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IDENTIFICATION OF CHANNEL MIGRATION BEHAVIOUR AND DELINEATION OF HISTORICAL CHANNEL MIGRATION ZONE OF KULIK RIVER WITHIN THE BARIND TRACT OF INDO-BANGLADESH

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ABSTRACT

Kulik river of barind tract of Indo-Bangladesh has been experienced significant channel migration and avulsion. Frequent shifting of channel invites instability in life and livelihood pattern of the people concerned astride. So, it is very necessary the migratory behaviour of the channel, its zone of wandering and its consequences on land loss and land building. This study mainly intends to find out migration behaviour of the channel since 1951 to 2014, delineation of channel migration zone and assessing land building and land loss in very recent times. For capturing migration behaviour, indices like dynamic channel shifting index, index of channel shifting asymmetry and lateral stability index have been used. Historical channel migration zone has been identified overlying all the previous courses and land loss and build has been detected comparing channel courses of two phases. From the analysis, it is found that channel course is frequently migrates over time and reach specific variation does exist. Total area under historical channel migration zone is 82.679787sq.km; average width of this zone is 1.34km. Both area and width of the lower reaches are usually greater than upper reaches. Both land building and land loss have been running simultaneously but net land loss is 66.46% which is of great concern to the river bank dwellers. For safe living and safety of the properties, it is better not to implement heavy infrastructures in this region.

KEYWORDS: *Channel migration, Lateral stability index (LSI), Dynamic channel shifting index (DCSI), Historical channel migration zone (HCMZ) and Land loss and land building.*

1. INTRODUCTION

Lateral movement of a channel, whether in a state of dynamic equilibrium or in an unstable state adjusting from one equilibrium condition to another, can be generalized as a response to the flow strength (water discharge and channel slope) and the sediment supplied to the system. Depending on the input conditions, lateral movement can take different forms. Some possibilities include: narrowing, widening, meander migration, avulsion and cutoffs. The varying form of the response depends upon the input conditions and the existing pattern and geometry of the channel (Friedman et al. 1998). Rivers exhibiting different planform types have been shown to move at different rates and to result from different causes or mechanisms (Brice 1982; Friedman et al. 1998). This section explores existing studies of the mechanisms by which channels move laterally, the rates of movement, and methods used to measure lateral movement. Lateral movements occur at different rates and are caused by different processes. Mechanisms of movement also vary with planform. Meander movement has been studied thoroughly (e.g., Hooke 1977) and can be broken down into several different types of movement like extension, translation, rotation, enlargement, lateral movement and complex change. Meanders can migrate consistently across their floodplain by eroding the concave bank and accreting on the convex bank (extension) or they can migrate down valley (translation). Braided rivers can move laterally by avulsion, cutoffs, migration and width change like extension and translation, rotation and increase in wavelength, rotation, extension and translation. For understanding detail mechanisms of channel migration, one can consult Parker and Ikeda (1989) and Elliott (1984). Both autogenic (in channel factors) and allogenic (external factors) are explained vividly.

The ***Channel Migration Zone*** delineates areas that have a moderate to high risk of channel occupation due to channel migration over the next 50-60 years (Skidmore, et al, 1999; Rapp and Abbe, 2003). With regard to its application as a management tool, a guiding document on techniques for CMZ delineation by the Washington Department of Ecology (Rapp and Abbe, 2003) states the following:

"The principal goal of delineating the Channel Migration Zone (CMZ) – the area where a stream or river is susceptible to channel erosion – is to predict areas at risk for future channel erosion due to fluvial processes. CMZ delineations help reduce risks to human communities by guiding development in and along river systems away from such areas. Limiting development within CMZs also reduces the costs of repairing or replacing infrastructure and major civil works that might otherwise be threatened or damaged by channel migration. Additionally, CMZ delineations can provide guidance in reducing degradation and loss of critical aquatic and riparian habitats, helping assure that fluvial process are accommodated and that the river landscape is not permanently degraded or disconnected from the river by development."

The impact of dam construction (as external factor) on downstream channel pattern and width is documented by numerous studies including Surian (1999), Williams and Wolman (1984), Kellerhals and Church (1989), Shields et al. (2000), Brookes (1992) and Xu (1996a, 1996b, 1996c, 1997a, 1997b), to name a few. Most often the change in channel pattern resulting from an upstream dam involves simplification of the channel, often from a multi-thread channel to single-thread (Brookes 1992). Channel shrinkage is documented on the Platte River following diversion and regulation from 1940 to 1995 (Johnson 1998). Varying response of meandering vs. braided rivers to dam construction has also been documented (Johnson 1998; Friedman et al. 1998).

Studies of the impacts of dams on lateral migration rates are not abundant, though most studies report decreased lateral movement following dam construction (Bradley and Smith 1984; Shields et al. 2000; Johnson 1992, 1998; Friedman et al. 1998). Shields et al. (2000) studied the 37 impacts of Fort Peck dam on lateral migration and channel pattern of the Missouri River.

Friedman et al. (1998) found that the rates of lateral migration on already meandering rivers decreased following construction of dam. Other studies document declining migration rates in meandering rivers where peak flows were reduced by dam construction (Johnson 1998; Scott et al. 1997). Xu (1997a) studied changes in lateral migration rates on the Hanjiang River in China. Pre dam measured bank erosion rates were 20-25 m/year and post dam they were about 7 m/year right after the dam and about 35 m/year 25 years later. He showed a positive relationship between braiding and number of bars per unit length of channel with bank erosion rate.

Leopold and Wolman (1957), Lane (1957, from Bauer 1999, pp. 69), Van den Berg (1995), Parker (1976), Change (1979) and Dade (2000) all demonstrate the shift from multi-channel toward a single thread straight or meandering configuration.

In the present paper, the main objectives are to detect channel migration behaviour of Kulik river at different reaches. Another major objective of this paper is to delineate Historical Channel Migration Zone (HCMZ) since 1951 to 2016. Here it must be mentioned that although this time span is taken into account, but while delineating this migration zone, cut off channels, ox bow lakes have also considered indicating earliest time beyond 1951. It is further to be investigated that how the palaeo channels, ox bow lakes are associated with present river course.

