Research
Volume 11:2,2020
DOI: 10.37421/21577587.11.2.318

Hydrology Current Research

ISSN: 2157-7587

Open Access

Relation between River Hydraulic and Channel Migration: A Case Study on Nagar River, India and Bangladesh

Pankaj Sarkar, Rumki Sarkar, Ganesh Biswas and Biswajit Das*

Department of Geography, Raiganj University, Raiganj, Uttar Dinajpur, India

Abstract

Flood plain morphology is intimately related to hydraulic characteristics of channel and rate of channel migration which involves in the evolution of the flood plain as well as the channel pattern. Channel migration is a complex geomorphological process driven by the interaction between fluid flow, alluvial channel beds and banks. Channel migration in alluvial flood plains involves in continuous shifting of channel position horizontaly i.e., oscillation of channel in meander belt, which can be distinguished from abrupt changes occurred by avulsion or by tectonic and climatic events. Increasing channel sinuosity results into channel migration which inturn affect the hydraulic geometry of the channel by changing the gradient, depth and width and flow velocity. Channel interchanges its plaimetry from straight to meandering with higher to a lower discharge in alluvial flood plain. Full bank discharge may have the capacity for maximum down cuts. In the upstream direction Nagar River has an average bed to bank depth 4m and in lower reaches it increases upto 5.5 m having a water depth 30cm to 1.6m respectively during pre-monsoon. Therefore, during the monsoon discharge may increase more than 3 times, which may cause valley deeping and migration too. To understand the channel shifting behaviour hydraulic properties of the river is to be explored. This paper attempts to present a detailed account of river hydraulics and channel migration to evaluate the present scenario of the Nagar River.

Keywords: River hydraulics • Discharge • Velocity • Width-depth ratio • Channel migration • Sinuosity

Introduction

Channel shifting is a natural phenomenon and now it is challenging for engineers, scientists, and geographers on how to best maintain societal needs with the structure and processes of nature [1-7]. Lateral channel migration and bank erosion are influenced by a number of variables, including land cover, hydraulic characteristics, bank composition, and also underlying geology [8-15]. In this study, to exhibit the relationship between lateral channel shifting and hydraulic characteristics. And we also correlate channel movement and hydraulic characteristics to understand the effect of changes in discharge on the trends and rates of lateral channel migration.

Objectives

- To analyse the hydraulic characteristics of the Nagar river.
- To calculate and explain the trend and rate of Channel migration.
- To find out the relation between river hydraulic and channel migration.

Research Methodology

Location of the study area

Nagar River originates from low land of Chopra C.D. Block, Uttar Dinajpur district, West Bengal, India. The river flows from the north-east to south-east direction by following the regional slope and meet Mahananda river at Pirganj, Malda district West Bengal. The total length of the river is 246 km out of which almost 119 km falls in Bangladesh and rest of the part falls in India. Nagar river almost follows 106 km between the India-Bangladesh International boundary. Nagar river flows over the Ganga-Kosi-Tista floodplain region of Quaternary deposits and it is fully recharged by the monsoonal rainfall. The river evolves under the tropical monsoon climate. Right bank tributary of the Nagar river is Sudhani, Sariyano, Daluncha, Pitanu and left bank tributary are Kulik, Sooin, and Srimoti [16] **(Figure 1)**.

Methods and Database

To analyse the hydraulic characteristics between the variables of the using power law equation, which initiated by Knighton. Hydraulic characteristics of the river are analysed by the using Leopold and Maddock equations [17-21].

There are two methods for measuring channel migration trend and rate i.e., sinuosity index and cross section analysis, which applied in the study area of Nagar River.

Sinuosity Index

It measures the lateral trend of channel shifting as Reach specific and different year wise:

Channel sinuosity = OL/EL (Schumm, 1963).

Where OL = Observed path of stream and

EL= Expected straight path of a stream

***Address for Correspondence:** Biswajit Das, Associate Professor, Department of Geography, Raiganj University, Raiganj, Uttar Dinajpur, India, Tel: +918016608049; E-mail: biswa.geo.das@gmail.com*

Received: 08 April, 2020; **Accepted:** 05 June, 2020; **Published:** 12 June, 2020

