. For presentation of lateral dynamics of the study area phase wise maps have been prepared. Drainage map 1924-1925 considered as Phase-1and base year for the study where as 1955-1956 considered as Phase-II, Phase-III presents the morphological conditions during 1969-1970 and to grow knowledge about the present situation of the study area a recent map of 2010 has also been created. After calculation of channel migration rate (following various methods) and the directionality of migration, results have been presented trough different cartograms and statistical tools. Mean Median Standard Deviation has been used to draw a general picture of the trend of lateral migration of the study.

Table-2
Reaches of Kalindri River and their Characters

Reach Id	Location	Relative Distance(Km)	Length (Km)	Straight Length (Km)	Basis of selection	Characteristics						
						Sinuosity Index	Morphology	Entrenchment ratio	width depth ratio	Riparian character	Bank material(Ribbon test value in Cm)	
											Left (cm)	Right (Cm)
K1	Debipur to Nurpur	0-17.88	17.88	8	Skewed Reverse Turn Meandering Reach; Morphology	2.24	Active flood plain	2.7	22	Settlement, Mango orchards, Barren land and some amount of agricultural land	0	0
K2	Nurpur to Mirdadpur	17.88-25.23	7.35	6.51	Straight Reach; Low rate of Migration; Stable Channel; Low erosion	1.12	Restricted flood plain and upland	2.45	35.63	Settlement, Mango orchards, Baren land and some amount of agricultural land	2	1.5
K3	Mirdadpur to Sailpur	25.23-65.48	40.25	11.10	Mature Highly Meandering; Ox Bow lake Formation; Deposition; Valley Incision	3.63	Left bank is In active flood plain and Right bank is a part of Active flood plain	3.58	25.2	Settlement, Mango orchards,Baren land and some amount of agricultural land	12	10
K4	Sailpur to Nimasarai	65.48-73.47	7.99	7.25	Straight Narrowing reach; Low rate of Migration; Channel scour Formation through human activities; Erosion; Flood prone	1.1	Left bank is a part of In active flood plain and Right bank characterized by marsh	3.17	40.98	Settlement, Mango orchards,Baren land and some amount of agricultural land	10	17.5

Results and Discussion

Identified reaches of Kalindri River and their characteristics: The entire course of river has been divided within four river reaches (Figure-1) following above mentioned parameters. Brief description of reaches has been given below:

Reach 1(K1): Reach 1 extends from Debipur (**87^{0} 53' 32**''E and **25^{0} 13' 35**''N) downstream for approximately 17.88 Km, to a point just above Nurpur barrage (**87^{0} 56' 06**''E and **25^{0} 09' 55**''N) (Figure-1). Sinuosity (ratio of channel length to valley distance) of the river in this reach is 2.24 which is relatively higher than reach K2 and reaches K4. Bank material both side of the river in this reach is predominated by sand, ribbon test value is almost 0 according to field visit.

Reach 2(K2): Reach 2 or K2 extending from a point above Nurpur Barrage (**87^{0} 56' 06**''E and **25^{0} 09' 55**''N) to Mirdadpur **(87^{0}58' 52'' E and 25^{0} 07' 26'' N).** The reach length is approximately 6.51 Km. The channel is almost straight and sinuosity index value is 1.12 which is relatively lower than other 3 reaches. According to GSI report this portion is a part of inactive flood plain of malda district.

Reach 3 (K3): Reach 3 or K3 extending from Mirdadpur **(87^{0}58'52'' E** and **25^{0} 07'26''N)** to a point just above of Sailpur (**88^{0} 04' 04'' E** and **25^{0}03' 42'' N**). Total length of reach is approximately 40.25 Km. Sinuosity index value of this reach is 3.63 which is relatively higher than other 3 reaches. One of the important features of this reach is formation of several ox-bow lakes due to massive lateral shifting of the river. Right bank of the river in this reach is a part of Inactive food plain where right bank is mainly active floodplain are characterized by Marsh and Paleo- Channel.