2. STUDY AREA

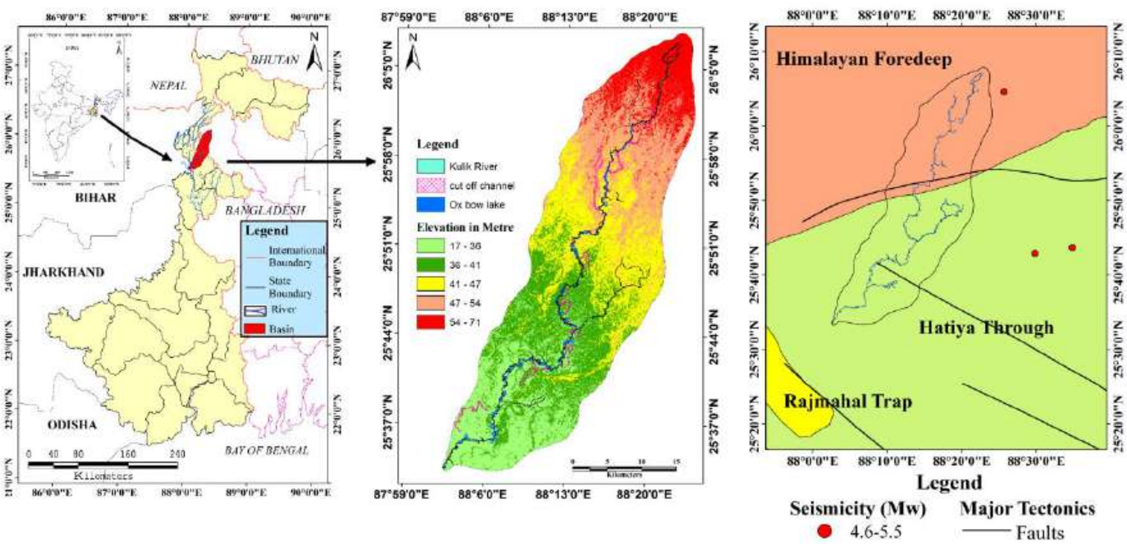


Figure 1: Location of the study area

The Kulik river basin is lie on of Barind tract of mature alluvium in the Indo-Bangladesh transboundary region. The basin area of this river is delimited by 25º32′00″ N to 26º10′06″N latitude and 87º60′00″ E to 88º24′56″ E longitude. Total length of the river is 133.27 km and basin area is 1038.513sq.km. Barind tract is an undulating uplifted flood plain and this part is to some extent elevated than surrounding physiographic sub regions (Ground water task force, July, 2002). Famous Kulik Bird Sanctuary adjacent to the Raiganj municipality is located astride of this river. According to UGGS topo sheet Kulik River was directly merged with Mahananda river but due to extreme events Kulik River drains to river Mahananda via Nagar river. Tectonically the upper segment of the basin is under Himalayan foredeep and lower segment under Hatiya through. Mature alluvium predominates over the region. Very adjacent part along river Kulik is inundated frequently and therefore newer alluvium are found. Region comes under sub humid monsoon climate with alternate wet and dry spell. Average annual rainfall of this region is 2280.53 mm. Out of which almost 80% rainfall happens during monsoon season (June to October). Intensive rainfall in this period often invites inundations in this region. Recent water trapping mechanism through sluice gates and diversion of water has reduced water availability in this river. At present average water level during monsoon time is 27.07 m. and during pre monsoon time river channel almost dry. Before 20 years ago, such water levels were 1.20 m (20-30%) above the present levels.

3. MATERIALS AND METHODS

River courses of different years have been extracted from Landsat satellite imageries of different sensors as mentioned in table 1. Most of the cases digitization of channel courses and other necessary features has been done from single band image. Google earth satellite image of the concerned region is also used as collateral materials for the same purposes. River courses of 1951 and 1969 have been taken from USGS toposheets and toposheets of survey of India (SOI) respectively. Here it is to be mentioned that necessary scale compromising is being done for keeping all these in single frame. Details of satellite images are described in table 1.

Table 1: Presents the specifications of Landsat 4-5 TM and 8 OLI images

Satellite	Sensor	Path/Row	Year	Resolution (m)	Wavelength (µm)
Landsat 4-5	TM (Thematic Mapper)	139/42	1988-2010	30	Band 1: 0.45–0.52 Band 2: 0.52–0.60 Band 3: 0.63–0.69 Band 4: 0.76–0.90 Band 5: 1.55–1.75 Band 7: 2.08–2.35
Landsat- 8	OLI (Operational Land Imager) and TIRS (Thermal Infrared Sensor)	139/42	2011-2014	30 (For band 8 resolution is 15 m)	Band 1: 0.435–0.451 Band 2: 0.452–0.512 Band 3: 0.533–0.590 Band 4: 0.636–0.673 Band 5: 0.851–0.879 Band 6: 1.566–1.651 Band 7: 2.107–2.294 Band 8: 0.50 - 0.68 Band 9: 1.363–1.384 Band 10: 10.60 - 11.19 Band 11: 11.50 - 12.51

3.1 Methods for identifying degree and direction of channel migration

Methods for measuring channel migration are well explained in the many scientific literatures (Shields et al 2000; Urban and Rhoads, 2004). 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. For measuring channel migration, polygon area method, dynamic channel shifting index (DCSI), index of channel shifting asymmetry (CSAI) and lateral stability index (LSI) have been used.

3.2 Polygon Area Method

The methodology for measuring total cannel migration between years is similar to that presented in Shields et al (2000) and Hughes et al (2006). The migration rate has been calculated using the following equation as also used by MacDonald et al (1991); Hughes et al (2006) and Hooke (2008).

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

Where: R_m represents migration rate, A is the area of the 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 centrelines.

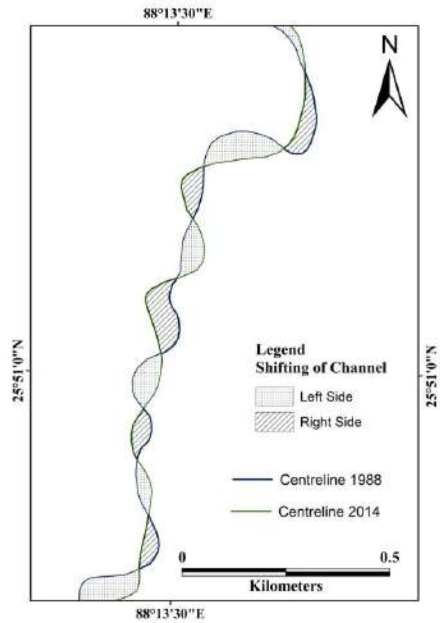


Figure 2: Method for calculating shifting area in different year (this figure is the portion of Reach 7)

In this work, several phases have been taken into consideration like 1951-1969, 1969-1977, 1977 - 1982, 1982-1988, 1988-1990, 1990-1995, 1995-2000, 2000-2005, 2005-2010 and 2010-2014. Shifting area has been calculated for each period of time. Based on these areas, in later stage dynamic channel shifting index (DCSI) has been calculated.

3.3 Dynamic Channel Shifting Index (DCSI)

Dynamic channel shifting index (devised by the present authors) highlights cumulative degree of channel shift at selected phases per unit length of stream. Here, total shifting area in terms of channel command area in different phases is being calculated and as most of the cases length of the river is not to be uniform, so it is calculated per unit length. While calculating shifting area, it is not considered that in which directions (divergent or convergent) channels are migrating because here only migration is the principal interest.

$$DCSI = Log\left[\frac{\left(\sum_{t=1}^{n} A_{t_1,\ldots,t_n}\right)}{(R_l)}\right]$$

Where,

$A_{t_1,\ldots,t_n}$ indicates channel shifting area in selected time interval in reference to previous phase and R_l means reach length

No definite range of DCSI value is generated from this equation. But, more value of it indicates greater dynamicity of channel shift and vice versa.

