Journal of Indian Geomorphology
Volume 10, 2022 ● ISSN 2320-0731
Indian Institute of Geomorphologists (IGI)

Hydro-Geomorphic Approach for Identifying River Dolphin Habitation in Kulsi River, India

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Abstract: *The Gangetic dolphin (Platanista gangetica) is a rare species found in the Kulsi river, a left-bank tributary of the Brahmaputra. These species are found everywhere in the entire course of the river during the monsoon season, but at the time of post-monsoon, they are found only in some selected sites due to the requirement for food, shelter, water quality, water quantity and geomorphic character of the river. The present study looks into the hydro-geomorphic parameters of the river as the suitable habitat of these rare species. The study is based entirely on field data collected from the channel at selected cross-section sites. Primary data on channel width, depth, velocity of flow, pH and water turbidity, riparian conditions and other geomorphologic characteristics was collected to identify suitable sites for the habitation of the dolphin species in the Kulsi river. The physicochemical, hydrological, and geomorphologic characteristics of the Kulsi river specify that the river health is satisfactory and suitable for resident dolphin population at a number of sites, which from upstream to downstream direction of the channel are Dumukh, Kukurmara, Jiakur, Chamaria, and Nagarbera. In these locations the depth of the channel is more near the confluence of tributaries, and also in the convex meander bends of the river where eddy counter-current prevails.*

Keywords: *channel shape, hydro-geomorphic, Gangetic dolphin, physiochemical, riparian condition, satellite image, GIS.*

Introduction

The Gangetic river dolphin, locally known as 'Sishu'or 'Hihu' in Assam was first reported by Roxburgh (1801), and are distributed along the Kulsi river, a tributary of the Brahmaputra. Mohan et al. (1997) confirmed the existence of the Gangetic dolphin in the Brahmaputra river and its tributary Subansiri and Kulsi. Wakid in 2005 assessed the dolphin population status and distributzion pattern in the Brahmaputra river system. He conducted a detailed ecological investigation on dolphins in eastern Assam in 2009 and recorded 17 dolphins in the Kulsi river from Gharamara to its confluence with the Brahmaputra near Nagarbera, about 76 km stretch of the river (Wakid and Braulik, 2009). They usually prefer to live where there is clean air, good quality deep waters near meander belts and confluence points of tributaries. Maximum number of dolphins are found in the rainy season (August to November), which starts decreasing dry season from December to February. The low count of dolphins in the dry season is mainly due to concentration of polluted water and their movement to other large rivers (Khondker and Abed, 2013). The Kulsi river is well known not only for its population of river dolphins but also for the extensive sand extraction activity from the river bed. During the monsoon season, the river experiences high water level, and people enjoy the aesthetic view of diving dolphins at every river site. However, in post-monsoon, the dolphins are found only in some selected sites depending on the physiochemical properties of the river water and also on the hydro-geomorphic parameters of the channel such as width, depth, velocity, eddy counter current, meander planform, interconnectivity of wetlands and tributary confluences. The dolphins prefer locations which are away from human interference and prey fishes are easily available. The dolphin habitat has been adversely affected by the depositional activity of the river which leads to decrease in depth in the lower reaches of the river and also due to the activity of sand mining with the use of machines, creating a noisy environment.

The downstream stretch of the Kulsi river is being degraded by frequent flooding, pollution by agrochemicals, sand mining and deforestation. Additionally, fishing and boating activities have threatened the existence of endangered resident dolphins. Environments, where there are predators or stressors eventually force the animal population to move out from that site. Unfortunately, the river dolphin population is on the verge of extinction due to poaching for oils and meat (Mohan and Kunhi, 1996; Choudhury, 2013), decrease in prey fishes owing to indiscriminate fishing activity without proper knowledge, and also the influence of natural and human activities. The river dolphins are listed by the International Union for Conservation of Nature (IUCN) as endangered (Smith *et al.*, 2012) and included in Appendix I of the Convention on International Trade in Endangered Species (CITES). In India, it has been placed in Schedule-I of the Wildlife (Protection) Act, 1972, and was declared the National Aquatic Animal in 2009. Research on the distribution pattern of Gangetic river dolphins, their population status, ecological investigation, and protection of this endangered species in the Brahmaputra-Barak river system has already been carried out. However, a comprehensive study on the hydro-geomorphic and environmental conditions of the dolphin habitat site has not been conducted yet. The present study investigates the hydro-geomorphic characteristics of the Kulsi river from the Ukium to Nagarbera (Fig. 2) for proposing suitable sites for the long-term conservation of the resident Gangetic dolphin population.

Geographical background

The Kulsi river is a left-bank tributary of the Brahmaputra river. In Meghalaya, the river is known as the Khri river, where the tributaries Um Krisinya, Um Siri, and Um Ngi meet with the Khri river at Ukium. After reaching the alluvial plain of Assam, the river is known as Kulsi river. The Kulsi river basin has a total area of around 1951 km2, situated between 25˚31′58.8″N to 26˚75′3.33″N and 91˚E to 91˚48′30″E (Fig. 1). The upstream portion of the study area is composed of high to moderately dissected structural hills and valleys; whereas, low to moderately denuded isolated hills mark the pediment complex. The low-lying alluvial plain to the north comprise of four geomorphic subunits viz. the young alluvial plain, old alluvial plain, active flood plain and old flood plain. The pediment complex is another geomorphic unit within the basin with moderate slope sustaining natural vegetation and grassland. The debris slopes are moderate to severely eroded with fine textured alluvial soil having high susceptibility to erosion. The slope gradient from Ukium (80 m) to Nagarbera (35 m) is only 41 cm km^{-1}. The upper catchment