Reach 4 (K4): The total extension of Reach4 or K4, from Sailpur **(88^{0} 04' 04'' E and 25^{0}03' 42'' N)** to Nimasarai Ghat **(88^{0}8' 07'' E and 25^{0}02'42'' N)** is about 7.99 Km. Sinuosity index of this reach is 3.17. Several scours (formed by human activities) are found in river bed. Flooding is a common phenomenon of this reach.

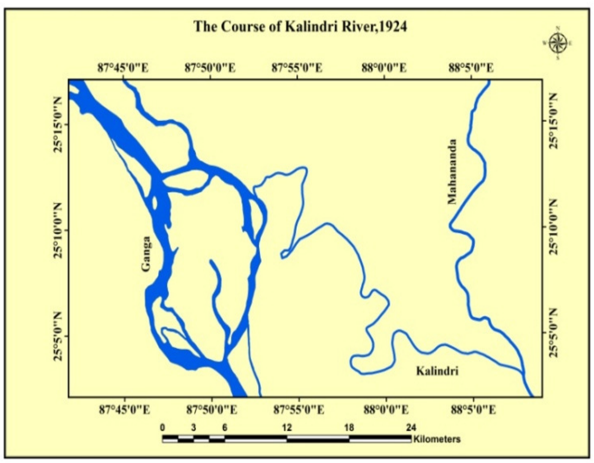


Figure-6
Course of River Kalindri, 1924

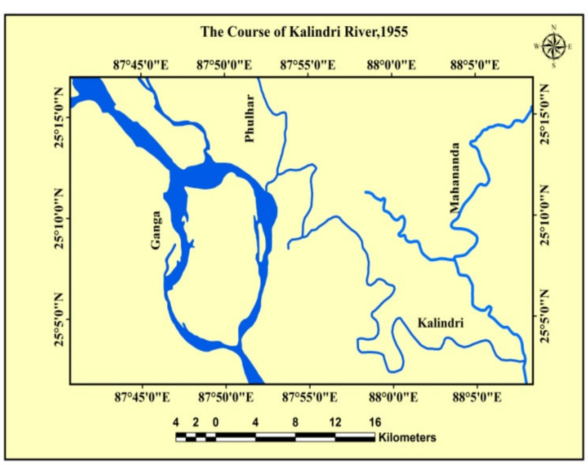


Figure-7
Course of river Kalindri, 1955

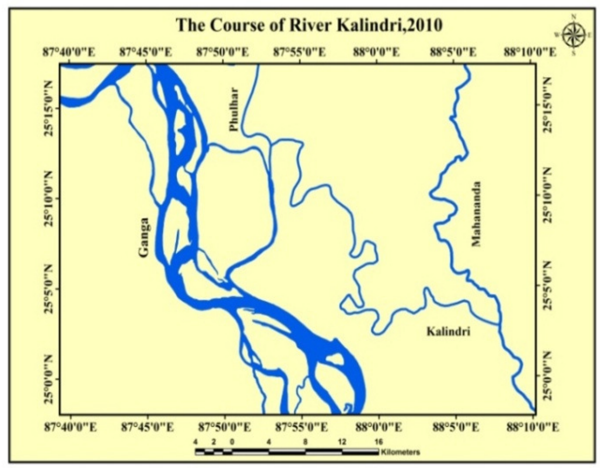


Figure-8
Course of Kalindri River, 2010

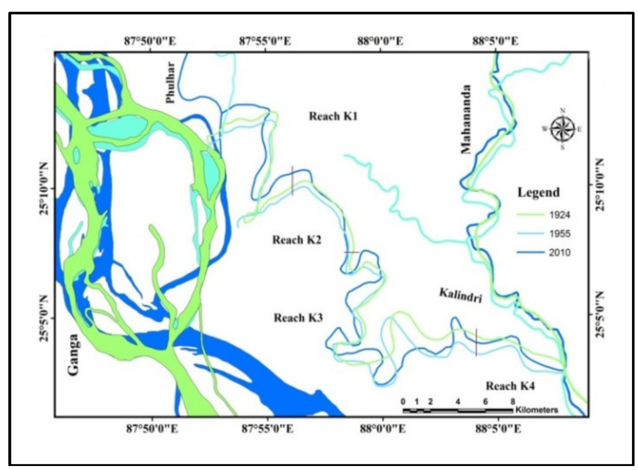


Figure-9
Overlay view of Courses of Kalindri

Channel Migration: Lateral dynamics of Kalindri River: There is a long history of to attain the phase I (1924-1925) condition before this considered phase .During that period the river Kalindri originated from the eastern branch of Ganga, almost 882m North East from Kamalpur ($87^0 52'38''$E and $25^0 11'33''$N) Ratua. From source it was flowing towards South east and join with the river of Mahananda at Nimasarighat (See Figure-6). The character of channel was sinuous in nature and several bends has been noticed in river Kalindri in that period. In phase-II (1955-1956) period there was a significance change in course of river Kalindri, River Pulhar was used to sends huge volume of water through the channel of Kalindri. Sinuosity of river almost same as previous phase. In this phase-III (1969-1970) Kalindri originates from river Phulhar, According to Sengupta[46] the Kalindri Originates from Phulhar few miles above from Rajmahal the river flows first towards east. From there it takes sharp bend to the south then again lows towards east and then again turns and flows along a widening course in a mainly south eastern direction until it falls into the Mahananda. Total length of river was 53miles.Trend of erosion in this period