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Dynamics of Dharla River in Bangladesh Relation to Sinuosity and Braiding: GIS-RS Based Spatial Investigation

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Abstract: *Channel pattern usually varies from place to place on different type landforms, climatic condition, and environment, relates to the plan view of a reach or entire river indicating sinuous, meandering, braided, and straight channels. As a floodplain riverine country most of the rivers are vibrant and Bangladesh experiences frequent hydrologic and geomorphologic events. Present study intends to analyze the dynamics of Dharla river channel in Bangladesh over time (1978-2018) through channel sinuosity ratio and braided index. Life and livelihood of people specially in the northern region of Bangladesh are largely reliant on this river and its' characteristics. Here satellite imageries, collected from earth explorer United States Geological survey (USGS), used to interpret, and delineate morphological variables. Different parameters such as, channel straight-line length or distance; parallel distance of river, valley length, bar formation, deposition for each year have measured from satellite images through geo-spatial techniques and GIS, remote sensing tools (ArcGIS 10. 5 and ERDAS Imagine 2010) to evaluate a channel, classified into straight, sinuous, meandering and braided depending on the sinuosity and braiding nature. 1.42, 1.51,1.55, 1.45, 1.46 sinuosity ratio and 0.28, 0.31, 0.34, 0.37, 0.69 braiding indices in 1978, 1990, 2000, 2010 and 2018 respectively shows river flowing as more sinuous and braiding in nature than meander. However, the unpredictable physical characteristics of river can be justified with the amount of char lands and water surface. Where, 403.90 ha, 242.96 ha, 303.60 ha, 156.93 ha, 170.52 ha char lands and 1833.78 ha, 1571.32 ha, 1655.37 ha, 1390.51 ha, 1772.83 ha. water surface in the aforementioned years do not refer the sinuosity and braiding features of Dharla river. River is changing with time and through sequential geomorphic process such as erosion, bar formation and fluvial agents like running water and this analysis is crucial for the sustainable management and approaching development of the rivers, surrounding floodplain and riverine ecosystem in Bangladesh.*

Key Word*: Instability; Channel Pattern; River Flow; Sedimentation; Morphology*

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I. Introduction

The hydro-morphological characteristics of this river are very dynamic in nature[1]. Geomorphological instability phenomenon or unstable landform means a dynamic fluvial system which is not in equilibrium with the natural environment and which tends to reach a balance by modifying itself[2]. Rivers are highly sensitive to environmental conditions[3,4] as well as, alluvial channels can respond or readjust at different rates with water, active tectonics, and human activities at a range of spatial and temporal scales[5,6]. Evolving, mobile rivers, as opposed to quasistatic channelized flows, create the valley floors and surfaces upon which they flow at any moment in time. Any changes may result in channel instability to river form and pattern[7,8,9,10,11,12,13,14], necessary to measure and monitor channel migration[15]. River is subjected to erosion and deposition, shifting along the reaches[16] or lateral migration[17] to reach the equilibrium condition. The hydrogeomorphic dynamics of river and other external factors directly distort its course from pervious path and measured by sinuosity index. Sinuous patterns traced by fluid flows are a ubiquitous feature of physical landscapes on Earth, and discussed as consequence of migration processes in meandering rivers. Sinuosity sometimes described as inherited from a preexisting morphology, which still does not explain where the inherited sinuosity came from[18]. The more direct path down the valley, which is by definition the sinuosity of the river[19]. River instability can detect from channel pattern which describe the plan-view of a river channel as seen from an air-plane[20] and the ratio of thalweg length to the air-line distance defined the degree of sinuosity of meandering rivers[21]. Some indexes of sinuosity formulated by scholars[22,23,24,25,26,27,28] like Leopold and Wolman, 1957; Brice, 1964; Schumm, 1963; Mueller, 1968; Prasad, 1982; Friend and Sinha, 1993; Knighton, 1998. Geomorphologically straight stretches often occur in conjunction with or between bends or along braided reaches[29]. In general, braiding intensity indices have been based on one of three characteristics: bar dimensions and frequency[23,30,31] (Brice, 1964; Rust, 1978; Germanoski and Schumm, 1993); the number of channels in the network[32] (Howard et al., 1970); and the total channel length in a given river length[33,34,27] (Hong and Davies, 1979; Mosley, 1981; Friend and Sinha, 1993). Various studies have been carried out on some major rivers with remote sensing and GIS technique for detecting spatio-temporal changes[35,36,37,38,39,40,41,42]. Riverbank erosion and channel shifting studied by various researchers in last few years[43,44,45]. While very few studies noted here considered transboundary issues, flood analysis with some erosion and accretion issues regarding Dharla river in Bangladesh[46,47,48,49]. Research related with the understanding of spatio-temporal channel pattern changing trend analysis by using sinuosity and Braiding index are not much frequent in the context of river basin in Bangladesh. Therefore, this study broadly aims to investigate the association of sinuosity with braiding index from 1978 to 2018 to identify the Dharla River channel pattern in, Bangladesh with geospatial techniques.