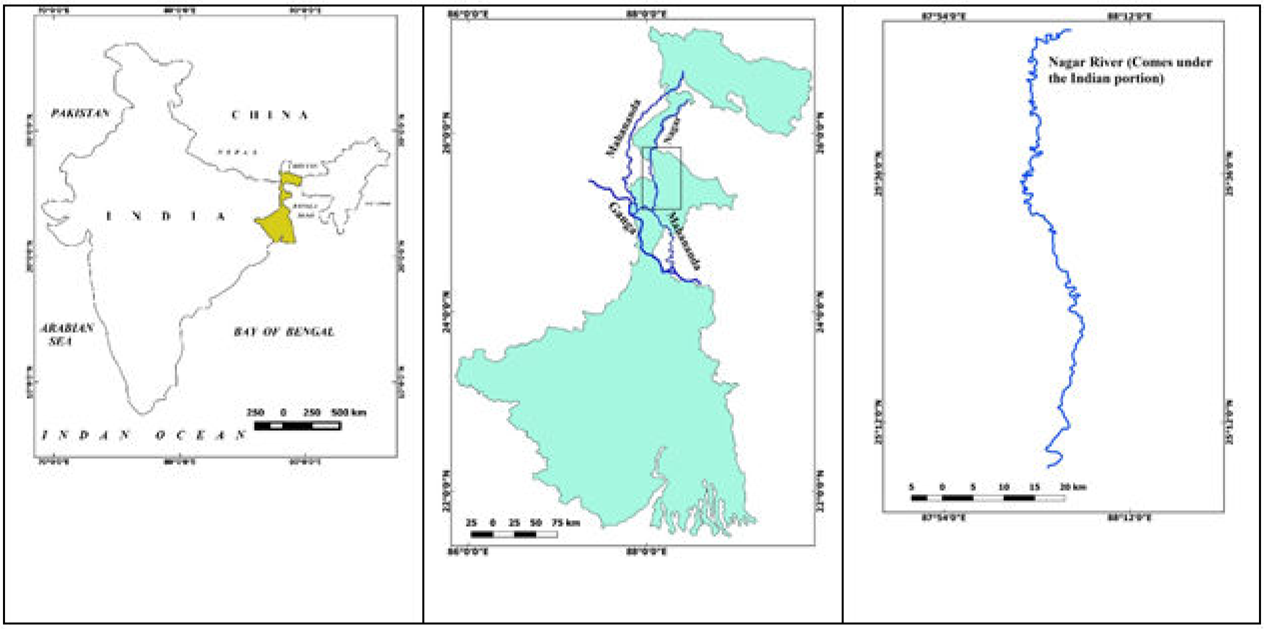

Figure 1. Location Map.

Cross section analysis

- It measures the consistency of channel migration, with the measure of distance of channel migration by following formula by Giardino and Lee.
- D = T1–T2
- Where 'D' is the distance of channel migration, T1 and T2 are the time periods of successive channel migration.

The water current meter has been used to measure the velocity of the river. Velocity data are collected in the period of pre-monsoon (March to April, 2019) season along the cross section. The velocity has been collected from the water surface towards the bed. A Cross section of the river is taken by using Auto level. The major data components used in this study include P.S map, Landsat satellite image, U.S Army map. These data were input into a GIS for compilation and analysis. This is a common data processing procedure, which applied in various river morphology studies. The delineation of the channel migration zone has been done through the help of a previous year map and recent map. First to digitize the all maps in a GIS software and then Historical Channel Migration Zone (HCMZ) has been delineated through the overlapped image and courses of the Nagar River in different periods.

Hydraulic characteristics of Nagar River

$Q= wdv$ (1)

$w= aQ^b$ (2)

$d= cQ^f$ (3)

$v= kQ^m$ (4)

Where Q represents discharge, w represents the exponent of width, d represents the exponent of depth, and v represents the exponent of velocity and w d v = Q; b+f+m = 1; a c k = 1

From equation 2, 3 and 4

$w=68.584Q^{-0.071}$

$d=0.2172Q^{0.481}$

$v=0.0635Q^{0.6012}$

b+f+m= -0.07+0.481+0.601=1.01

a × c × k= 68.58 × 0.217 × 0.063= 0.94

The hydraulic geometry exponents are quite variable, depending on the local conditions. Variations of this morphology are dependent on the shape of the channel, stream pattern, roughness and bed and bank materials [21-25].

The exponent of velocity is greater than depth (m>f) that indicates the velocity increase faster than the depth with increasing discharge and increasing the channel competence and capacity of the suspended load. The velocity component dominates over the depth and width components which indicates with the increase of discharge velocity increases first which results into the down cutting of the river bed. Both the valley walls and the bed are more resistant, which results into the increase of velocity with the increase of the discharge. Again, it also indicates that the valley walls are comparatively more stable than the river bed. Banks are cohesive as the b (-0.07) is very low. The less consistency of the bed is again depicted by the ratio where f>b, i.e., width-depth ratio decreases with the increasing discharge **(Figure 2)**.