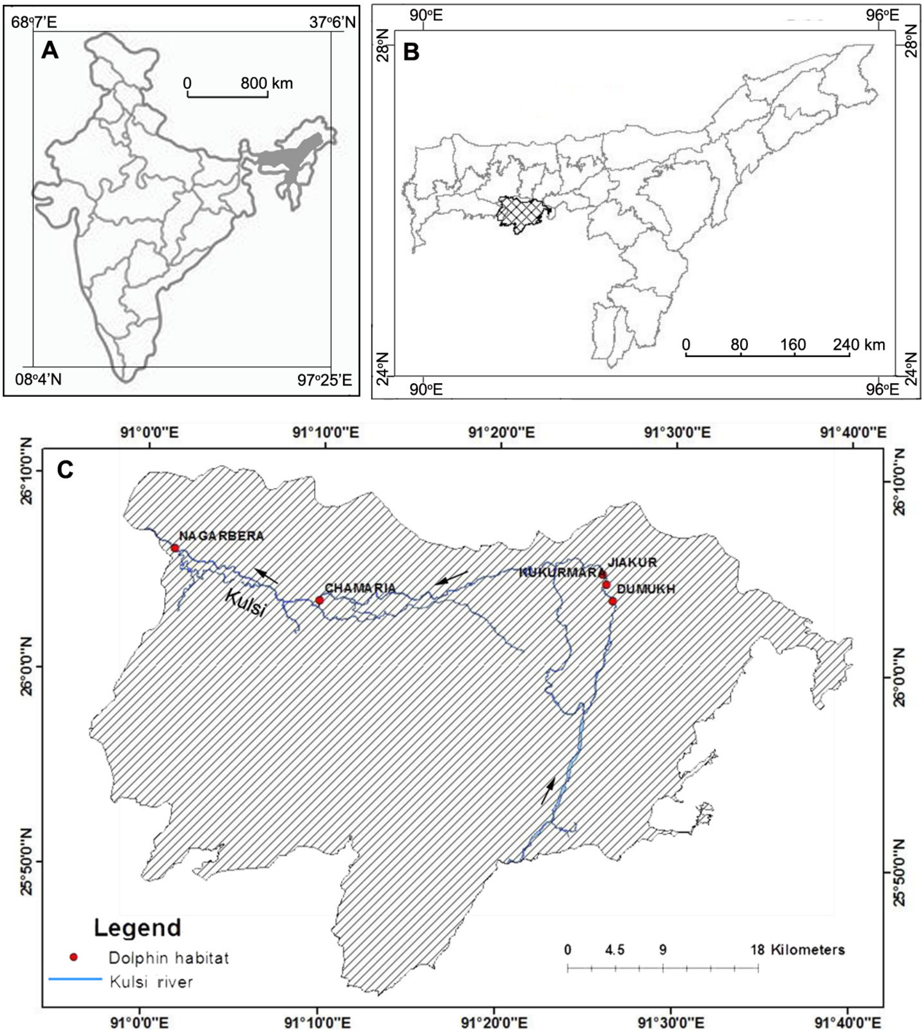

Figure 1. Location of Assam in India (A), lower Kulsi basin within Assam (B) and the dolphin habitat along the lower Kulsi river (C).

area is composed of Proterozoic gneissic structure and the lower catchment belongs to the age of Meghalayan and formed during the Barpeta-I formation.

Materials and methods

The present paper is mainly based on primary field data and subsequent laboratory analysis.

Hydro-geomorphic survey of selected sites

From Ukium to Nagarbera, 26 cross-sectional data were collected during the pre-monsoon season of 2019 using boats throughout the course. There are five sites where Gangetic dolphins are reported owing to favourable depth of the water bodies, velocity and water discharge of the river, availability of prey fishes, and lack of human interference like sand mining etc. The five sites are Dumukh, Kukumara, Jiakur, Chamaria, and Nagerbera (Fig. 1C). Forty-five cross-sections were surveyed from these five sites during the winter season (December-January) of 2019–2020. The hydro-geomorphic parameters like width,