II. Material And Methods

Study Area: Bangladesh is one of the riverine countries in the world and more than seven percent of its lands are occupied by river systems (Hossain et al. 2008) where, Dharla River is one of the fifty-four transboundary rivers passed over from India to Bangladesh[50]. This is a noteworthy river for the people of northern region in Bangladesh originates at the Brahmaputra River Basin. Bangladesh as a downstream riparian country experiences flow variation due to seasonal changes, barrage, dam, artificial canal in many transboundary rivers e.g., Teesta, Dharla[51]. In India Dharla is known as Jaldhaka River, originates from the Himalayan ranges and flows through Jalpaiguri and Cooch Behar districts of West Bengal. After enters towards Bangladesh as Dharla, a continues slow meandering channel through Lalmonirhat District and flows until discharges into the mighty Brahmaputra River near Kurigram District. Average and maximum depth is 12 feet (3.7m) and 39 feet (12m) respectively near Kurigram with 62 km length[52]. Entire course of Dharla River is located between 89°28'-89°44'E and 25°41'-26°0'N at the upper reach of Bangladesh (Figure 1) and 15 cross-sections (CS) have selected randomly to examine the impartial sequential changes of (Table 1). Dharla river becomes wide and turbulent during monsoon season but revels as braided in winter. River valley and basin is formed by active and non-calcareous grey sandy alluvial complex type soil[53]. Deposition of silt form many small chars which turns visible in the time of low water level[54]. Furthermore, erosion take serious turn through the reach and surrounding floodplain (20 km from left bank and 27 km from right Bank), flood in the confluence of Dharla River cause environmental, socio-economic and human lives damage[47].

Data and Methods: All the spatio-temporal analyses accomplished in this study are based on recent historic changes of the Dharla River using multi-temporal Landsat satellite images from 1978 to 2018 through Remote Sensing (RS) and Geographic Information System (GIS). In this study, georeferenced data from Multispectral Scanner System (MSS) for 1978, Thematic Mapper (TM) for 1990, 2000, 2010 and Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) for 2018 were required for identifying the dynamics (Table 1). Based on availability, satellite images have acquired from United States Geological Survey (USGS) earth explorer[55] (http:// earthexplorer.usgs.gov/), only dry season images are considered. Herein, photogrammetric image processing has processed in ERDAS Imagine 2010 and radiometric correction is used to minimize radiometric differences. Besides, cloud free Landsat scenes enhanced by using histogram equalization algorithm and georeferenced to Bangladesh Transverse Mercator (BTM), an area specific standard UTM (Universal Transverse Mercator) projection.