Results and Discussion

The exponent m/f>2/3 indicates that Froude number increase with the increasing discharge and transport capacity increases. Again m>f+b i.e., exponent of velocity is greater than the exponent of depth and width indicates the velocity increases faster with discharge than the cross-sectional area. Frictional force and resistance of the bed also increase and bed and bank are becoming non-erodible. This sequence of calculating exponents i.e., m>f>b reveals that due to increase of discharge, velocity will increase rapidly as consequence river bed erodes faster than the river banks. Overall the channel becomes deeper and narrower.

The channel is almost straight as the m (0.601) value is higher than the b (-0.07) value (according to Knighton if m ranges from 0.24-0.71 indicates large) **(Table 1)**.

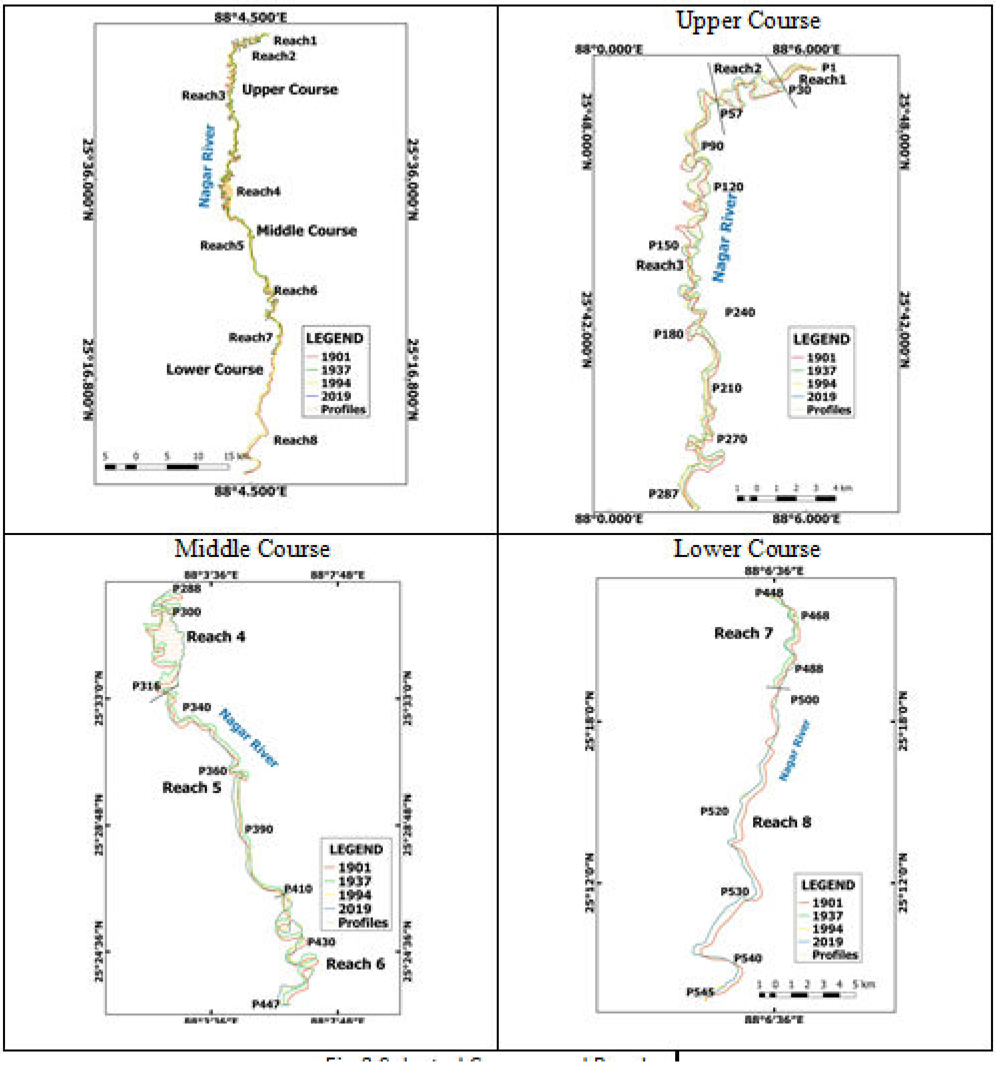

Figure 2. Channel migration behaviour of selected Courses and Reaches.

Table 1. Calculation of the velocity, discharge, w/d ratio, energy (TH) and Froude number.