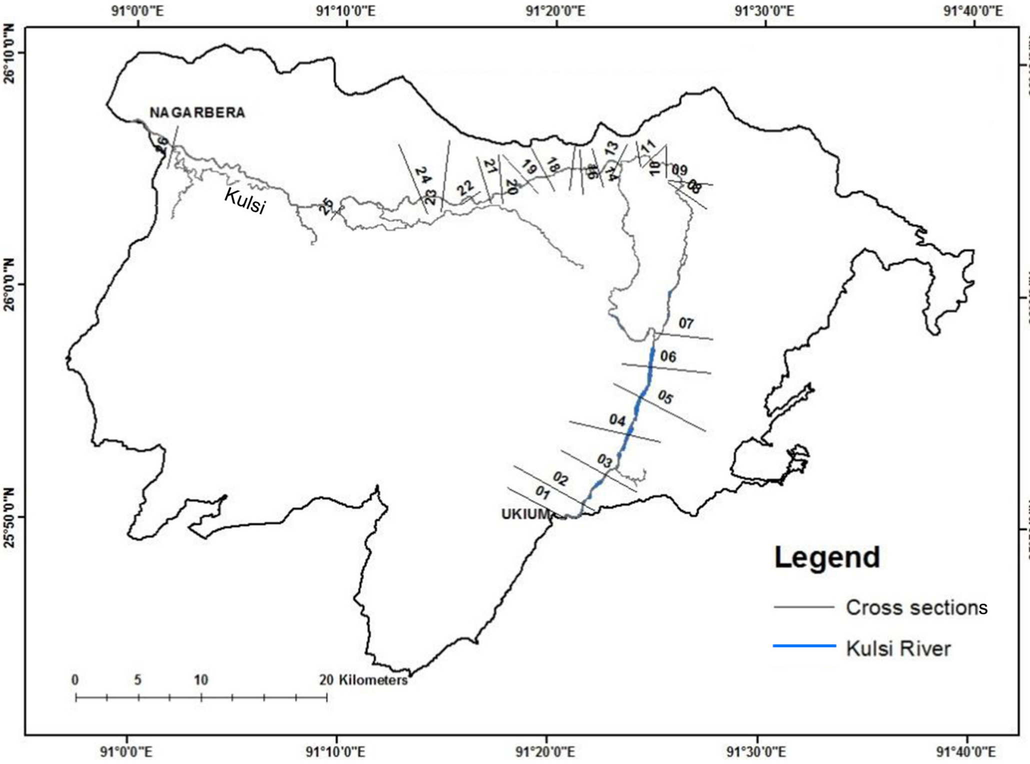

Figure 2. Location of sample cross-sections from Ukium to Nagarbera in lower Kulsi basin

depth, and velocity were measured for each cross-section. A cup-type current meter was used to measure the depth-wise velocity of the river water at each dolphin-site, and the surface velocity of water was recorded through by float method. Spatial information of each cross-section, viz. location, height, and extension was collected from the field using GPS. Figure 2 shows the location of the 26 sample cross-sections from the Ukium to Nagarbera.

Analysing the physiochemical parameters of the water for assessing the quality

Water samples of Kulsi river from the five dolphin habitat sites were collected during the winter (December-January) of 2019–2020. To test the water quality, the Turbidity LMTB-200 was used for turbidity, which gives the readings in the nephelometric turbidity unit (NTU) and a field PH meter was used to test the temperature and PH of the water.

The secondary data sources used in the study

The base map of the study area was prepared using the Survey of India (SoI) topographical sheets no. 78N/4, 78N/8, 78O/1, and 78O/5 with 1:50,000 R.F. The maps were collected from the office of the SoI, northeastern zone, Assam and Nagaland Geospatial Data Centre, Guwahati. The annual average discharge data of Kulsi river at Kukurmara from 1991 to 2018 was collected from Central Water Commission, Shillong (Meghalaya). Database on river courses and present riparian condition was prepared from high-resolution IRS LISS IV satellite image, acquired on 19th February 2018.

The information collected from the primary and secondary sources was tabulated, summarised, and analysed using quantitative and computer-aided techniques. Finally, charts, tables, and graphs were prepared using appropriate cartographic methods. A spatial database was created from satellite data and SoI topographical sheets in the GIS environment. Data integration and measurement of the spatial database was done using Arc GIS version 10.5.

Results and discussion

Channel characteristics from Ukium to Nagarbera

The channel shape is the product of width and mean depth at a given channel cross-section. Channel width at any given point along the course of a river represents straight cross-sectional distance, and the stage of the river represents the mean depth of the channel. The channel width varies with changes in the discharge. The bank full stage of the river denotes maximum channel width. The channel width considerably changes in the rivers having seasonal rainfall regime. The depth of the channel denotes the vertical height from the water level in the channel to the channel bed. The width, depth, velocity, and discharge characteristics were recorded at every cross-section. It was observed that the channel width of the upper course, varying from 29.46 m to 273 m, up to cross-section seven was found to be much wider than the sections further downstream (Table 1).

Table 1. Cross-sectional and hydrological data from Ukiam to Nagerbera along 26 sample cross-sections

Cross section	Width (m)	Mean depth (m)	Mean surface velocity (m s^{-1})	Discharge (Q) (m^3s^{-1})
1	65.95	0.78	3.23	166.58
2	225.60	0.14	3.20	100.94
3	196.20	0.16	5.57	173.76
4	29.46	0.92	6.10	165.33
5	118.00	0.27	1.95	61.99
6	90.10	0.32	2.51	72.37
7	273.00	0.13	3.71	132.61
8	40.60	0.71	0.19	5.36
9	36.90	2.40	11.64	1030.84
10	44.10	0.58	3.69	93.63
11	36.00	1.03	10.03	371.91
12	41.20	1.18	5.25	255.23
13	70.20	0.88	4.78	295.29
14	44.90	0.68	6.12	186.31
15	35.20	1.83	6.81	438.67
16	55.30	1.72	5.00	475.58
17	49.80	1.62	4.00	322.70
18	53.80	0.40	3.24	70.25
19	48.00	0.47	2.38	53.69
20	49.80	1.12	1.48	82.25
21	51.60	1.18	4.97	301.72
22	54.80	1.75	4.05	388.58
23	57.30	2.97	3.52	599.64
24	53.30	0.91	3.12	152.16
25	58.00	0.98	5.00	284.20
26	68.00	1.30	11.00	972.40

However, high sediment deposition in the Kulsi riverbed also lowers the channel depth in this stretch, where it varies from 0.13 m to 0.92 m. Due to high sedimentation and sand mining activities along the course of the Kulsi river, resident dolphins are rarely found during the monsoon season. From cross-sections 8 downstream, up to cross-section 26 near the confluence of the Kulsi river with Brahmaputra, the channel width varies from 35 m at cross-section 15 to 68 m at cross-section 26. In the same stretch he average depth of the channel varies from 0.57 m to 2.40 m, respectively. The surface velocity of water increases with increasing depth. Therefore, maximum discharge was found to be 1030.838 m^3s^{-1}, representing a suitable site for the habitat of the Gangetic dolphin. From Ukium to Nagerbera, it is observed that there are five such dolphin habitat sites.