was almost towards south (towards English Bazar Mathurapur road). After formation of Nurpur the water level of kalindri drops as per people perception. Several scour (regionally called mooni) has been formed in bed of Kalindri due to extraction of sands by human activities. As mentioned above present source of Kalindri is river Phular. Except rainy season the course of Kalindri remain dry as the mouth of Kalindri at Najirpur blocked by sand deposition and siltation.

Lateral Migration based on Sinuosity: The Figure 10 displays meandering character by sinuosity index values within different period. The sinuosity index value ranges from 1.70 to 2.41 during 1767 - 2010. Total length of the river Kalindri is 73.20 Km. (highest) in 1982 whereas 51.59Km. in 1767 (lowest). The general trend shows that Sinuosity of river Kalindri increases from 1767 to present. The increasing sinuosity of river depicts that meandering pattern of river Kalindri increases. In present condition several ox bow lakes and other paleo-channel showing the shifting character of river.

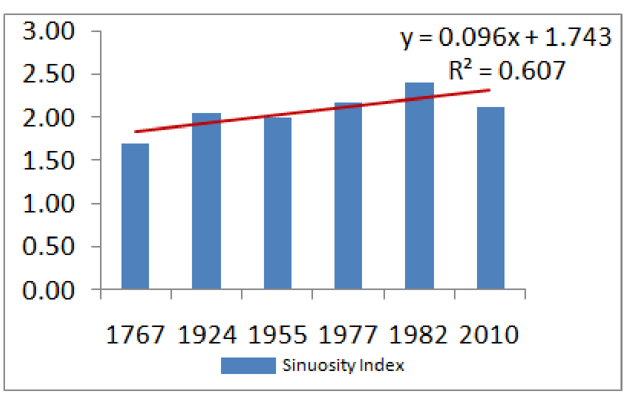


Figure-10
Trend of Sinuosity Index of River Kalindri (Since 1767 to 2010)

Figure-11
Bank Erosion due to Lateral Shifting of Kalindri River, Madia Ghat, May 2015

Reach specific Lateral migration based on Sinuosity: Reach wise migration rate also has been measured for several years which are mentioned below (Figure-12 to 17).The sinuosity Index value is relatively higher in K1 and K3 reach than other reaches in all of the concerned period. Higher SI values in K3 reach in all of the phases indicates higher rate of meandering in this specific reach. Trend of SI values indicates increasing trend of sinuosity form K4 reach to K1 reach during all of the observed year only except 2010. In 2010 trend of sinuosity also K3 reach sinuous but magnitude of sinuosity relatively lower than previous concerned year.