S. No	Width in M	Average depth in M	Average velocity	Total Discharge(Q) m^3s^{-1}	Width-depth ratio	Froude Number	Energy (TH)
1	67.2	0.9326	0.086285	4.95090	72.05662	0.0285267	39.0004
2	69	0.3246	0.544699	11.78847	212.56932	0.3052445	39.0151
3	67.3	0.268	0.241745	4.58632	251.11940	0.1412212	37.0027
4	61.9	0.3923	0.30295	6.93588	157.78741	0.1544282	35.0047
5	36.1	0.2862	0.590818	7.67647	126.13557	0.3135163	34.0141
6	51.9	0.7338	0.332004	12.01588	70.72772	0.123743	32.0056
7	42.8	0.684	0.447837	12.55347	62.57310	0.1728849	32.0102
8	42.2	0.3612	0.519286	8.90369	116.83278	0.2758662	30.0137
9	65.2	0.512	0.293985	7.53845	127.34375	0.1193072	31.0036
10	37.1	0.908	0.38811	14.53036	40.85903	0.1300403	30.0077

11	34.2	1.6909	0.301268	21.66912	20.22592	0.0672773	29.0038
12	42.2	0.776	0.155506	5.93361	54.38144	0.0563615	31.0012
13	100.7	0.5892	0.114782	5.30321	170.90971	0.0477428	31.0007
14	144.4	1.3486	0.02609	5.84255	107.07400	0.0071731	29.0000
15	93	1.85	0.47781	70.42317	50.27027	0.1121592	21.0116

In upper course the overall down cutting erosion with slower rate as ‘b’ decreases. And as ‘r’ value also decreases that indicates with increasing distance, elevation reduces at a slower rate from the source to 40km. distance. In this course the rate of transportation comparatively decreases, so the gradient has decreased since 1994 to 2019 **(Figure 3A)**.

Of middle course, these are opposite to previous i.e., erosion, transportation both is increasing as ‘r’ value increases from 1994 to 2019. But ‘r’ value decreases from 1994 to 2019 that indicates elevation decreases gradually **(Figure 3B)**.

But in lower course ‘r’ value is very insignificant, but positive in 1994 and negative in 2019 i.e., elevation increases with distance at a very slow rate. And ‘r’ value increase with negative relation which indicate elevation decreases with reference to distance with high rate, i.e., the erosion and transportation capacity of Nagar river increases from 1994 to 2019 **(Figure 3C)**.

In the overall study of Nagar River, it is exhibited that the river is high erosive and transportation capacity as ‘b’ value increases from 1994 to 2019. And also, the ‘r’ value increasing, that depict the elevation of Nagar river decreases from 1994 to 2019, i.e., the down cutting and transportation rate increasing **(Figures 3 and 4)**.

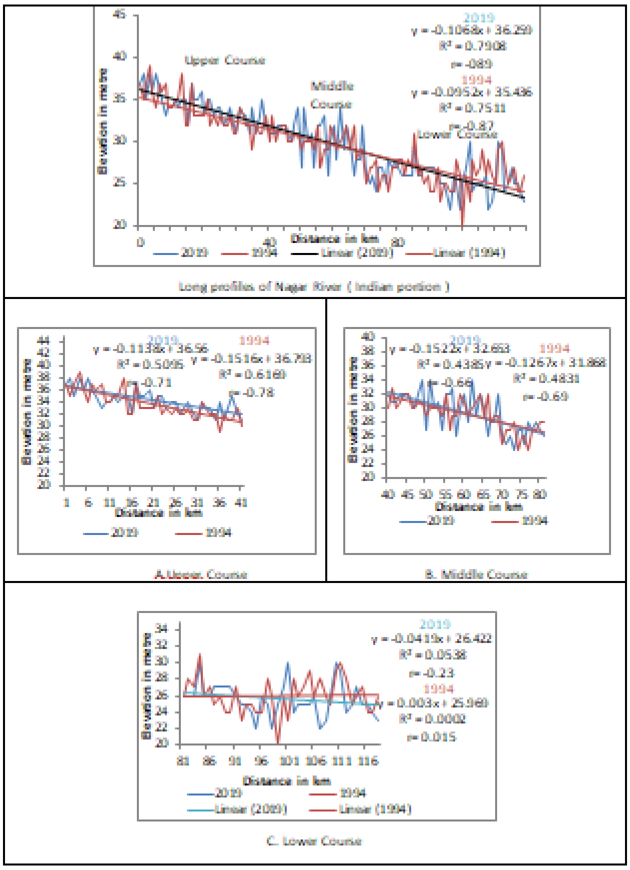

Figure 3. Regression analysis of Long profiles of Nagar River.