Table 1: Properties of used Satellite Images

Satellite	Sensor	Band	Path/ Row	Date of Acquisition	Spatial Resolution
Landsat	MSS	4, 5, 6, 7	138/ 42	December 25, 1978	60 m
Landsat	TM	1, 2, 3, 4, 5, 6, 7	138/ 42	December 16, 1990	30 m
Landsat	TM	1, 2, 3, 4, 5, 6, 7	138/ 42	December 27, 2000	30 m
Landsat	TM	1, 2, 3, 4, 5, 6, 7	138/ 42	December 23, 2010	30 m
Landsat	OLI & TIRS	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11	138/ 42	December 13, 2018	30 m

Generally, stream sinuosity indexes are usually resulting by dividing the length of a reach as measured along a channel by the length of a reach as measured along a valley[25]. It is the ratio between actual path (observed length, OL) and the straight (expected length, EL) path of a stream[24]. Incorporating Geographic Information System (GIS) and remote sensing with satellite images as a tool, the sinuosity and braiding index explained that deal with the pattern of streams and adjoining areas.

Equation for sinuosity ratio (Equation 1): $\text{Sinuosity} = \frac{\text{River Parallel Distance}}{\text{Straight– line Distance of River}}$

Equation for braiding index (Equation 2): $BI = 2\sum L_b / L_r$

Here, BI= Braided Index, L_b= Length of all the Char or Bar, L_r= Central Line between the banks of the channel

Finally, images have been clipped by using area of interest (AOI). To maintain methodological consistency, manual onscreen digitization at same scale under similar zooming level (1:150,000) by using ArcGIS 10.5 software and its extensions have used to delineate channel boundaries, channel straight line length or distance;

parallel distance of river, valley length and bars from each image rather than automated technique. Using overlay techniques; two temporally succeeding (1978-1990; 1990-2000; 2000-2010; 2010-2018) data are compared in order to calculate sinuosity ratio and braiding index over that epoch. Intersection points between bankline positions are computed to determine sinuosity, braiding, shifting direction etc. Time series remote sensing satellite imageries interpretation afford improved outcomes in channel geometry to assess changing tendencies. Quantitative data including sinuosity (Equation 1) and braiding (Equation 2) has extracted from secondary sources like satellite images. However, the entire summary has shown through tables as well as interpretation by maps and diagrams.