In 1767 the sinuosity of K1 reach is higher than the present SI value of K1 (as measured SI=2.38 in 1767 and SI=2.31 in 2010). K4 reach is also almost straight throughout all of the concerning periods. But general trend in sinuosity in K3 reach increases from 1767 to present, degree of SI value in K3 is 2.30 in 1767, 2.77 in 1977 and 3.16 in 2010.

Lateral Migration based on Area method: Table 3 displays migration rates statistics for two distinct time periods (since 1924-1955 and 1955-2010) measured. The average migration rate is 5.84m./year during 1924 to 1955 (31 years) and 3.89m./year during 1955 to Present. Total 29502.50 square Km. area was affected by migration during period 1924 to 1955.Where almost 29182.84 square Km. area has been affected by channel migration during period of 1955 to 2010 which is relatively lower than preceding phase. Almost 530.59 square km. of area per year affected by channel migration from 1955 to 2010 which is relatively low than the preceding phase, the rate of migration affected area per year in since 1955 to 2010 is 951.69 square km. per year. The variability of migration rate based on area method is 80.04 % during 1924-1955 and variability of migration rate is 70.27 % during 1955 to 2010. Higher value of co- efficient of variation of phase 1924 -195 than 1955-2010 showing that migration rate in 1955-2010 is more consistence than time frame of 1924-1955. Higher value of Standard deviations in phase-1 indicates great fluctuation of the values of migration rate within this specific time frame. The study suggests that relatively higher value of migration rates recorded for the river prior to construction of the Nurpur barrage which was constructer in early 70’s decade.