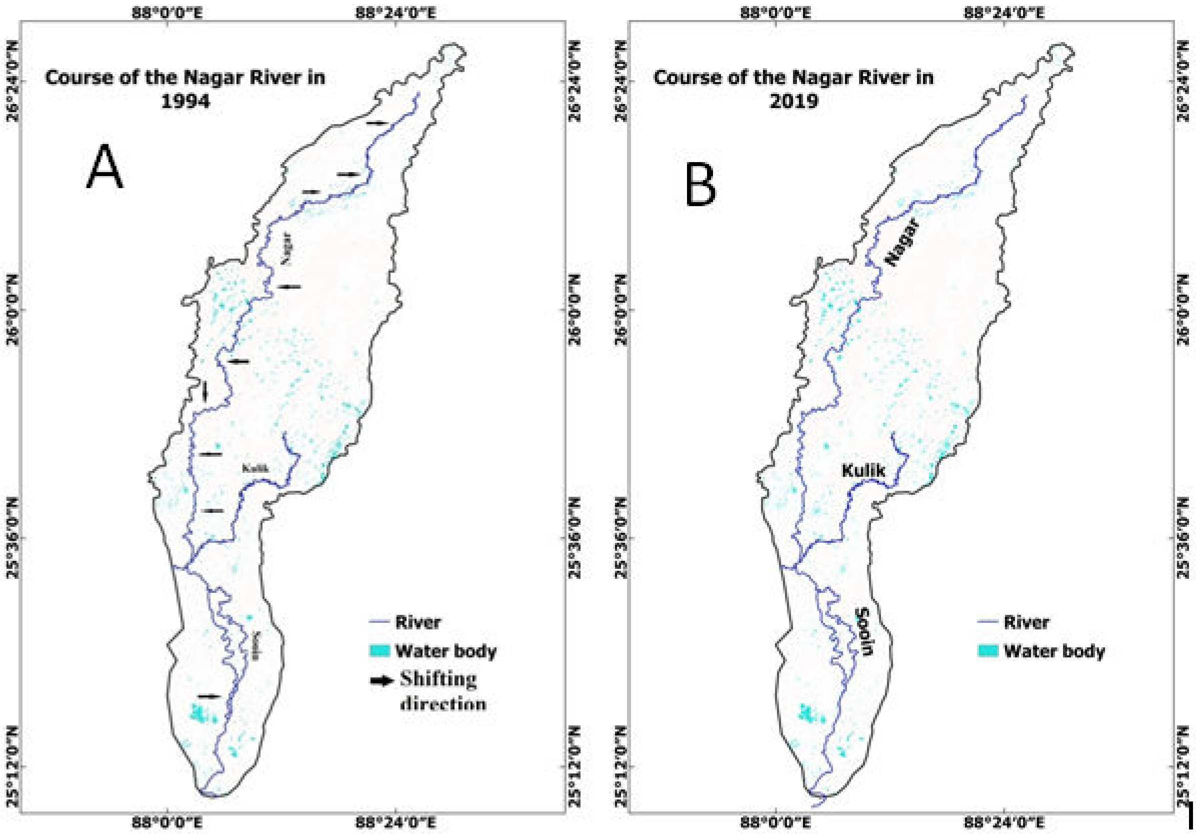

Figure 4. Channel shifting detection and analysis (A) Shifting direction in different portion of Nagar River by using Landsat 4-5 TM image in 1994 and (B) Landsat OLI- 8 image in 2019.

Year wise channel shifting (based on sinuosity index)

Sinuosity Index expresses the meandering characteristics of river channel [23-26]. The value ranges from 1.58 to 1.90 (**Figure 5**). Highest length of Nagar River record in 1937, the length is 107.66 km. and the lowest length is 89.67 km in 1994. From these calculations, it shows that the general trend of sinuosity decreases from 1901 to present. In previous days the sinuosity of Nagar River was more than the present day, which depicts that the river is more meander in 1901 and 1937, than 1994 and 2019 period. It is also exhibit that the river trend towards increasing sinuosity from 1994 to 2019.

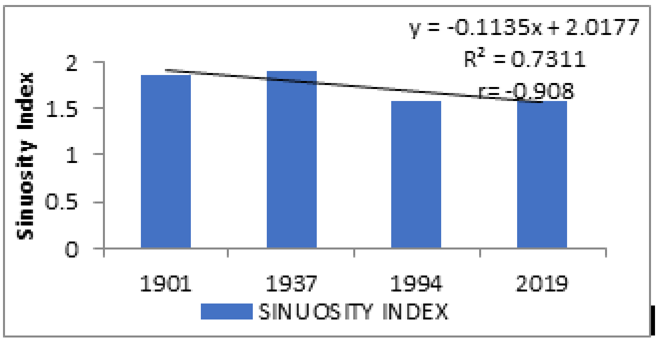

Figure 5. Sinuosity Index (1901 to 2019).