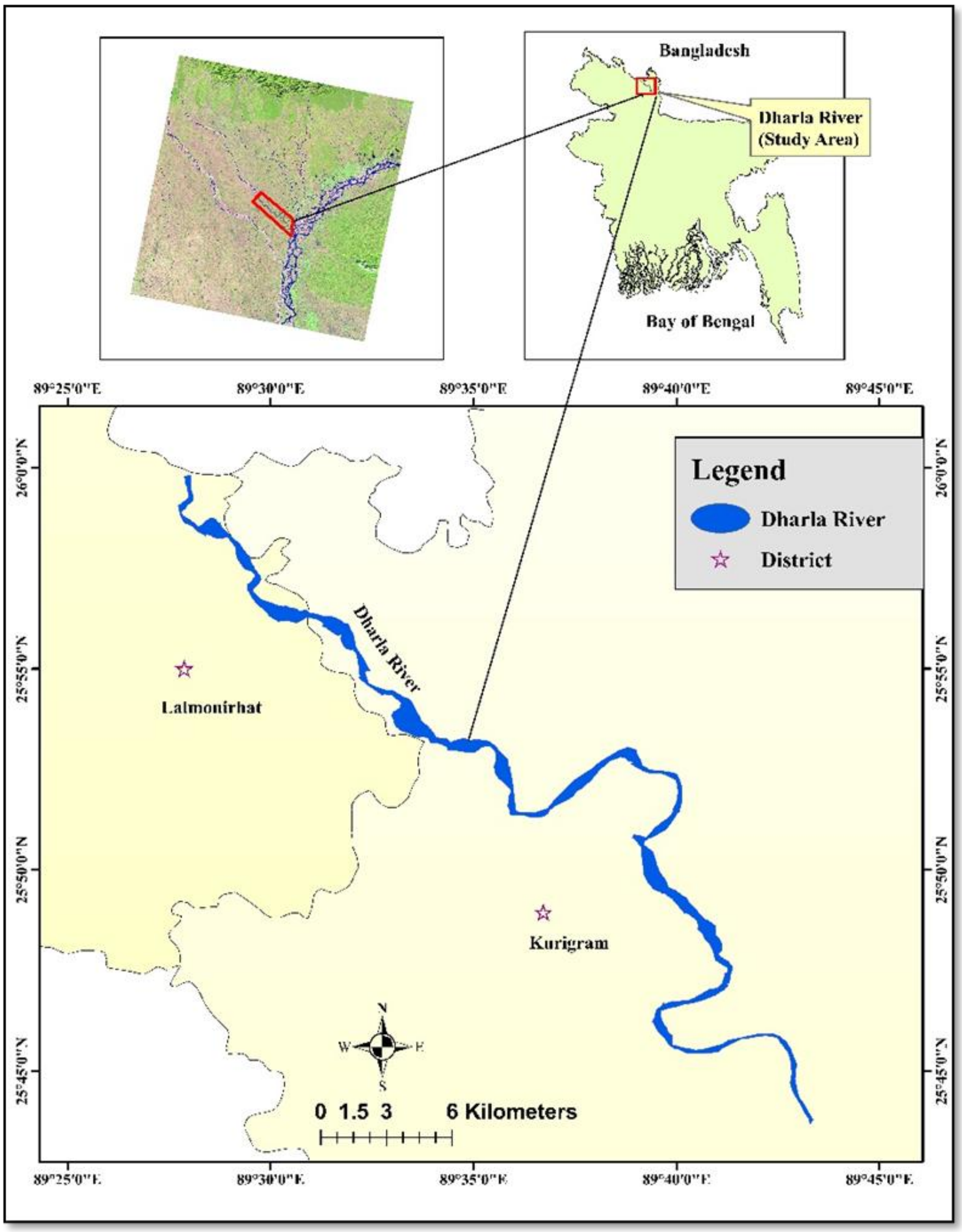

Figure 1: Location of Dharla River in Bangladesh

III. Result and Discussion

Sinuosity Ratio: Meandering is a natural geomorphic feature in river which results in gradual migration of the rivers course and erosion of the banks (Ayman and Ahmed, 2009). where meandering nature of the river deals with the Sinuosity (S) and sinuous is a plan-form between straight and meandering (Morisawa, 1985). In this study, Landsat Satellite imageries of 1978, 1990, 2000, 2010 and 2018 are examined (Equation 1) for extraction of morphological variables like, Sinuosity Ratio Index (SRI) expresses the present and predict future channel pattern such as Straight channel. When SRI is less than 1.05 (SRI<1.05); sinuous channel, when SRI is between 1.05 and 1.5 (1.05≤ SRI<1.5) and meandering channel, when SRI is more than 1.5 (SRI>1.5) (Leopold and Wolman, 1960; Schumm, 1963; Yeasmin and Islam, 2011). However, Dharla river channel pattern classification in terms of Sinuosity Index is made based on the reference value of Sinuosity Ratio given by Morisawa (1985), where SRI<1.05 indicates Straight channel, SRI >1.05 point to Sinuous, SRI>1.30 specifies Braided, SRI>1.50 directs Meandering channel and finally, SRI>2.00 shows Anastomosing River.

Table 2: Variation of sinuosity from (1978- 2018) in the Dharla River

Year	Sinuosity	Type
1978	1.42	Sinuous and Braided
1990	1.51	Meandering
2000	1.55	Meandering
2010	1.45	Sinuous and Braided
2018	1.46	Sinuous and Braided

Meandering and sinuosity study from the historical analysis of meander bends reveals the fact that pattern changing tendencies of the Dhalra river is dynamic and has fluctuated than the earlier times. During 1978 the river was flowing through sinuous and braided channel with 1.42 sinuosity rather than meandering channel. But after that period in 1990 and 2000, it started to meandering its course with 1.51 and 1.55 sinuosity respectively by creating meander necks/ cut offs. because in these periods, sinuosity index increased high and river bends sharply from its normal path. Sinuosity calculation for the entire segment of the Dharla river has recorded (Table 3) and it implies that the river is steadily losing its meander character and is transforming into a sinuous course later, in 2010 and 2018 sinuosity was 1.45 and 1.46 correspondingly with braided nature. Therefore, findings from the spatio-temporal analysis visibly indicating that Dharla river is mostly a sinuous braided type river in nature instead of meander nature, though the sinuosity values are relatively neighboring to the meander values.