3.4 Index of Channel Shifting Asymmetry (CSAI)

This index (devised by the present authors) explains the degree of channel shift differential in two sides of a river. High difference of area in two sides indicates lop sided channel shifting. Of course it may be for natural or manmade causes.

$$CSAI = \frac{\left| \left(\sum_{t=1}^{n} \square R_{a_{t_1,\ldots,t_n}} - \sum_{t=1}^{n} \square L_{a_{t_1,\ldots,t_n}} \right) \right|}{\sum_{t=1}^{n} \square T_{a_{t_1,\ldots,t_n}}}$$

Where,

$\sum_{t=1}^{n} \square R_{a_{t_1,\ldots,t_n}}$ means cumulative area of channel shift in different phases at the right hand side of the main channel

$\sum_{t=1}^{n} \square L_{a_{t_1,\ldots,t_n}}$ means cumulative area of channel shift in different phases at the left hand side of the main channel

$\sum_{t=1}^{n} \square T_{a_{t_1,\ldots,t_n}}$ means cumulative total area of channel shift in different phases at both side of the main channel

This value ranges from 0-1. '0' value shows there is no disparity of channel shifting in two sides of the river. '1' value shows absolutely lop sided trend. In the equation, modulus sign is used therefore, it is difficult to understand the wings of asymmetry. But, if is required the one can calculate it without this sign and it is possible to introspect it.

Lateral channel movement has been measured by bankline change in other studies, such as Brice (1982), Nanson and Hickin (1986), and Hooke (1986). Others have chosen to quantify lateral movement by using the channel centreline (Shields et al. 2000) or by area of floodplain eroded (Marston et al. 1995; Lewin et al. 1978). Hooke (1986) found that maximum rates of erosion between bank lines were higher than those between centrelines, but were of the same order of magnitude. Also, she found that difficulties in distinguishing eroded from deposited areas made measurement of average lateral movement rates by quantifying areas of movement and dividing by the reach length unsatisfactory.

3.5 Lateral Stability Index (LSI)

It is simply a ratio between unchanged active channel area and previous active channel area. Using the overlay coverage of different years, the percentage of the "active channel" that remained in the area of the old active channel was measured:

$$LSI = \frac{\left| \left(AC_{a_{t_1}} - AC_{a_{t2}} \right) \right|}{AC_{a_{t_1}}}$$

LSI= Lateral stability index; AC_{at1}= Active channel area of t_1(previous) time phase and AC_{at2}= Active channel area of t_2 (previous) time phase

A value close to 1 indicates that the channel has not moved and is relatively stable. Small values of the index indicate that the channel has moved from its location at the beginning of the time period.

3.6 Methods for identification of historical channel migration zones

The present study mainly concentrates on historical channel migration zone considering past channel courses. For doing this at least 50-60 years of time span should be taken into account (FEMA, 1999; Rapp and Abbe, 2003). Pollack and Kennard (1999), Bolton and Shellberg (2001) reported that many of the scholars think that 100 years time frame is more appropriate for delineating HCMZ. In this study more than 66 years including relic channels courses has been considered. The method for delineating the HCMZ is to overlay the digitized polygons for the bank full channel for each time series, and merge those polygons into a single HMZ polygon. Same method is also suggested by Graf (1984), Perkins (1996), Skidmore et al. (1999), Ham and Church (2000) for delineating channel migration corridor.

3.7 Methods for Predicted Channel Migration Zone

For demarcating the future channel migration zone 580 cross profiles have been drawn over the overlaying rivers of different phases. Shifting of younger channel is measured along all the cross sections in reference the older channel. Net migration has been calculated based on total leftward or right ward shifting of channel in selected phases. For calculating yearly rate of migration, net migration is divided by total historical length of time. For defining 100 years predicted migration zone migration rate is multiplied with year of prediction. This method is defined by FEMA (1999), Rapp and Abbe (2003). Mukherjee and Pal (2017) also applied this method for future prediction of channel migration.

4. RESULTS AND ANALYSIS

Based mainly on sinuosity, presence of relic channels and channel bifurcation, 17 channel reaches have been identified in Kulik river (table 2). Channel migration has been analyzed based on these reaches. For micro level details, superimposition of channels of different periods has been done separately for different reaches. Some superimposed river courses of various reaches have been shown in figure 3.

Table 2: Characteristics of reaches of Kulik River

Reach	Length (km.)	Mean Width (Metre)	SD	CV width (%)	Sinuosity	Frequency of Ox bow Lake
R1	5.186	64.875	20.025	30.867	1.49	0
R2	9.248	102.75	58.127	56.571	1.10	0
R3	4.046	16.333	6.286	38.486	1.35	2
R4	10.505	29.833	10.043	33.664	1.45	25
R5	12.487	33.785	13.868	41.048	1.57	53
R6	10.607	42.1	22.413	53.238	1.89	23
R7	10.696	41.188	22.238	53.991	2.13	23
R8	8.479	50.666	26.239	51.788	1.78	16
R9	5.079	30.111	13.476	44.754	1.91	8
R10	5.043	26.571	6.604	24.854	1.31	20
R11	5.833	36.818	17.302	46.993	1.92	8
R12	20.861	41.111	27.342	66.508	2.65	49
R13	3.696	33.166	7.494	22.595	1.62	6
R14	3.215	45.125	21.51	47.668	1.28	8
R15	4.895	40.363	9.124	22.605	1.54	18
R16	6.95	41	12.398	30.239	1.60	17
R17	6.444	38.416	7.403	19.271	1.61	5