Channel characteristics of dolphin habitat sites

CHANEL CROSS-SECTIONAL CHARACTERISTICS

For the morphological measurement of the channel at the dolphin habitat sites, 45 cross-sections were surveyed in the Kulsi river. The detailed analysis of the cross-sections reveals that at the Dumukh site (Fig. 3A, Table 2) the width of the channel varies from 32 m at cross-section A9 to 42 m at cross-section A5. For all the 45 cross-sections depths were measured from the left bank to the right bank, and the maximum depth at Dumukh site was measured as 2 m at cross-section A9. The sinuosity index of the Kulsi river at the Dumukh course is 1.04 and sediment depositions was observed mostly on the left bank at this almost straight stretch of the channel. The riverbed, throughout the studied stretch was composed of fine textured sediment, mostly in the groups of sand, but at some sites there are moderate to low percentage of silt, and clay.

At the Kukurmara site (Fig. 3B, Table 2) the width of the channel varies from 20 m at cross-section B1 to 54 m at cross-section B9. Depths were measured from the left to the right bank, and the maximum depth is measured as 5.9 m at cross-section B3. The sinuosity index of Kulsi at the Kukurmara course is 1.5, indicating a meandering channel pattern.

At the Jiakur site (Fig. 3C, Table 2) the width of the channel varies from 33 m at cross-section C2 to 44.6 m at cross-sections C5, C6, and C8. The maximum depth was measured as 2.9 m at cross-section C6. Sediment deposition occurred at the concave bends of the channel, at both the left and right banks of the river, except for cross-section C1, which was located at a straight segment of the channel. The sinuosity index of the Jiakur course is 1.01, indicating a nearly straight channel segment.

At the Chamaria site (Fig. 3D, Table 2) the width of the channel varies from 45.04 m at cross-section D6 to 84 m at cross-section D7. Maximum depth at this stretch was measured as 4.5 m at cross-section D8. The deposition of sediment was observed at mid-channel location at cross-sections D1, D3, D7, and D10. Near cross-sections D6 and D8, deposition was mostly adjoining the left bank of the channel and at the right bank at cross-sections D2 and D5. The sinuosity index of the Chamaria course is 1.46, indicating a highly sinuous reach.

At the Nagarbera site (Fig. 3E, Table 2) the width of the channel varies from 46 m at cross-section E3 to 68 m at cross-section E5.

Maximum depth was measured as 5.1 m at cross-section E2. Deposition of sediment was observed on the channel bed adjoining the left bank at cross-sections E1, E2, E3 and E5. Mid-channel deposition was prominent at cross-section E4, near a sinuous reach of the channel. The sinuosity index of the Nagarbera course is 1.12, representing a slightly sinuous stretch.