Course wise channel shifting

In **Table 2** the total river channel is divided into three courses based on the changes of channel sinuosity, there are total three courses. Of upper and middle course, the sinuosity decreases with a higher rate, but in lower course sinuosity increases from 1901 to 2019. The sinuosity characteristics of upper and middle course depict that the river becomes straighter, but this trend is higher in the upper course than the middle course. Of upper course the 'r' and 'b' both values is higher than the middle and lower course. S.I value of upper and middle course decreases and in both courses the gradient is high and the trend of down cutting also high from 1901 to 2019, but in upper course this trend is more than the middle course.

Table 2. Course wise trend of sinuosity index since 1901 to 2019.

Course	Location	SI	1901 to 2019

		1901	1937	1994	2019	a	b	r	Remarks
Upper (Source to 40km)	25°49´54″N 88°6´17″E to 25°36´33″N 88◦2´33″E	1.95	1.94	1.59	1.57	2.14	-0.15	-0.95	From the SI value of these courses, the river trends towards straight, which express the river going to stable conditions.
Middle (40 to 81 km)	25◦36´33″N 88 °2´33″E to 25°22´49″N 88°6´10″E	1.76	1.84	1.5	1.54	1.91	-0.10	-0.85	Here also the SI value trends towards straight, but the rate is comparatively slower than upper course.
Lower (81 to 118 km)	25°22´49″N 88°6´10″E to 25° 7´38″N 88°4´0″E	1.34	1.37	1.37	1.36	1.34	0.006	0.57	But in lower course, it's totally reversed than both upper courses i.e., the river trends towards sinuosity characteristics.

In lower course S.I values increased from 1901 to 2019. The actual length of Nagar River in lower course is higher in 2019 than the river course 1994, i.e., the trend of sinuosity increases from 1901 to 2019, which depict the erosion and transportation gradually decreases and deposition increases.

Reach wise channel shifting

The Course also divided into eight Reach (R1, R2, R3, R4, R5, R6, R7 and R8) based on the trend of change of Sinuosity Index and migration rate of the channel. Highest Sinuosity index value record in Reach-2, Reach-4 in 1901 and 1937 respectively, which is the more than 2.0, others rest of reach record less than 1.0 S.I value. The high deviation (SD) of change of Sinuosity index record in R2 and R4 is 0.55 and 0.57 respectively **(Table 3 and Table 4)**.

Table 3. Reach wise trend of Sinuosity Index since 1901 to 1937.

County	Location	Reach	SI				SD
			1901	1937	1994	2019	
Upper Course	2549◦2 33 E	R1	1.06	1.15	1.19	1.1	0.06
		R2	2.26	2.45	1.33	1.51	0.55
		R3	1.76	1.71	1.48	1.44	0.16
Middle Course	25◦36 33 N 88 2 33 E to 25 22 49 N 88 6 10 E	R4	2.46	2.61	1.55	1.55	0.57
		R5	1.32	1.35	1.27	1.26	0.04
		R6	1.82	1.94	1.77	1.92	0.08
Lower Course	25 22 49 N 88 6	R7	1.32	1.38	1.36	1.35	0.03
		R8	1.32	AB	1.36	1.34	0.02

Table 4. Trend of channel shifting in different time period.

Channel shifting behaviour since 1901 to 2019 (Reach wise)				
X: reaches, Y: Sinuosity Index	**a**	**b**	**r**	**Remarks**
1901	1.870	-0.045	-0.22	SI decreases from R1 to R8 which indicates the river is more stable in lower course than upper course. And the rate of change is comparatively more than 1937.
1937	1.897	-0.024	-0.089	Here also the SI decreases from R1 to R8 but the trend of change is going slow from upper to lower course.

1994	1.310	0.023	0.31	In 1994 the SI increases from R1 to R8 and the rate of change is going higher from upper to lower course.
2019	1.325	0.024	0.24	In these years SI also increases from R1 to R8 but the rate of change is going higher than 1994 from upper to lower course.

Migration consistency in different period

In **Table 5** the migration consistency of Nagar River in the phase 2 (1937 to 1994) is higher than other two phases. The rate of change of channel migration is 5.36, 5.416, 2.294 metre/year in phase 1, phase 2 and phase 3 respectively. The recent phase (phase 3) exhibits that the river is more stable than the previous two phases.

Migration consistency also differs from course to course and reaches specific. Highest migration rate record in the middle course (R4), the value is 11.33 and 15.41 metre/year in phase 1 and phase 2 respectively. In the middle course Reach 4 (phase 2) record the high Standard Deviation, i.e., these records the high rate of change of channel migration. Most of reach record the migration rate below 5 metre/ year **(Table 6, Table 7, Table 8 and Table 9)**.

Table 5. Migration Consistency in Different Period.