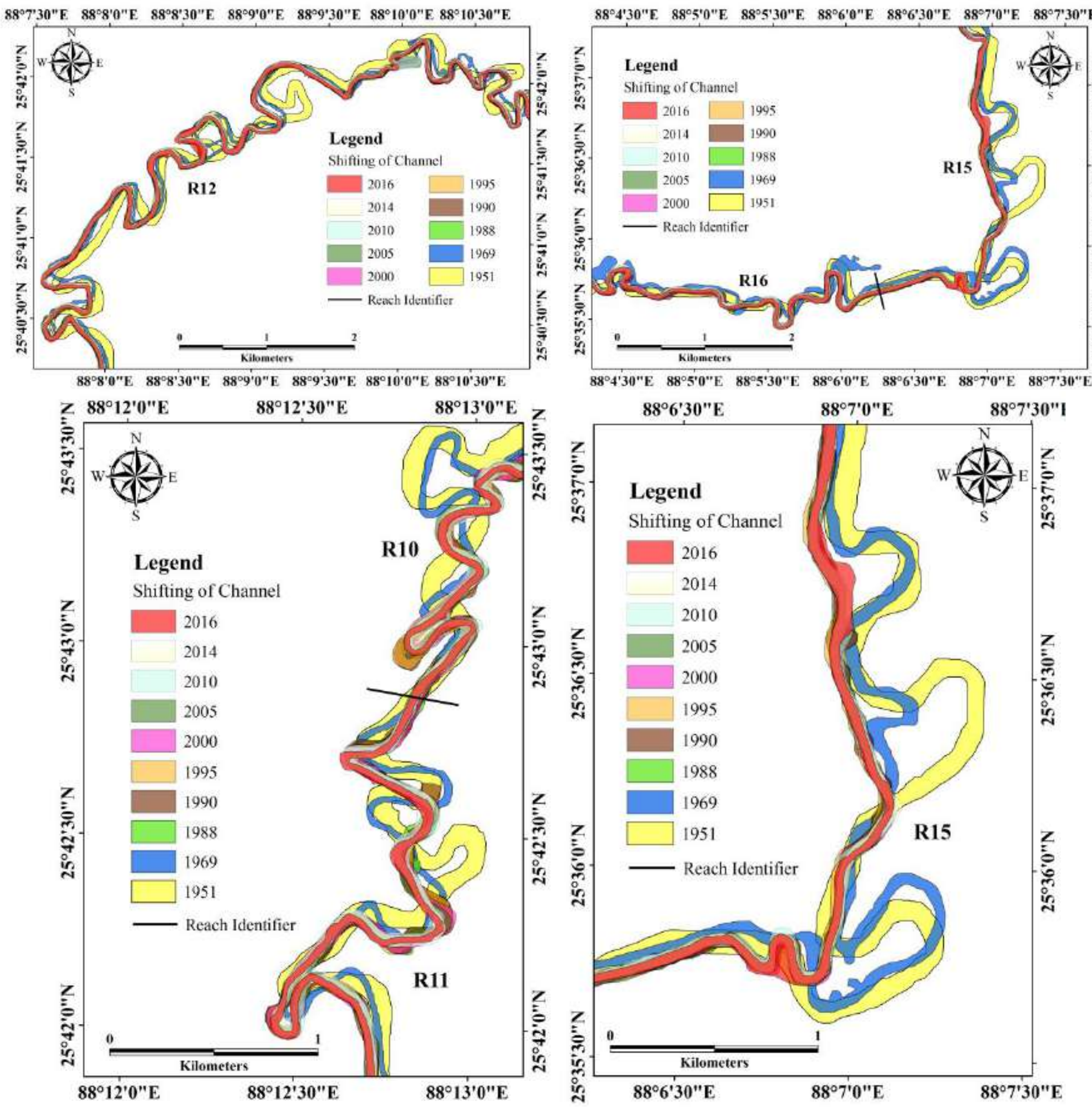


Figure 3: Channel migration (1951 to 2016)

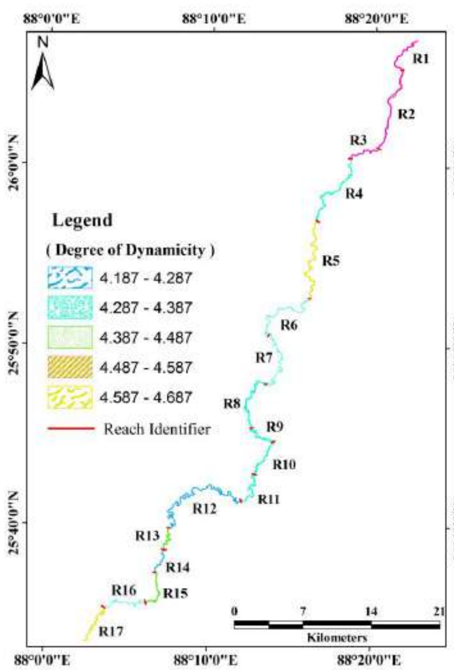
4.1 Measurement of Dynamic Channel Shifting Index

Phase wise calculation of channel command area and shifting of channel toward left and right in reference to the previous course, it is found reach 17 is highly migratory followed by reach 5 and 6. At reach 17, rate of channel migration is 48653.63sq.m./km. channel length. DCSI value also speaks the same. At reach 17 DCSI value is 4.687 (table 3), so here from it can be stated that highest level of channel changes have occurred at this reach as historical time phase considered. From left and right ward migration trend, it is observed that the right ward trend is quite enhanced in compare to the left. Obviously, from this it is also clear that right side of the channel is more susceptible for both channel migration and bank erosion. Figure 4. shows classification of channel reaches based on their degree of channel shifting dynamicity. Five classes have been shown indicating their degree of dynamicity. Highest dynamicity is recoded at reach 17 and reach five (DCSI value rages from 4.587 to 4.687) whereas least dynamicity is found at the reaches of 12 and 14.

Table 3: Measurement of dynamicity and asymmetric pattern of Kulik River on the basis of areal shift

Reach	Reach length(km)	Total shift (sq.metre)	total left ward shift (sq.metre)	total right ward shift (sq.metre)	Area of shifting/km. reach	DCSI	Rank based on degree
R1	5.186	182568	47400	135168	35204.01	4.546	5
R2	9.248	330806	185936	144870	35770.54	4.553	4
R3	4.046	133605	63001	70604	33021.5	4.518	6
R4	10.505	229892	138104	91788	21884.06	4.340	11
R5	12.487	585954	391598	194356	46925.12	4.671	2
R6	10.607	455087	140919	314168	42904.4	4.632	3
R7	10.696	232680	119722	112958	21753.93	4.337	12
R8	8.479	169401	72515	96886	19978.89	4.300	15
R9	5.079	115610	59028	56582	22762.35	4.357	10
R10	5.043	115765	58371	57394	22955.58	4.360	9
R11	5.833	117131	67764	49367	20080.75	4.302	14
R12	20.861	321163	132037	189126	15395.38	4.187	17
R13	3.696	100003	19011	80992	27057.09	4.432	8
R14	3.215	53422	24619	28803	16616.49	4.220	16
R15	4.895	133335	52271	81064	27239.02	4.435	7
R16	6.95	143254	55523	87731	20612.09	4.314	13
R17	6.444	313524	39826	273698	48653.63	4.687	1
Total	133.27	3733200 (100%)	1667645 (44.67%)	2065555 (55.33%)	28011.46	4.447	