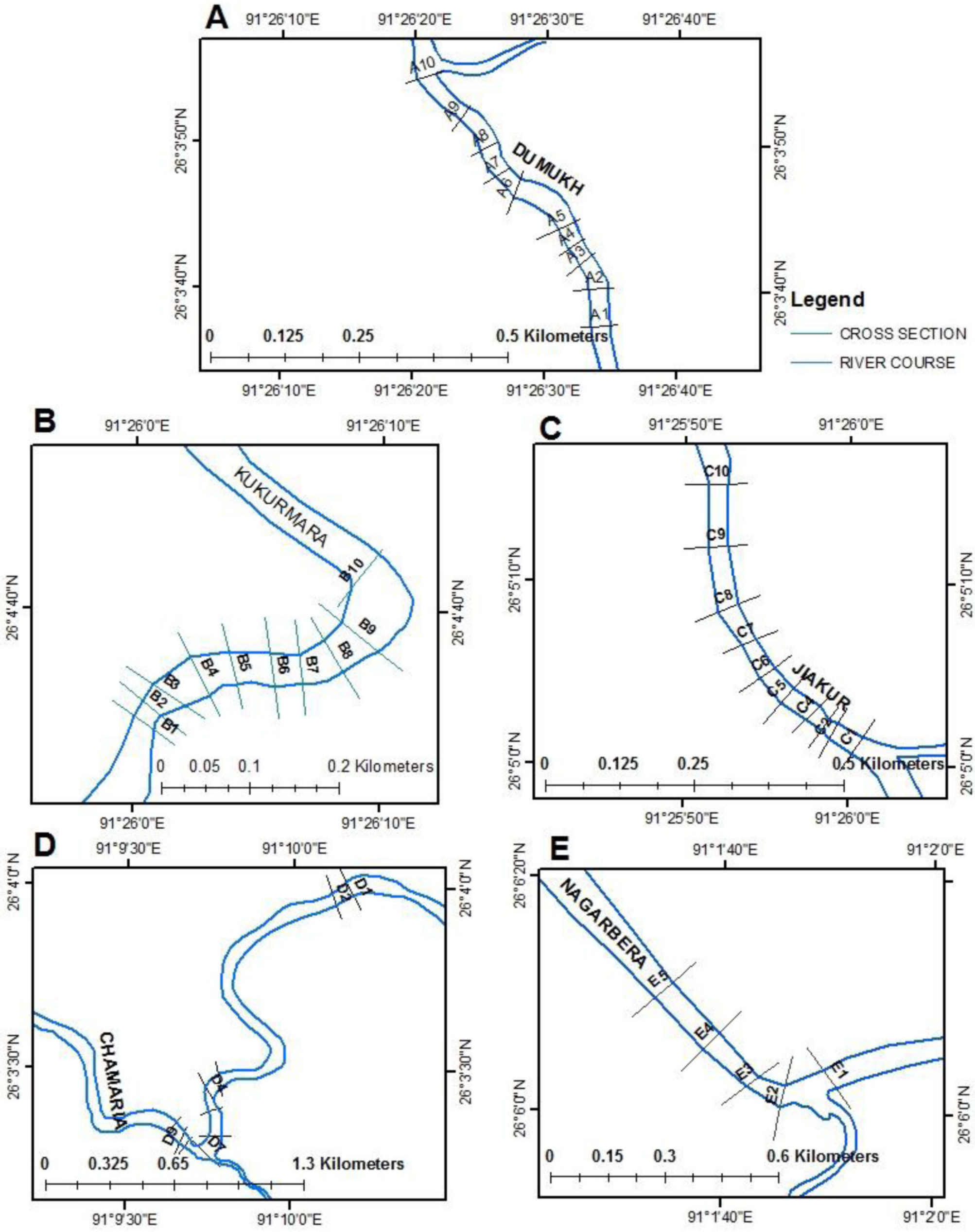

Figure 3. Channel planforms at the five Gangetic dolphin habitat sites along the Kulsi river and the position of the cross-sections at each habitat site

Based on the field data it was observed that the average depth and the width of the channel were found to be high in the Kukurmara site and Chamaria site, respectively (Table 2). Maximum discharge of Nagarbera site is located at the confluence of the river Brahmaputra; so the amount of discharge is also high. Therefore, these sites can be considered as most suitable for the habitation of Gangetic dolphins.

Table 2. Cross-sectional characteristics of Kulsi channel at five resident dolphin sites

Site	Cross-section	Depth (in m)		Width (m)	Area (m^2)	Velocity ($m\ s^{-1}$)	Discharge ($m^3\ s^{-1}$)
		Max	Average				
A. Dumukh	1	1.10	0.567	36.50	20.695	0.346	7.160
	2	1.13	0.601	46.20	27.766	0.216	5.997
	3	1.79	0.878	34.50	30.291	0.176	5.331
	4	1.04	0.630	33.60	21.168	0.190	4.021
	5	0.94	0.648	42.00	27.216	0.238	6.477
	6	1.10	0.629	34.80	21.889	0.211	4.618
	7	1.90	1.035	34.80	36.018	0.146	5.258
	8	1.95	1.103	36.45	40.204	0.196	7.880
	9	2.00	1.506	32.00	48.192	0.220	10.602
	10	1.53	1.014	39.60	40.154	0.236	9.476
B. Kukurmara	1	3.40	2.004	20.00	40.080	0.142	5.691
	2	5.60	3.439	39.00	134.121	0.137	18.374
	3	5.90	3.570	46.00	164.220	0.096	15.765
	4	4.90	2.538	49.00	124.362	0.062	7.710
	5	2.70	1.938	43.00	83.334	0.137	11.416
	6	1.60	1.117	46.00	51.382	0.262	13.462
	7	1.40	0.933	39.00	36.387	0.237	8.623
	8	1.90	1.057	43.00	45.451	0.217	9.862
	9	3.00	1.863	54.00	100.602	0.105	10.563
	10	3.90	2.170	41.00	88.970	0.176	15.658
C. Jiakur	1	1.60	1.200	38.00	45.600	0.300	13.680
	2	2.00	1.440	33.00	47.520	0.300	14.256
	3	2.10	1.256	33.20	41.699	0.266	11.091
	4	2.10	1.191	35.30	42.042	0.200	8.408
	5	2.00	1.229	44.60	54.813	0.200	10.962
	6	2.90	1.371	44.60	61.146	0.150	9.171
	7	2.40	1.224	39.00	47.736	0.233	11.122
	8	2.30	1.111	44.60	49.550	0.200	9.910
	9	2.50	1.308	41.70	54.543	0.266	14.508
	10	2.50	1.702	41.20	70.122	0.133	9.326
D. Chamaria	1	1.10	0.731	74.00	54.094	0.466	25.207
	2	1.50	0.770	52.00	40.040	0.283	11.331
	3	1.60	0.872	48.00	41.856	0.356	14.900
	4	3.90	2.250	47.00	105.750	0.133	14.064
	5	3.00	1.637	46.00	75.302	0.250	18.825
	6	2.10	1.396	45.00	62.820	0.310	19.474
	7	2.80	1.136	84.00	95.424	0.366	34.925
	8	4.50	2.300	54.00	124.200	0.263	32.664
	9	2.10	1.560	63.00	98.280	0.386	37.936
	10	1.50	0.975	58.00	56.550	0.556	31.441
E. Nagarbera	1	2.70	1.308	67.00	87.636	0.410	35.930
	2	5.10	2.318	63.00	146.034	0.133	19.422
	3	4.20	1.860	46.00	85.560	0.280	23.956
	4	3.10	1.771	67.00	118.657	0.393	46.632
	5	3.20	1.300	68.00	88.400	0.360	31.824