	Migration rate metre/year		
Year	1901 to 1937 Phase 1	1937 to 1994 Phase 2	1994 to 2019 Phase 3
Mean Migration	5.36	5.416	2.294
Median Migration	3.778	4.421	1.178
SD	5.377	4.983	3.003

Table 6. Reach specific upper course migration consistency.

	Migration rate metre/year								
County	**Upper Course of Nagar**								
Year	**1901 to 1937 Phase 1**			**1937 to 1994 Phase 2**			**1994 to 2019 Phase 3**		
Reach ID	R1	R2	R3	R1	R2	R3	R1	R2	R3
Mean Migration	1.86	2.96	5.64	3.3	8.04	5.14	2.15	4.5	3.26
Median Migration	1.94	2.53	3.85	3.39	5.33	4.58	2	3.48	2.12
SD	1.26	2.34	5.7	1.49	7.06	3.5	0.95	3.89	3.56

Table 7. Reach specific middle course migration consistency.

	Migration rate meter/year								
County	**Middle Course of Nagar**								
Year	**1901 to 1937 Phase 1**			**1937 to 1994 Phase 2**			**1994 to 2019 Phase 3**		
Reach ID	R4	R5	R6	R4	R5	R6	R4	R5	R6
Mean Migration	11.33	4.68	5.54	15.41	3.88	5.19	1.13	0.79	2.76
Median Migration	9.44	4.06	4.57	13.82	3.86	4.56	0.68	0.6	2
SD	9.16	3.48	4.48	10.98	1.74	4.36	1.37	0.92	3.36

Table 8. Reach specific lower course migration consistency.

	Migration rate metre/year					
County	Lower Course of Nagar					
Year	1901 to 1937 Phase 1		1937 to 1994 Phase 2		1994 to 2019 Phase 3	
Reach ID	R7	R8	R7	R8	R7	R8
Mean Migration	6.04	AB	3.87	AB	0.56	0.81
Median Migration	6.39	AB	3.33	AB	0.49	0.52
SD	4.02	AB	2.96	AB	0.4	1.38

Table 9. Showing the migration range.

Value Range (metre/year)	Remarks
Above 10	High Migrated
5 to 10	Moderate Migrated
Below 5	Low Migrated

Interrelation between river hydraulic and channel migration

Hydraulic characteristics indicate that the river cuts its bed more than valley wall. The channel in the upper and middle course depicts the same as the SI decreases from 1901 to 2019 in both the upper and middle course. The rate of change of SI is higher in upper course which indicate that the channel become straighter over time than the middle segment. In lower course SI increases from 1901 to 2019 as a result lower course, these trends are totally opposite from upper and middle i.e., the river trends to sinuous from straight.

Channel migrates more at the place where the width-depth ratio is lower. In the Nagar River at reach 2 and 4 migration is maximum and in these two zones the width-depth ratio is lowest. The SI value decreases on middle segment also but the gradient is lower. The upper course deeper its valley by down cutting, as the channel becomes more stable than the previous time. Likely higher channel migration rate in the upper course decreases over time by valley deepening and the channel become more consistent.

SI values increase in the lower course during the concerned period. It indicates that the channel becomes more sinuous in this segment. Channel oscillation is higher. Froude number dramatically decreases in this segment, which again reveals that the water depth component with gravity (gd) dominant over the velocity component and it results into lesser transport capacity and the channel become sinuous to maintain its flow. Gravity wave is dominant in the lower course. Vary lower values of Froude number forms thalweg and point bars in the channel.

Migration occurs in the middle course due to abrupt changes in the river course, but in the lower course channel migrates slowly by lateral erosion. Highest SD value in reach 2 and 4 and represents the dynamic nature of the channel where the river form low magnitude meander from instance meandering (>2.4) since 1901 to 2019.

Moderately stable channel is found in reach 3, as SI values decrease gradually and Froude number range from 0.14 to 0.31. Gravity wave dominants in this segment and thalweg and pointbar forms along this portion.

Major findings

From the database analysis, it can be concluded that the lower Froude number indicates more stable channel or lower rate of migration. It is also observed that channel migrates more at the places where the width-depth ratio is lower.

Conclusion

Along the river channel it is found that there are no gradual changes in width that is from the source region to the confluence. The width instead of increase haphazardly increases or decreases due to human interventions like construction of the bridge, embankment, settlement, etc. depth also varied along the channel instead of gradual decrease from source to mouth region. River hydraulic basically is the inter adjustment along the hydraulic variables like width-depth and velocity with increasing discharge. As a consequence of modification channel artificially, fluctuation in river energy is the result and effect which again affects the channel pattern that is sinuousness or the planimetry. As the river interrupted by human activities, it became difficult to predict and manage the channels. The total evolutionary processes highly affected by the human activities.