Note; reach 17 is the most dynamic in nature rather than any other reach



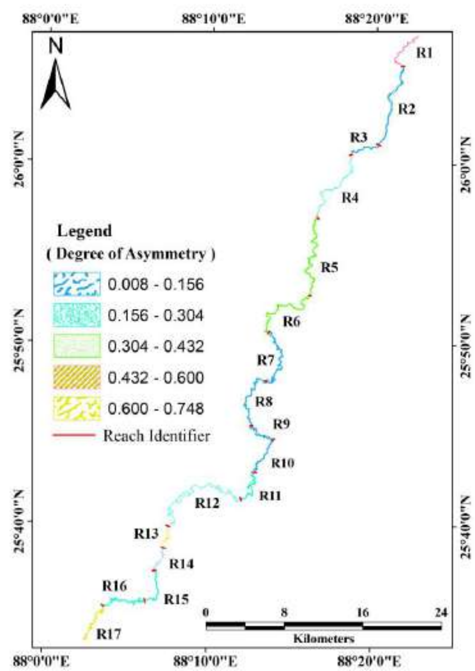


Figure 4: Dynamic channel shift index at different reaches **Figure 5: Channel Shifting Asymmetry Index**

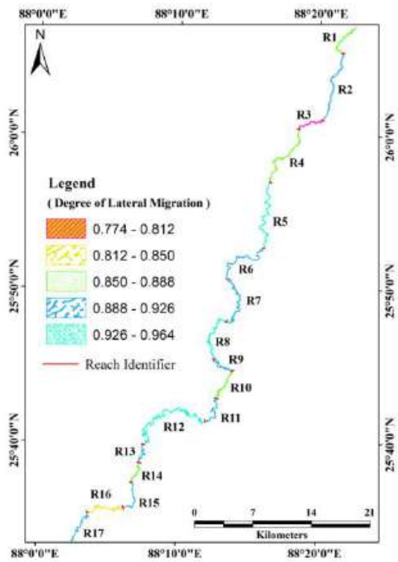


Figure 6: Lateral Stability Index

4.2 Channel Shifting Asymmetry Index (CSAI)

Table 4: Showing channel shift asymmetry at different reaches and as a whole

Reach	CSAI	Remarks	Reach	CSAI	Remarks
R1	0.481	Right ward skewed	R10	0.008	Left ward skewed
R2	0.124	Left ward skewed	R11	0.157	Left ward skewed
R3	0.057	Right ward skewed	R12	0.178	Right ward skewed
R4	0.201	Left ward skewed	R13	0.620	Right ward skewed
R5	0.337	Left ward skewed	R14	0.078	Right ward skewed
R6	0.381	Right ward skewed	R15	0.216	Right ward skewed
R7	0.029	Left ward skewed	R16	0.225	Right ward skewed
R8	0.144	Right ward skewed	R17	0.746	Right ward skewed
R9	0.021	Left ward skewed	Total	0.107	Right ward skewed

Overall channel shift for the entire river is highly asymmetric as the CSAI value is very small (0.107) which is near to 0. Reach specific analysis portrays maximum number reaches (11 numbers) have shifted towards right and rest have shifted toward left. From this trend, it can be predicted that right side is more vulnerable to channel migration. According to their degree of asymmetry, reach 10 is highly asymmetric (CSAI=0.008) followed by reach 9 (Table 4). On the contrary, reach 17 is quite symmetric in nature (CSAI=0.746). Figure 5 illustrates the reach wise CSAI pattern explaining the above mentioned facts.

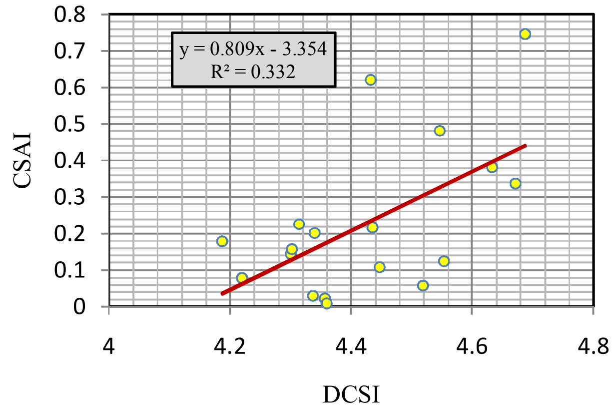


Figure 7: Control of DCSI on CSAI

Figure 7 shows the control of DCSI on CSAI through linear regression line. For the regression model (y = 0.809x - 3.354) and R^2 value (0.332) it can be said that dynamicity of channel migration creates a kind of channel shifting asymmetry in very positive direction. High degree of dynamicity brings high degree of channel asymmetry.

4.3 Control of Elevation Factor on Degree of Channel Shifting

Here, it is intended to know is there any control of elevation on channel shifting magnitude. Table 5 shows the mean elevation of different reaches of channel and their respective channel migration area. Result does not represent any strong control of elevation on migration magnitude (Figure 8).

Table 5: Range of different reaches and their respective degree of channel shift

Reach	Reach length(km)	Elevation Range (metre)	Mean Elevation(metre)	Channel Migration Area (sq.metre)
1	5.186	63-56	59.6	182568
2	9.248	56-54	55	330806
3	4.046	54-53	53.5	133605
4	10.505	53-45	49	229892
5	12.487	45-41	43	585954
6	10.607	41-43	42	455087
7	10.696	43-44	43.5	232680
8	8.479	44-41	42.5	169401
9	5.079	41-33	37	115610
10	5.043	33-34	33.5	115765
11	5.833	34-39	36.5	117131
12	20.861	39-32	35.5	321163
13	3.696	32-28	30	100003
14	3.215	28-31	29.5	53422
15	4.895	31-30	30.5	133335
16	6.95	30-30	30	143254
17	6.444	30-32	31	313524