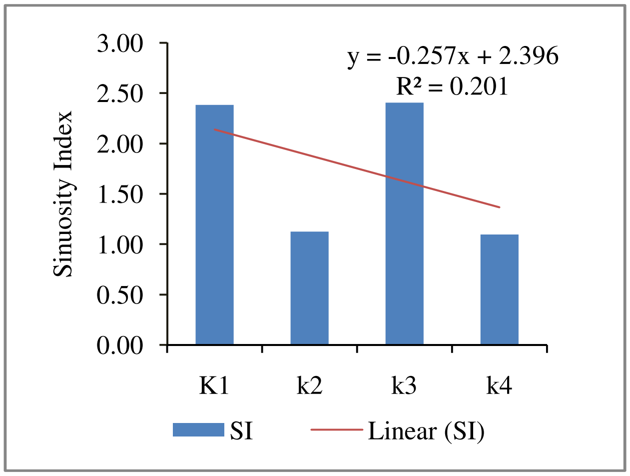


Figure-12
Reach specific Sinuosity, 1767

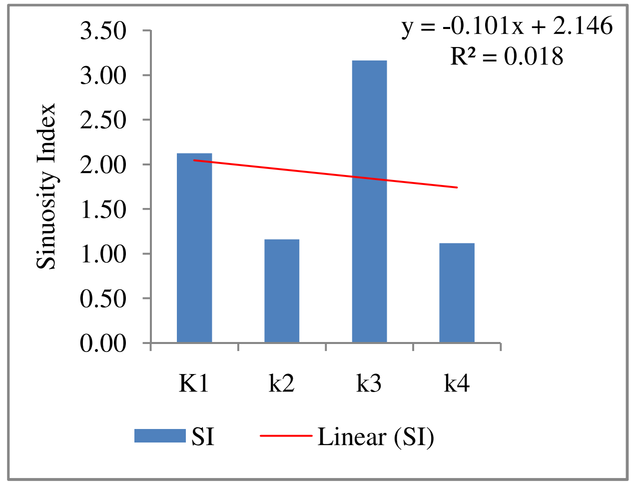


Figure 15
Reach Specific Sinuosity, 1977

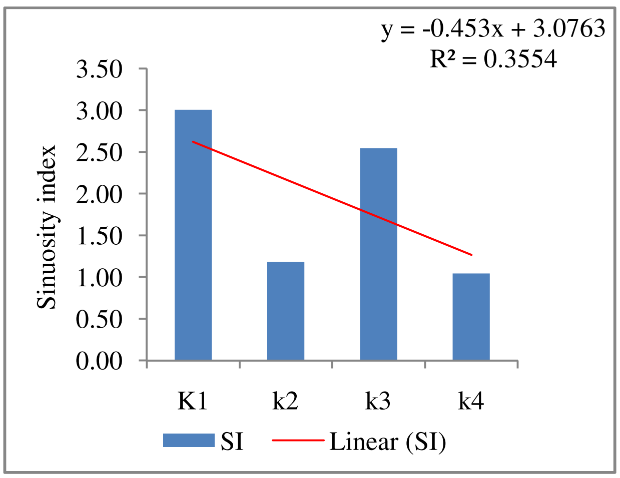


Figure-13
Reach specific Sinuosity, 1924

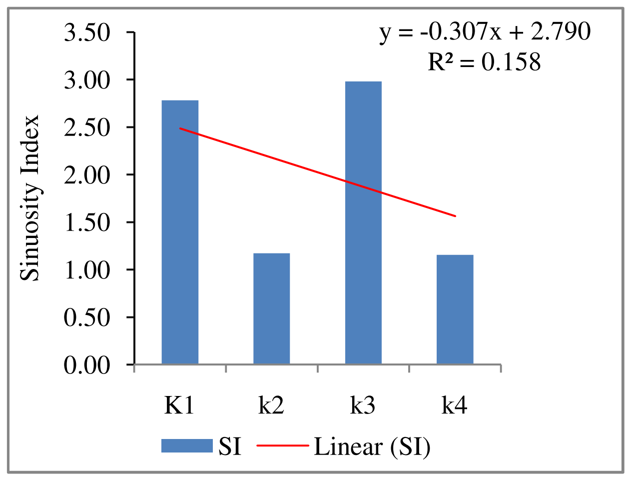


Figure 16
Reach Specific Sinuosity

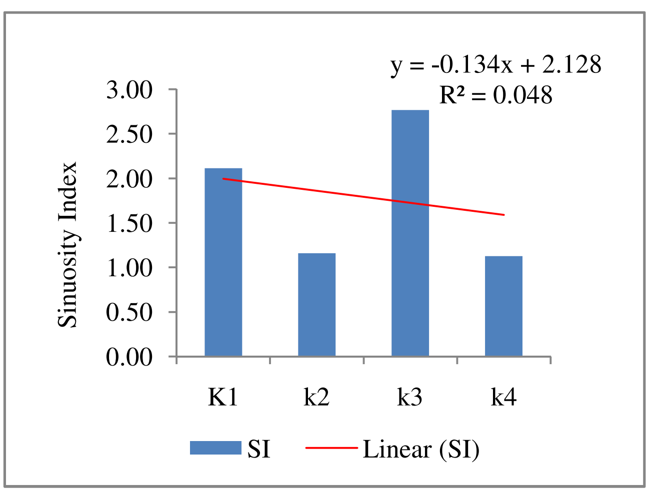


Figure 14
Reach Specific Sinuosity, 1955

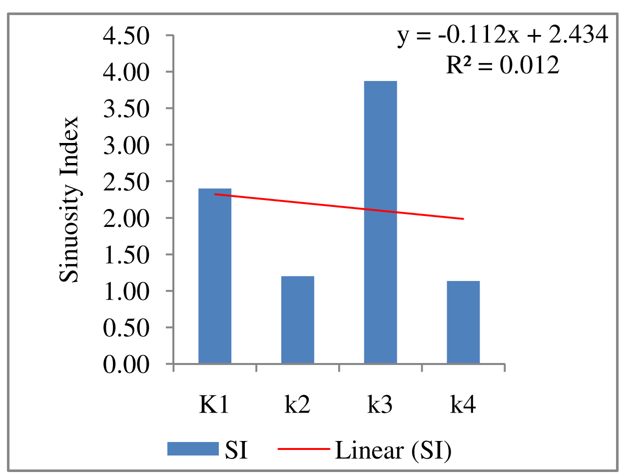


Figure 17
Reach Specific Sinuosity, 2010

Table-3
Migration rate Statistics (Calculated following the polygon area method)