References

1. Dixon, Simon J, Gregory H. Sambrook Smith, James L. Best, and Andrew P. Nicholas, et al. "The planform mobility of river channel confluences: Insights from analysis of remotely sensed imagery." *Earth-Sci Rev* 176 (2018): 1-18.
2. Giardino, John R, and Adam A Lee. “Rates of channel migration on the Brazos River. Yangling: Department of Geology & Geophysics”. Texas A & M University (2011).
3. Haron, Nor Azidawati, Goh Qiu You, Mohd Sofiyan Sulaiman, and Badronnisa Yusuf, et al. "Evaluation of River Stability By Morphological Assessment". *Res J (IUKLRJ):* 11.
4. Debnath, Jatan, Nibedita Das Pan, Istak Ahmed, and Moujuri Bhowmik. "Channel migration and its impact on land use/land cover using RS and GIS: A study on Khowai River of Tripura, North-East India." *Egypt J Remote Sens Space Sci* 20 (2017): 197-210.
5. Postel, Sandra, and Brian Richter. “Rivers for life: managing water for people and nature.” Island Press (2012).
6. Rudra, Kalyan. "Shifting of the Ganga and land erosion in West Bengal: a socio-ecological viewpoint." Centre for Depelopment and Environment Policy (2006): 1-43.
7. Majumdar, Samrat, and Sujit Mandal. "Channel shifting of the River Ganga and land loss induced land use dynamicity in Diara Region of West Bengal, India: A geo-spatial approach."

8. Charlton, Ro. “Fundamentals of Fluvial Geomorphology”. *Routledge* (2007).

9. Nusrat, Jahan Ety, and Md Shahedur Rashid. “Changing pattern of downstream of Ganges River course:A comparison with Rennell's map of 1760'S”. *Int J Sci Res* 7(2017): 90-105.

10. Gregory, Kenneth John, ed. River channel changes. *John Wiley & Sons* (1977).

11. Hickin, Edward J. "Hydraulic geometry and channel scour, Fraser River, British Columbia, Canada." *In River geomorphology* (1995): 155-167.

12. Knighton, Dave. “:Fluvial forms and processes. Edward Arnold, London. DE Walling University of Exeter, UK. Knighton, UK". (1984).

13. David, Knighton. "Fluvial forms and processes: A new perspective." (1998).

14. Rudra, K. The Encroaching Ganga and Social Conflicts: The Case of West Bengal, India, Independent Broadcasting Associates, Littleton, 4(2005). Available:http://www.ibaradio.org/India/ganga/extra/resource/Rudra.pdf[Accessed on 04 June 2015].

15. Sarkar, Rumki, Pankaj Sarkar, and Ganesh Biswas. "Channel Shifting Behaviour and Delineation of Channel Migration Zone: A Study on Nagar River of West Bengal, India." 8 (2019).

16. Government of West Bengal, “Development and Planning Department District Human Development Report: Uttar Dinajpur”. *HDRCC* (2007):5-8

17. Chorley, RJ, Schumm SA, and Sugden DE. London: Methuen London and New Yourk. *Geomorphology* (1984).

18. Leopold, Luna Bergere, and Thomas Maddock. “The hydraulic geometry of stream channels and some physiographic implications.” US Government Printing Office 252 (1953).

19. Morisawa, M. Rivers form and process. USA, America: Longman (1985).

20. Leopold, Luna Bergere, Markley Gordon Wolman, and John P. Miller. “Fluvial processes in geomorphology. Courier Corporation” (1995).

21. Sarkar, Rumki, Biswajit Das, and Ganesh Biswas. “Analysis of River Long Profile and Hydraulic Geometry to Evaluate the Present Scenario of Kulik River, India and Bangladesh.” *Int J Current Res* 11 (2019): 5005-5017.

22. Hickin, Edward J. "Vegetation and river channel dynamics." *Can Geogr* 28 (1984): 28111-28126.

23. Leopold, Luna Bergere, and Walter Basil Langbein. “The concept of entropy in landscape evolution.” US Government Printing Office 500 (1962).

24. Lee, Jong-Seok, and Pierre Y. Julien. "Downstream hydraulic geometry of alluvial channels." *J Hydraul Eng* 132 (2006): 1347-1352.

25. Das, Somen. "Changing hydro geomorphological characteristics of kalindri river malda district and their impacts on riparian livelihoods a geographical overview." (2012).

26. Sinha, Rajiv. Threshold. Geomorphology. (2014):157-170.

How to cite this article: Sarkar P, Sarkar R, Biswas G and Das B. "Relation between River Hydraulic and Channel Migration: A Case Study on Nagar River, India and Bangladesh". Hydrol Current Res 11 (2020) doi: 10.37421/21577587.11.2.318