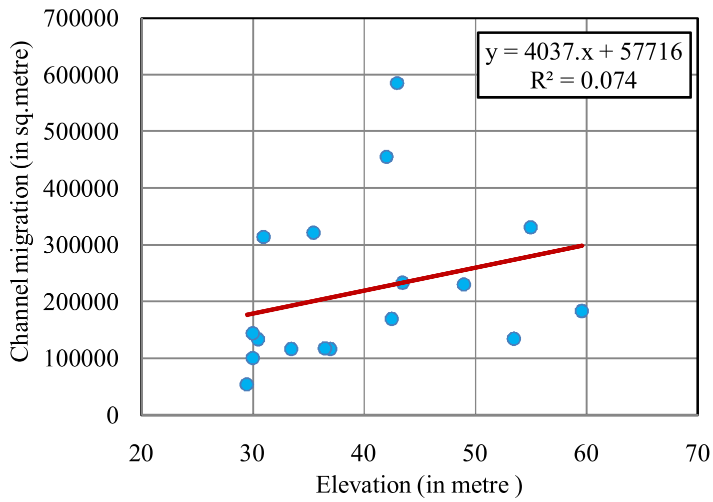


Figure 8: Control of elevation on channel migration area

4.4 Lateral Stability Index

Lateral Stability Index (LSI)Table 6 depicts in all the time phases selected for study the channel courses are stable as LSI values are very near to 1. Even there is no definite trend of channel stability change over advancing time. Table 7 shows reach wise trend of LSI over different time phases. Coefficient of variation (CV) for the same has been calculated for bringing degree of phasal fluctuation of stability. Reach wise stability pattern and inter phase fluctuation represents that most of the reaches are stable with little variations. Strong spatial differences are not found regarding LSI (figure 6). Nanson and Hickin (1986), Lawler et al. (1999), Hooke (1979) and MacDonald (1991) all found that lateral migration increased as the energy of the flow increased in meandering rivers. In this river degree of channel historical change of stream energy is very low and it causes very little lateral channel shifting. In recent time, installation of sluice gates and diversion of water from Kulik river to its catchment area will cause for lowering stream energy in near future. So, if it is analyzed only for the recent years, its degree may be quite high. For describing LSI, scholars in this field endorsed some major driving factors like drainage area and bank material (Hooke, 1980), channel planform and sediment supply in the channel (Hickin and Nanson, 1975), bank resistance (Hickin and Nanson, 1984), geological control (Thorne, 1991), stream energy (Lawler et al, 1999; Bladesoe, 1999), damming over stream (Shields et al, 2000) and toe materials of the river bank slope (Nanson and Hickin, 1986). Almost uniform type of bank materials, geological set up are responsible for very little lateral shifting of channel. Not directly dam but sluice gates and water diversion is the emerging cause for changing nature of lateral channel shifting. The involvements between flow energy, plan form and migration (lateral) can be coalesced to recommend that lateral migration may boost with rising stream flow energy up to a threshold. Above the threshold, the river may either migrate laterally within a wide straight braid plain, or continue to wander, avulse and braid resulting in extremely high migration rates, such as on the Brahmaputra River (Coleman, 1969). Several studies found that there was a maximum erosion rate for meandering rivers corresponding to a *Rc/W* somewhere between two and three (Hickin and Nanson 1975, 1984; Nanson and Hickin 1983; Biedenharn et al. 1989).

Table 6: LSI for the entire river in different phases

Year	Channel command area(sq.metre)	Changed area (sq.metre)	Unchanged area (sq.metre)	LSI
1988	6554705	803046		
1990	7357751	267967	5751659	0.877
1995	7625718	79516	7089784	0.963
2000	7546202	212132	7546202	0.989
2005	7758334	245541	7334070	0.972
2010	7512793	330185	7512793	0.968
2014	7842978		7182608	0.956

Table 7: LSI for different reaches in different phases

Reach	1988-1990	1990-1995	1995-2000	2000-2005	2005-2010	2010-2014	Average LSI	SD	CV(%)
R1	0.995	0.993	0.924	0.680	0.826	0.881	0.883	0.109	12.312
R2	0.949	0.927	0.972	0.840	0.948	0.718	0.892	0.088	9.904
R3	0.551	0.794	0.851	0.654	0.868	0.925	0.774	0.130	16.849
R4	0.954	0.842	0.864	0.779	0.870	0.969	0.880	0.065	7.400
R5	0.999	0.998	0.891	0.894	0.950	0.986	0.953	0.046	4.797
R6	0.863	0.963	0.935	0.852	0.843	0.985	0.907	0.056	6.220
R7	0.945	0.822	0.965	0.899	0.978	0.868	0.913	0.055	6.080
R8	0.977	0.910	0.972	0.946	0.945	0.861	0.935	0.040	4.232
R9	0.902	0.928	0.986	0.898	0.886	0.884	0.914	0.035	3.869
R10	0.665	0.998	0.969	0.922	0.940	0.807	0.883	0.114	12.943
R11	0.820	0.872	0.885	0.907	0.992	0.957	0.906	0.056	6.216
R12	0.873	0.996	0.965	0.980	0.970	0.998	0.964	0.042	4.387
R13	0.729	0.995	0.858	0.986	0.936	0.869	0.895	0.091	10.138
R14	0.662	0.943	0.916	0.926	0.937	0.899	0.881	0.099	11.215
R15	0.552	0.987	0.982	0.991	0.974	0.872	0.893	0.158	17.691
R16	0.622	0.977	0.840	0.903	0.911	0.821	0.846	0.112	13.260
R17	0.796	0.996	0.919	0.922	0.979	0.858	0.912	0.068	7.489

4.5 Historical Channel Migration Zones

FIGURE 9(A-B) REPRESENTS HISTORICAL CHANNEL MIGRATION ZONE IN TWO PARTS ALONG RIVER KULIK DEMARCATING THE IDENTIFIED REACHES. TABLE 8 CALCULATED THE AREA UNDER HCMZ AT DIFFERENT REACHES. REACH 12 IN THE MIDDLE SEGMENT OF THE RIVER COURSE RECODED MAXIMUM STRETCH OF CHANNEL MIGRATION CORRIDOR. VERY LOW SLOPE FACTOR AND REGIONAL FLAT OR SLIGHT TOPOGRAPHIC DEPRESSION IS CAUSED FOR SUCH ACUTE CHANNEL SHIFTING CONDITIONS. THIS CHANNEL MIGRATION CORRIDOR IS SUBJECTED TO RISK DUE TO STREAM BANK DESTABILIZATION, STREAM INCISION, STREAM BANK EROSION, AND SHIFTS IN LOCATION OF STREAM CHANNELS. RATE OF THESE PROCESSES IS REDUCED AFTER DIVERSION OF WATER FROM KULIK RIVER THROUGH SLUICE GATES. INCREASING CONTROL OF FLOW REGULATION IN RIVER

THROUGH RETAINING WATER IN RESERVOIR OR DIVERTING WATER THROUGH CANAL SYSTEM SHRINKS LATERAL MOVEMENT OF WATER AS REPORTED BY BRADLEY AND SMITH (1984), SHIELDS ET AL. (2000), JOHNSON (1994, 1998), FRIEDMAN ET AL. (1998). WITHIN VERY SHORT SPAN OF TIME ALL THE OTHER EFFECTS LIKE STRAIGHTENING OF MAIN CHANNEL (XU, 1997, SHIELDS ET AL., 2000), ATTENUATION OF ACTIVE CHANNEL WIDTH (FRIEDMAN ET AL. 1998, NICHOLAS ET AL. 1999), DECLINING EROSION RATE (LEON, 1998), MULTI THREAD CHANNEL TO SINGLE THREAD CHANNEL (DADE, 2000) ETC. ARE NOT PROMINENTLY EVIDENT AT THIS STAGE BUT THESE ARE ALSO SOME OF THE FUTURE CASUALTIES. LYNCH ET AL. (1977) ALSO POINTED OUT CHANGING NATURE OF MIGRATION CORRIDOR BRINGS INSTABILITY AND STRESS AMONG THE SPECIES DEPENDING ON THE TOLERANCE OF THE SPECIES AND INDIVIDUAL AND IT MAY LIMIT GROWTH, ABUNDANCE, REPRODUCTION AND SURVIVAL.