	Migration Rate (metre/year)	
	1924-1955	**1955-2010**
Mean	5.48	3.89
Median	3.78	3.44
Standard Deviation	4.39	2.73
Co-efficient of variation	80.04(%)	70.27(%)

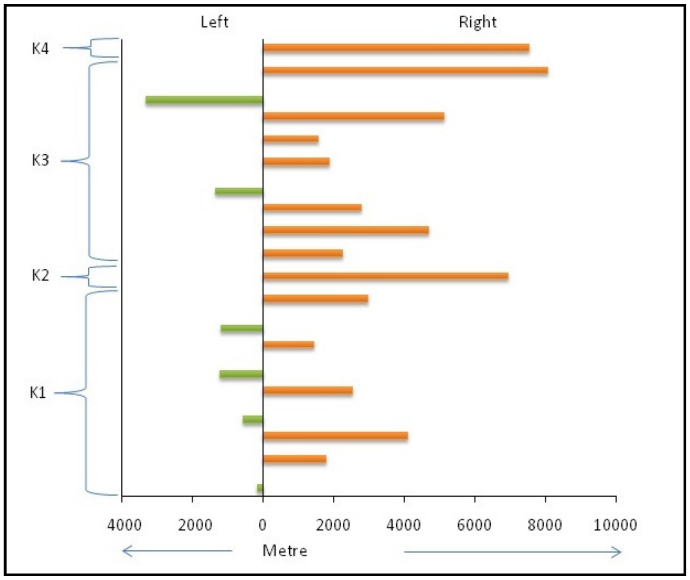


Figure-18
Directionality of Migration length of stream in 1955 in reference to course of 1924

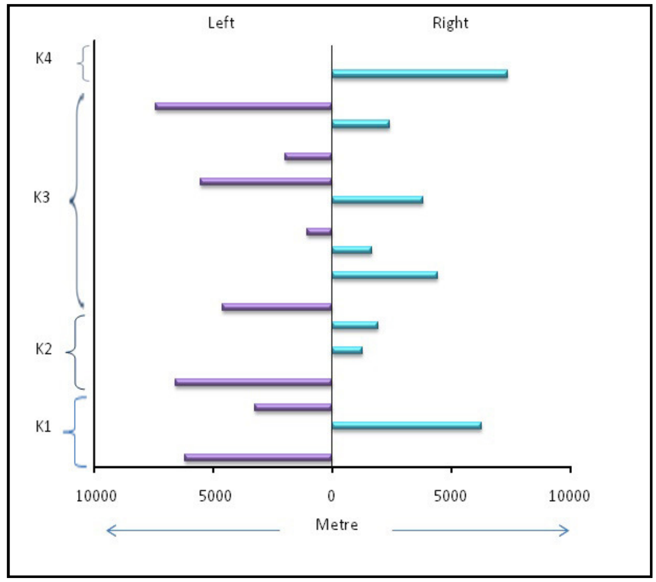


Figure-19
Directionality of Migration length of stream in 2010 in reference to course of 1955

Directionality of Channel Migration: The figure 18 and figure 19 displays the directionality of migration length. Figure 18 shows the directionality of migration length of Kalindri in 1955 in reference to the course of 1924 (Phase-I). Total length of migration in 1955 is considerably higher in right side of river than left side. The higher length of K4 reach depicts that higher rate migration of course in K4 at right bank. In K2 reach the general trend of directionality of channel migration is almost towards right bank in Phase-I.