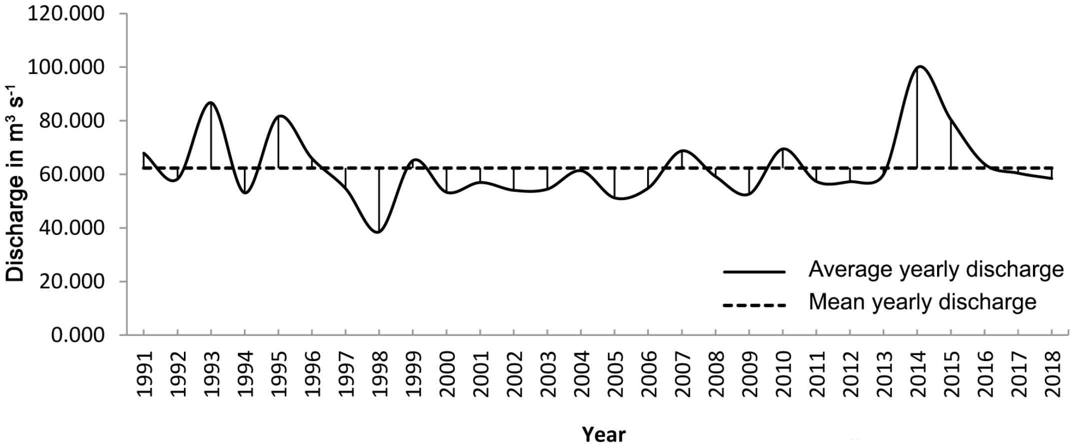

Figure 4. Annual average discharge of Kulsi river at Kukurmara for the years 1991–2018 (Central Water Commission, Shillong).

FLOW CHARACTERISTICS

The flow regime of the Kulsi river is mainly dependent upon the seasonal rhythm of the monsoon. The river exhibits unique flow characteristics marked by significant seasonal variations. Peak flow occurs during the summer monsoon. More variable runoff patterns are observed during the rainy season, with peaks occurring after each storm event. The base flow maintains the channel in the pre-monsoon period, just before the onset of the subsequent monsoon. Observation of gauge data for about 50 years is generally needed to describe the characteristic natural flow regime of the river, including its seasonal trend and variability. In the case of Kulsi river a 28 years database reveals that the yearly average discharge of the Kulsi river varies from 99.789 $m^3 s^{-1}$ in 2014 to 38.541 $m^3 s^{-1}$ in 1998. From 1991 to 2018, the mean yearly discharge was 62.359 $m^3 s^{-1}$.

Figure 4 represents the deviation of the annual discharge from the mean annual discharge for the 28 years period from 1991 to 2018. The time cycle of these annual peaks seems to be irregular both in its period and amplitude. It is also observed that there has been a wide variation from year to year since 1991. The duration of periods of continuous departures both above and below the mean seems to have increased substantially. The sustained high discharge years are 1993, 1995, and 2014. There is a high positive deviation in 2014, which descends to a negative deviation in 2018. The deviation of discharge in 1998 is considered highly negative. From 1997 to 2006, there was a continuous departure of low discharge except in 1999, which is slightly above the mean level. The documented changes in the discharge can be categorised into three type — 1) normal discharge (2004, 2013 and 2017), 2) above normal discharge (1991, 1993, 1995, 1999, 2007, 2010, 2014, 2015 and 2016) and 3) below normal discharge (1992, 1994, 1997, 1998, 2001, 2002, 2003, 2005, 2006, 2008, 2009, 2011, 2012 and 2018). Figure 5 shows annual discharge showing regular fluctuation with peaks occurring almost every alternate year. The pattern of variation of the annual peak flow of the river represents the period from 1991 to 2018. It is observed from the annual hydrograph of Kulsi river that the magnitude of peak flow maximum, especially in the early part and later part of the sequence; and the trend of peak flow decreased from 1996 to 2013. The highest peak flow of 99.789 $m^3 s^{-1}$ was recorded in 2014, and the lowest flow of 38.541 $m^3 s^{-1}$ in 1998.

Riparian condition

Gangetic dolphins occupy freshwater river systems, their tributaries and connected lakes in southern Asia. They prefer areas of the river that create eddy counter-currents such as small islands, river bends, convergent tributaries (Moreno, 2003; Pilleri, 1970), downstream shallow and narrow places (Kasuya and Haque, 1972), sharp meander (Sinha, 1997), meander pool (Bairagi *et al*., 1997), of the mouth of irrigation canals, near villages and ferry crossing area (Pilleri and Bhatti, 1982; Pilleri and Zbinden, 1973-74), downstream of bridge pilings (Choudhary et al., 2006; Smith *et al*., 2001), sandbars and channel with muddy or rocky substrates (Kelkar *et al*., 2010). Riparian condition of Kulsi plays a vital role in providing suitable habitations for river dolphins. Kulsi's riparian zone has interconnecting wetlands, ox-bow lakes; cutoff necks of meanders and the junction of tributaries which support favorable habitat for dolphins. The river Kulsi, a tributary of the Brahmaputra, acts as a breeding ground for dolphins because the riparian condition of Kulsi is most suitable for dolphin breeding. Breeding period of Gangetic dolphins spans throughout the year, but the prominent breeding season is from October to March, with a peak in December-January before the beginning of the dry season (Jefferson *et al*., 2008).