Braided Index: The braiding index of the Dharla River have been increasing by planform changing (Table 3), which is the indication of erosion and accretion differences along the banks that caused morphometric changes. Channel sinuosity appears to increase with water and sediment discharge from straight to sinuous single channels, but then decreases towards the transition to braiding (Bridge, 2003). The Braiding index (BI) has studied here from 1978 to 2018, shows a continuous increasing trend from 0.28, 0.31, 0.34, 0.37 and to 0.69 in 1978, 1990, 2000, 2010 and 2018 respectively (Table 3) based on the equation (2). Result implies the increasing flow velocity in monsoon, high flash flood magnitude, thalweg shifting, high sedimentation, lateral migration and in river char or bar formation that is seasonally or lastingly in lower reaches.

Table 3: Variation of Braided Index, Char land and Water Surface

Year	BI	Total Water Surface (ha)	Total Char (ha)
1978	0.28	1833.78	403.90
1990	0.31	1571.32	242.96
2000	0.34	1655.37	303.60
2010	0.37	1390.51	156.93
2018	0.69	1772.83	170.52

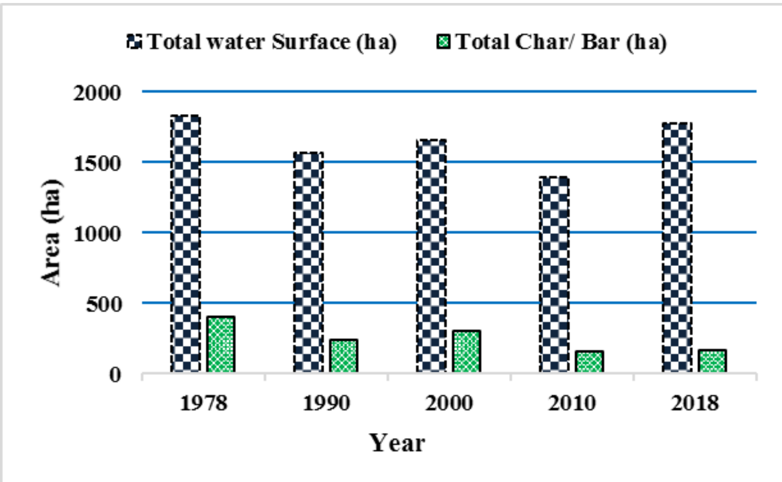

Figure 2: Variation of Char land and Water Surface

Findings signifies that the Dharla River becomes sinuous or meander to semi braided river in nature. Scattered and localized deposition islands formed in the middle or on the banks of the river supporting the aforementioned results (Table 3), the braiding index (BI) has been increased with the increase of number of islands. But unpredictably, the total area of the island or char and water surface area was not referring the continuous increasing like braiding index (Figure 2 and 3). About 403.90 ha, 242.96 ha, 303.60 ha, 156.93 ha, 170.52 ha was total char lands in 1978, 1990, 2000, 2010 and 2018 respectively while total area of water surface was 1833.78 ha, 1571.32 ha, 1655.37 ha, 1390.51 ha and 1772.83 ha. From the fluctuation of sinuosity, island area and braided index indicate that the Dharla River has an impulsive nature. The comparison between sinuosity ratio and braiding index, demonstrates that the changing rate of braiding index (BI) is not more than sinuosity ratio (SR) and changes in channel dynamic specify the frequent temporal shifting (Figure 3).