The Phase–II mainly showing the directionality of channel shifting in 2010 with respect to course of 1955. This phase displays quite different situation than previous phase where directionality of migration is almost towards its left bank of the concerned river. Overall situation reflect constant and frequent nature of channel sifting towards both side of the river during various period with varying intensity. But according to field visit-2013, 2014 and 2015 the rate of shifting of river in recent years decreases than previous decades.

Reach specific migration consistency analysis: The Table-4 displays the reach wise summary statistics of migration rate. According to this table migration rate is almost 28.60metre per year during period 1924to1955 (Phase1). During Phase 1 in K2 reach average rate of migration was almost 14.23m./year, the rate was decreasing in to 12.58 m. /year in Phase 2 within K2 reach. K3 reach in Phase1displays higher rate of migration than the situation of K3 reach in phase-2. From 1924 to present the migration rate decreases as the migration rate in 1924-55 was recorded 14.76m./year which is reduced into 8.30m. /year in Phase 2. But the variation of migration rate both the side of river increase in Phase 2 within K3 then previous phase. Migration rate within of K4 reach in Phase 2 almost reduced to half of the total volume of migration rate recorded in Phase 1.

The migration rate recorded 28.60m/year in Phase1 which is reduced to 11.31m/year in Phase 2 for K4 reach. Variation of migration in Phase 1 within K1 reach is very high but the situation has been converted in to stable condition in Phase2 within this particular reach. The table-4 depicts that co-efficient of variation in K1 in Phase 1 is 1755.30% during 1924 -1955 which has been reduced 12.79 % within the period of 1955 to 2010 which indicates the stable situation in K1 in recent years. In overall the rate of migration almost decreases in Phase2 than the rate of Phase1 (within all of reaches) but the reach wise variation of migration is not following any general trend.