Interconnecting wetlands of the Kulsi river plays a significant role in determining the dolphin habitat. Wetlands are the home of different species of fish and invertebrates. Fishes such as gobies (*Glossogobius giuris*), herring (*Setipinna phassa*); crustacea such as prawn *(dendrobranchiate*), and mollusks are the leading food of dolphins (Reeves and Brownell, 1989). Dolphins of the Kulsi river feed predominantly on benthic species from Kulsi and its interconnecting wetlands. Figure 5 shows the riparian condition of the dolphin habitat of lower Kulsi basin. The map is prepared based on IRS LISS IV data (date of acquisition is 19.2.2018). It is observed from map 5A that the tributary stream Batha joins Kulsi river at Dumukh site where the maximum depth is 2 m at cross-section A9. The interconnected Sol wetland is located about 100 m away from Batha river. It covers an area of 14.90 ha during the winter season. The interconnected Dora wetland is located near Kukurmara, and the Jiakur dolphin habitat covers about 31.67 ha of the submerged area during the winter season (Fig. 5B). At Chamaria, the tributary stream Boko and Singra meets the Kulsi river, creating a favorable condition for the habitat of Gangetic dolphins (Fig. 5C). The Deosila is a tributary stream of the Kulsi river which converge with Kulsi near Nagarbera. It flows along the extensive low-lying zone of wetlands near Kalyanpur (Fig. 5D). Therefore, it is evident that the conservation and restoration of wetlands of the lower Kulsi basin are the essential pre-requisite for the conservation of dolphins, management of flood plain and for overall sustainable development of the area.

The Kulsi river at Kukurmara, Chamaria, and Nagarbera course flows a sinuous path. The sinuosity indexes of these courses are 1.5, 1.46, and 1.12, respectively. If the sinuosity index is 1.5 or more, then the course planform is called meandering (Mueller, 1968). Therefore, the course of Kulsi at Kukurmara and Chamaria forms a highly sinuous almost meandering path. These meander bends of the Kulsi river support favorable habitats for resident dolphins. The cross-sectional profile of a meandering path with its characteristic flow structure at the Nagarbera site is shown in Figure 6. The maximum depth of the channel cross-sectional profile at the meander bend is formed alongside the concave bank. It happens due to the action of helical flow in the meander bend. The orientation of the helical flow depends on the vertical flow velocity distribution (Corney *et al*., 2006). The surface

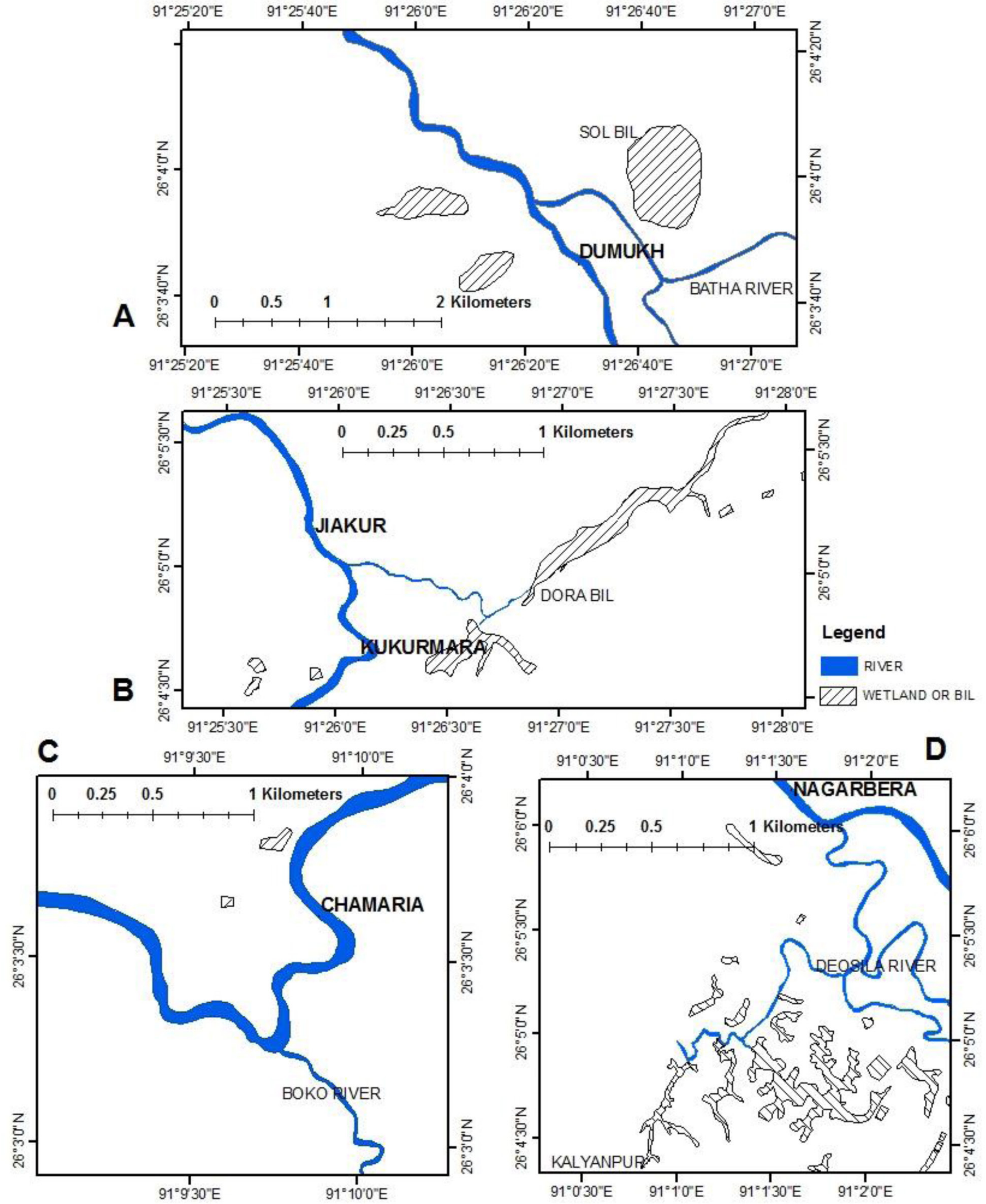

Figure. 5. Interconnecting wetlands and tributary confluences of five Gangetic dolphin habitat sites along lower Kulsi river

flow is towards the concave bank, and the base flow is toward the convex bank. The helical flow of the meander bend plays an essential role in sediment transport and deposition (Azpiroz-Zabala, 2017). Such meander bends with maximum depths are favorable habitat for dolphins.