TABLE 8: AREA OF HCMZ IN DIFFERENT REACHES

Reach	Area (sq.metre)	Reach	Area (sq.metre)	Reach	Area (sq.metre)
R1	1019979	R7	7303716	R13	1513264
R2	2338036	R8	8475954	R14	1347590
R3	1901152	R9	2250412	R15	3039170
R4	6878584	R10	5442242	R16	2537015
R5	7212687	R11	5750735	R17	1704468
R6	4565899	R12	19398884	-	-

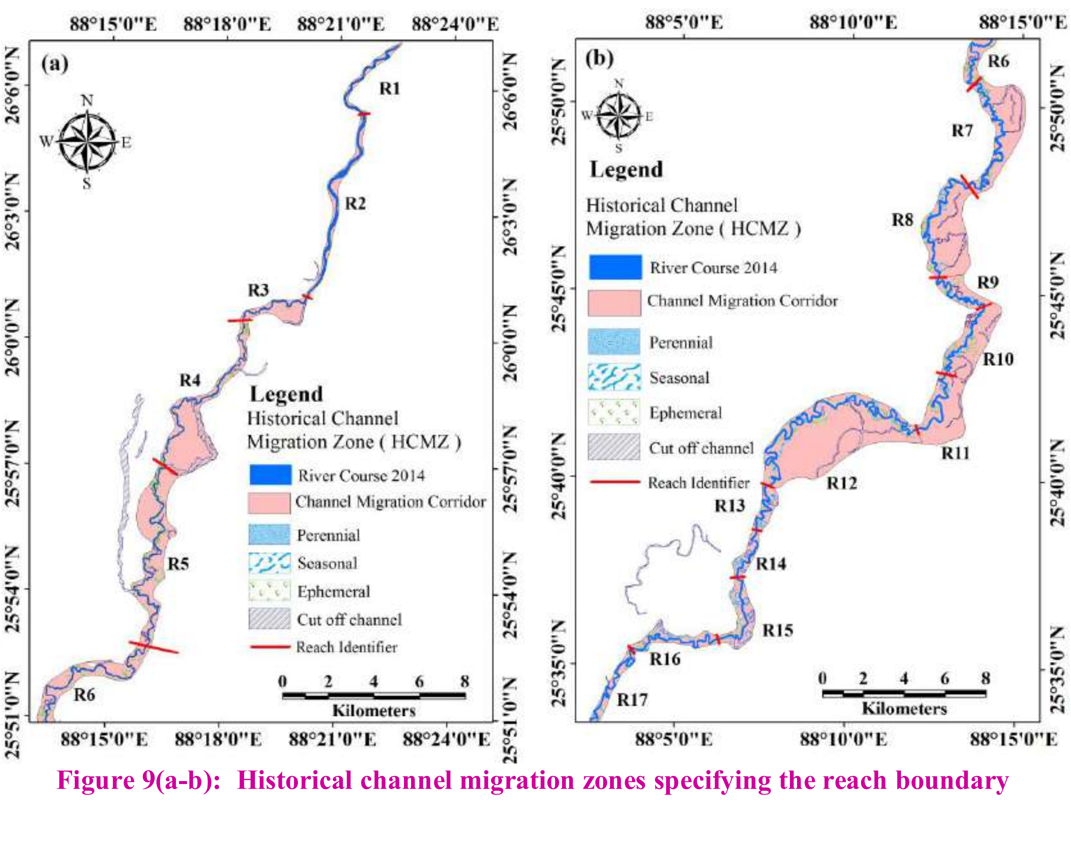


Figure 9(a-b): Historical channel migration zones specifying the reach boundary

4.6 Predicted Channel Migration Zone

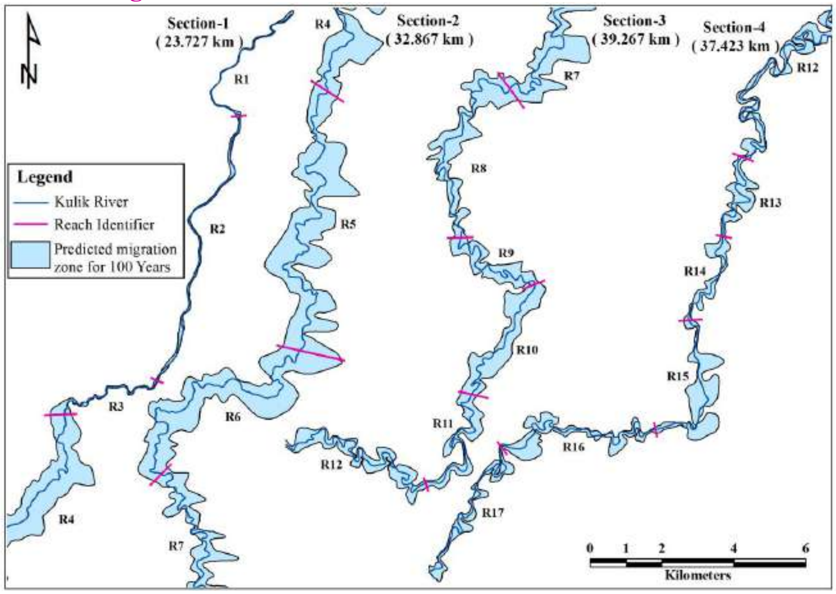


Figure 10: Predicted channel migration zone in coming 100 years

TABLE 9: PREDICTED CHANNEL MIGRATION AREA IN COMING 100 YEARS

Reach	Area (sq.metre)	Reach	Area (sq.metre)	Reach	Area (sq.metre)
R1	212510	R7	4584158	R13	838781
R2	639123	R8	3115746	R14	657396
R3	392404	R9	1523238	R15	1801788
R4	7124316	R10	2371080	R16	1544098
R5	8379961	R11	1369106	R17	1027803
R6	6713787	R12	4201687	-	-

Figure 10 shows predicted channel migration zone for next 100 years dividing entire length of Kulik river into four section for better clarity. Table 9 highlight calculated area under predicted channel migration zone at different reaches. Total predicted migration zone is 46496982 sq.metre. This area is 43.76% lesser than historical channel migration zone. It does mean tendency of channel migration will be reduced. About 43.76% area will be out of migration vulnerability zone in coming 100 years. Reach specific analysis exhibits that reach 5 of the river course will be propulsive for migration but its limit is not beyond historical channel migration zone. Other reaches shows significant squeeze of migration zone. Attenuation of flow (least square regression of flow since 1984 to 2016 is $y = -0.054x + 137.3$ $R^2 = 0.354$) in this river caused by historical shift of Tista system from Mahananda system to which Kulik river belonged, excessive diversion of river water for mainly agricultural purposes. Reduction of flow is directly related with stream energy. Such reduction of channel migration area in the one hand will provide concerned hazard free agriculture land and habitat but brings danger to the riparian ecosystem of this region.