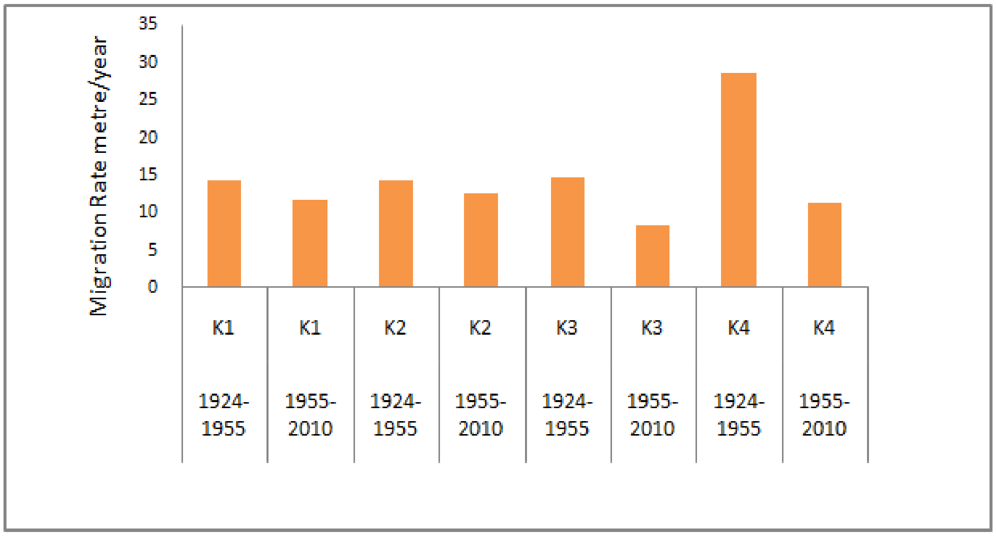


Figure-20
Reach specific migration rate

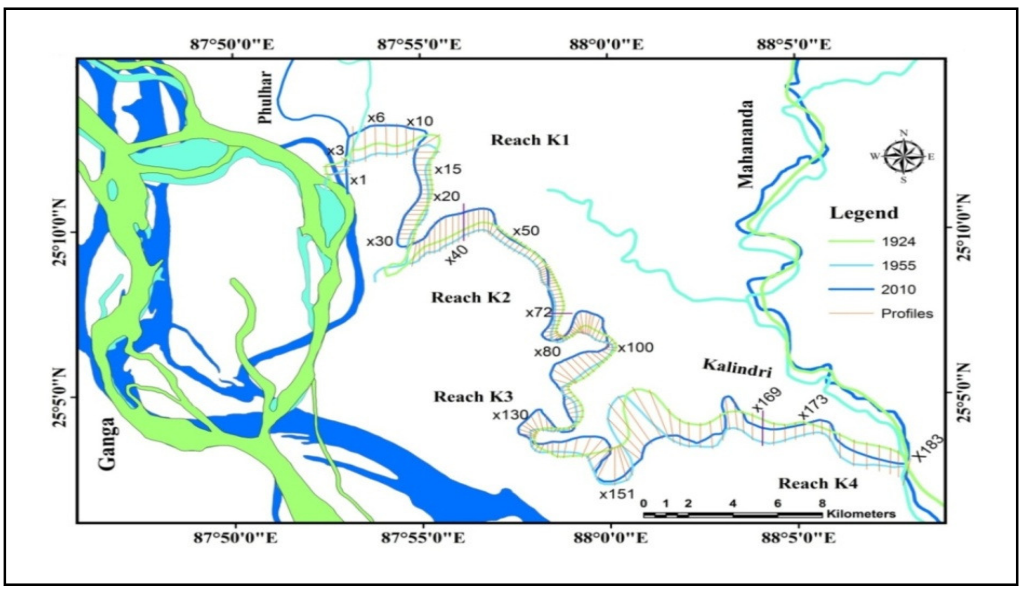


Figure-21
Section lines over of courses of Kalindri of various time periods for meassurement of channel migration rate

Table-4
Reach specific summary of migration rates along different section lines

Migration rate metre/year								
Year	1924-1955(Phase1)				1955-2010(Phase2)			
Reach Id	K1	K2	K3	K4	K1	K2	K3	K4
Mean	14.23	14.23	14.76	28.60	11.74	12.58	8.30	11.31
Median	354.61	14.39	7.26	30.12	13.33	7.09	8.14	11.11
Standard Deviation	249.80	2.46	18.35	12.18	1.50	6.63	19.60	3.95
Co-efficient of variation (%)	1755.30	17.31	124.30	40.44	12.79	52.71	236.14	34.92

Figure-22
Source of Kalindri River, October, 2014

Figure-23
Source of Kalindri river. May 2015

Conclusion

The study suggests that the Kalindr river was highly migration prone and showing a long history of lateral shifting of its course. Before 70's decade of previous century the Kalindri River originates from the river Phulhar at Debipur (Figure-1).In that period Phulhar sends its huge volume of water through the channel of Kalindri into Mahananda River. Volume, Discharge and velocity etc. are relatively higher in that period than present. According to field study both the bank of the river formed by alternative deposition of sand, silt and clay. At K3 reach almost 3 metre below the surface of the soil profile there is a layer of fine sand which converted the region prone to migration and bank erosion. Early 70's of the previous century the construction of Farkka barrage project over the Ganga completed, the project is designed to serve the need of preservation and maintenance of the Calcutta Port.

Constructions of Nurpur barrage over the Klindri River also completed for maintenance and control the excessive discharge toward the downstream of the barrage, huge volume of water of Ganga diverted through the feeder canal to feed the Calcutta port. Suddenly the level of water of Phulhar drops and at the mouth of Kalindri flow of water prevented by sand bars. The course between Debipur to Najirpur converted into a pool of line with stagnant water for inadequacy of water and finally Kalindri left that portion (debipur to Najirpur) and create a new link at Najirpur is the present source of the river. According to field study 2013, 2014 and 2015 lateral channel migration of Klaindi almost stopped due to inadequate volume of water. As the level of water of Phulhar drops the discharge, volume, velocity of water of Kalindri decreases. In present situation except rainy season the course of Kalindri remain dry for scarcity of water as the mouth of the river kalindri blocked by sand deposition and siltation (Figure-22 and 23).

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