Selected physiochemical quality of water

Freshwater dolphin usually lives at normal

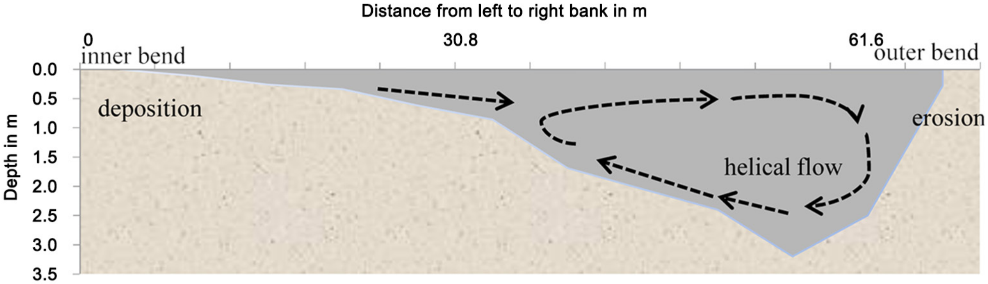

Figure 5. The model of flow structure over a cross-sectional profile of meander bends at cross-section 5 of the Nagarbera site.

Table 3. Results of three selected water parameters of five dolphin habitat sites. pH and water temperature are measured at the time of the field survey during the winter season (December-January) of 2019-2020.

Sl. No.	Dolphin Site	Turbidity (NTU)	pH	Water Temperature (°C)
1	Dumukh	1.3	7.30	25.1
2	Kukumara	2.9	7.45	27.1
3	Jiakur	2.4	7.35	26.9
4	Chamaria	5.9	7.20	27.0
5	Nagarbera	8.1	7.25	26.9

temperature, needs clean air, and good quality of water. The results of three physicochemical parameters of water, viz. turbidity, pH and water temperature of five samples collected from the dolphin habitats of Kulsi river are shown in Table 3.

Turbidity affects light penetration in water bodies and therefore determines productivity (Mazumder *et al.,* 2014). The turbidity of water at the five dolphin habitat sites range from 1.3 NTU to 8.1 NTU. Nagarbera and Chamaria sites recorded comparatively higher turbidity of 8.1 NTU and 5.9 NTU respectively, owing to siltation and suspended sediments in the water near the confluence of Brahmaputra. Silt, clay, and other suspended particles contributed to high turbidity levels during the rainy season (Dagaonkar and Saksena, 1992; Garg *et al*., 2006). pH is closely linked to biological productivity (Islam *et al*., 2012) and a high pH value is related to high level of photosynthetic activity in the water (Hujare 2008). pH of all five dolphin habitat sites of Kulsi river was found to be neutral, ranging between 7.20 –7.45. This indicates that the health status of the river water is safe for dolphins. pH value determines plankton growth (Chisty 2002) and pH values ranging between 5.0 and 8.5 are suitable for plankton growth (Umavathi *et al*., 2007). The temperature tolerance range for the Gangetic river dolphins is from 8°C in cold water to 33°C in warm water (Moreno, 2003). The water temperature recorded at the Dumukh site was 25.1°C and at Kukurmara site it was 27.1°C during winter. These water temperatures of Kulsi river during the winter are due to low water levels and clear atmospheric conditions in the daytime.

Conclusion

Hydro-geomorphic characteristics of the Kulsi river play a significant role in identifying the suitable habitation of dolphins. The entire course of Kulsi from Dumukh near Ghoramara up to its confluence with Brahmaputra support suitable habitation of the species in monsoon and winter. In winter, five habitat points, namely Dumukh, Kukurmara, Jiakur, Chamaria, and Nagarbera provide favorable hydro-geomorphic and environmental conditions for dolphins. Out of which Kukurmara and Nagarbera sites are most favoured, where maximum depth and discharge of channel are recorded as 5.1–5.9 m and 18 m^3 s^{-1} to 46 m^3 s^{-1} respectively during the winter season. The Kulsi river and its convergence point with tributaries, mainly Batha, Boko, Singra, Kharkar, and Deosila, act as a nourishing ground for the dolphin population. Interconnecting wetlands and meandering planform support suitable environmental conditions for dolphin habitation. Therefore, managing these channel courses and conserving wetlands are essential requisites for building a healthy habitat condition to protect the resident dolphin.

There is limited availability of observed data on hydro-geomorphology in dolphin habitats. This research delineates potential dolphin habitat sites in the Kulsi river using extensive fieldwork and high-resolution satellite data (5.8 m) for the first time. The research will contribute to the local government and communities if conservation efforts in the suggested sites may be prioritised to preserve the endangered species.

Acknowledgment

We are very much grateful to the funding agencies Science and Engineering Research Board (SERB) and the Department of Science and Technology (DST), Government of India for their financial support for this project. We are also thankful to the wonderful field assistants, local communities, research scholars, fishermen and all those who directly and indirectly contributed in making this research successful.

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Date received: 14 September 2022
Date accepted after revision: 31 December 2022