4.7 Land loss and land gain due to channel migration

In flood plain area, land building and land loss due to shifting of channel are two very usual events (Dunne et al., 2010). Channel avulsion often causes diversion of huge water from main river and it creates shortage of water in the channel (Slingerland and Smith, 1998, 2004). Tooth et al. (2007) reported that increases (2-3 times) in floodplain gradient in a downstream direction enhance the probability of such processes. Such incidents encourage channel incision, leaving of extra channel space and thereby gradually new land emerges out (Das and Pal, 2016). Similarly, natural levee, embankment etc. also restrict sediment spilling in its flood plain and aggrades the channel (Mukhopadhyay and Pal, 2009). It often causes emerging of new islands, shallowing of river, partial land building in different parts of the river course (Das and Pal, 2016). Land loss and land gain has been calculated in respect to the comparison of channel command area between two selected phases. It is fact that if channel command area increases than its previous phase, it does indicate occurrences of land loss and other the other hand if channel command area of the later phase is reduced it indicates building of land. Table 10 shows temporal change of land loss and land gain. From the table it is found that event of land loss is more common than land build and therefore, it causes concern to the people who are residing astride. Table 10 indicates channel command area has been gradually increasing over time. Both least square regression trend (y = 15384x + 7E+06) and coefficient of determination (r^2=0.600) establish the same. Net land loss is 66.46%. It is calculated ratioing between area of land build and land loss. Land loss and build is also calculated reach wise at different temporal scales (Table 11). There is no definite trend of land loss and build in different reaches over period of time. It means once a reach was prone to erosion is experienced to land building.

TABLE 10: TOTAL CHANNEL COMMAND AREA OF INDIVIDUAL YEAR

Year	Channel Command Area(sq.metre)	Land loss/ build (sq.metre)
1988	6554705	
1990	7357751	1988-1990: Land loss is 803046
1995	7625718	1990-1995:Land loss is 267967
2000	7546202	1995-2000: Land build is 79516
2005	7758334	2000-2005: Land loss is 212132
2010	7512793	2005-2010: Land build is 245541
2014	7842978	2010-2014: Land loss is 330185

TABLE 11: REACH WISE LAND BUILDING AND LOSS ALONG KULIK RIVER

Land (sq.metre) Year	1988-1990		1990-1995		1995-2000		2000-2005		2005-2010		2010-2014	
Reach	Build	loss	Build	loss	Build	loss	Build	loss	Build	loss	Build	loss
1	1742	-	-	2494	26552	-	-	103537	74276	-	-	42105
2	-	31309	-	47671	19677	-	-	108755	41169	-	-	209884
3	-	52892	-	35129	30733	-	-	60523	31188	-	-	15426
4	22718	-	-	74893	74432	-	-	104767	74991	-	-	15623
5	-	731	-	1578	75215	-	-	64875	33880	-	8895	-
6	-	70015	-	21276	39162	-	-	83516	101465	-	-	8217
7	-	28362	-	97381	-	23413	74977	-	-	13529	-	79901
8	-	9704	-	38945	-	13717	27797	-	-	26723	-	66941
9	-	22231	-	18005	3648	-	2991	-	-	2993	-	30623

10	-	71005	594	-	8815	-	523220	-	-	416108	-	51509
11	-	51969	43454	-	-	38541	34286	-	-	2382	-	13150
12	-	125837	4020	-	-	40569	23831	-	33527	-	-	2544
13	-	51693	-	1250	34731	-	-	3009	13578	-	-	25950
14	-	48484	10862	-	-	16516	15747	-	-	12191	21857	-
15	-	92001	3799	-	5359	-	2612	-	-	7515	43077	-
16	0	102591	8645	0	0	69616	46628	0	0	38017	93114	0
17	0	63476	0	1432	0	33273	34568	0	0	8191	63197	0
	0	797840	0	268680	82679	0	0	215401	249484		0	331733

Table 12 represents the variation of channel command area over different time phases but the degree of variation is not so high as indicated by coefficient of variation (CV varies from 4-21%). So both land building and land loss phenomena are very gradual. From the least square regression trend values it is clear that reach 11, 12, 13, 15 and 17 do not show any significant change over time as indicated by very least r^2 value (<0.15). Reach number 2, 3 7, 8 and 9 are appeared as relatively dynamic pattern of land building and land loss. Symmetric pattern of reach materials are mainly responsible for it. Meandering character, its concavity and convexity of meanders explain the spatial pattern of erosion and accretion. Slip of slope segment is quite prone to land loss. Divergent slope from channel bend accelerated land loss in some sites.

Table 12: Reach wise trend of channel command area

Reach	Y= a+bx	R^2	Mean area (sq.metre)	SD	CV (%)
1	1775.x - 3E+06	0.251	363255	35053.99	9.649966
2	9987.x - 2E+07	0.765	732846.1	113112.5	15.43468
3	3004.x - 6E+06	0.575	189801.7	39237.71	20.673
4	1261.x - 2E+06	0.103	513446.9	38866.9	7.569801
5	-1935.x + 5E+06	0.396	662347.6	30454.83	4.598014
6	568.9x - 56594	0.016	572137.1	43656.83	7.630483
7	4243.x - 8E+06	0.462	608028.9	61851.79	10.17251
8	3634.x - 7E+06	0.723	470406	42349.13	9.002677
9	1454.x - 3E+06	0.404	256667.9	22665.62	8.83072
10	1770.x - 3E+06	0.288	269594.3	32655.89	12.11298
11	4.314x + 30304	5.00E-06	311671.9	19790.46	6.349774
12	1975x - 3E+06	0.143	1100815	51752.09	4.701252
13	-308.3x + 83409	0.022	217304.1	20569.48	9.465754
14	599.3x - 1E+06	0.103	180388.9	18482.88	10.24613
15	690.5x - 1E+06	0.04	273284	33941.88	12.42
16	2215.x - 4E+06	0.153	370556.3	56036.93	15.12238
17	155.1x + 54057	0.001	364301.3	35446.7	9.73005

5. CONCLUSION

From the above analysis, it can be articulated that the present river is migration sensitive and maximum rate of channel is found at reach 17 followed by reach 5 and 6. At reach 17, rate of channel migration is 48653.63sq.m./km. channel length. Overall channel shift for the entire river is highly asymmetric as the CSAI value is very small (0.107). Strong spatial differences are not found regarding LSI but confluence reaches are relatively less stable with greater inter phase temporal variation. Reach 12 in the middle segment of the river course recoded maximum stretch of channel migration corridor. Very low slope factor and regional flat or slight topographic depression is caused for such acute channel shifting conditions. Land loss is more common than land build (net land loss is 66.46%) and therefore, it causes concern to the people who are residing astride. **C**hannel command area has been gradually increasing over time. Considering these results, planning should be guided accordingly. Within active channel migration zone, heavy infrastructure should be prepared for living creatively with river and slight modification in terms of erecting revetment could be done in the migration sensitive channel bends. Of course, further study is needed to know how far modification in this regard can be entertained otherwise reverse effect will be infiltrated into the system.

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