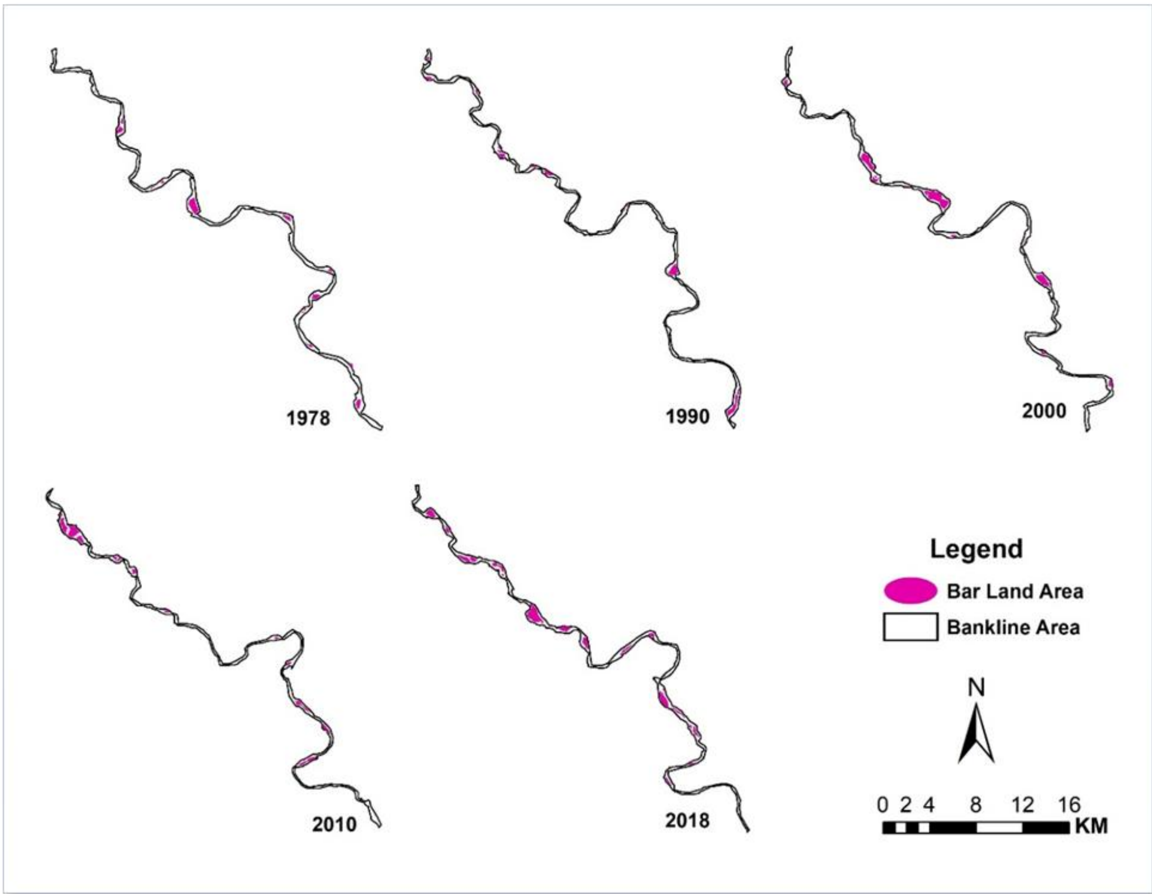

Figure 3: Total Surface Area and Total Bar Area of Dharla River (1978- 2018)

IV. Conclusion

Rivers are one of the utmost benedictions for Bangladesh and its prosperity. But at present day most of the rivers and riverine ecosystems here are on the edge of the worsening due to anthropic and natural reasons, while transboundary rivers like Dharla river are not out of this condition. Dharla River is one of important monsoon dominated and severe flood prone rivers which carries out almost all the geomorphic work of erosion, transportation, and deposition during summer monsoon season. Proper channelization and restoration and management of rivers, watershed as well are crucial for improving our river systems. For this reason, sinuosity ratio and braiding analysis is necessary to understand the topographical and hydrological characteristics, channel pattern as straight, meandering, braided, anabranching or anastomosing, erosion-accretion condition, river instability etc. of a particular river basin. To develop an effective watershed management plan and predicting future changes of river, sinuosity, and braiding Indexes both can provide a sound basis.

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