International Journal of Environmental Planning and Management
Vol. 7, No. 3, 2021, pp. 72-86
http://www.aiscience.org/journal/ijepm
ISSN: 2381-7240 (Print); ISSN: 2381-7259 (Online)

Morphological Dynamics of Braided River Near Bogibeel Bridge, Assam

Kuldeep Pareta*

DHI (India) Water & Environment Pvt Ltd., New Delhi, India

Abstract

The construction of any structure on a river affects its flow and morpho-dynamics. A river like the Brahmaputra, which has a high volume of flow and sediment, can have huge consequences. Therefore, a morphological study understanding the effect of a structure on a river is also necessary. The present paper focusses on the morphology and morpho-dynamics of Brahmaputra river near the Bogibeel bridge, which aim is to investigate the effect of the bridge on the river morphological behaviour and to inspect any attack on the structure of the bridge and its components (guide bunds, embankments, abutments) by the river. This study of the reach of Brahmaputra river near Bogibeel bridge has been carried-out using the cross-section data - bathymetry data (2004-2017), Landsat satellite imageries (2004-2021), and field assessment data (2020). Morphological dynamics of rivers are affected by any natural and anthropogenic perturbation in the system. The effect of any structure can be seen in the morphological changes in the river system pre-and post-construction. It is, therefore, necessary to familiarize with the major geomorphic attributes of Brahmaputra river. Notable these are braided planform, bedforms and sediment transport. The erosion and deposition pattern of Brahmaputra river reach nearby Bogibeel bridge is showing a decreasing trend, which corresponds to the good river training work and flood management in that area over the last few years. Riverbed level change analysis indicate that the average change in the riverbed level is -0.20 m. the maximum fall in the bed level was found to be 1.15 m from the year 2010 to 2011. The slope of the deepest channel of the study reach of the river is found to be nearly 0.35 m / Km. In the trend analysis of the riverbed slope, the results reveal that there is a fall in the slope of the overall channel at a rate of 0.01 m / Km per year, i.e. the slopes are getting steeper. This can be due to narrowing of the river near the bridge leading to active degradation of channel. During the field assessment survey, it has observed that due to Bogibeel bridge, the water level and frequency of flood is increase in u/s (within 6 Km) of Bogibeel bridge. The study can be used as a baseline for future studies near the Bogibeel bridge, and similar studies may be carried-out for other constructed or upcoming bridges on Brahmaputra river.

Keywords

Morphodynamics, River Morphology, Brahmaputra River, Bogibeel Bridge, RS/GIS

Received: May 11, 2021 / Accepted: July 10, 2021 / Published online: July 26, 2021

1. Introduction

River and channel are sorts of natural watercourses on the surface of the earth and have become the crucial part of geological components [1]. The river course has persistently moved in space over the long haul and tends to accomplish balance positions to oblige itself with various fluvial geomorphic just as a climatic condition [2]. This change occurs in different regions, including fluvial, glacial, dry, wind, coastal, and karst morphology because of the Earth's dynamic events [3]. River morphology is the consequence of a common collaboration of four general classifications of factors like

* Corresponding author
E-mail address: kpareta13@gmail.com, kupa@dhigroup.com

fluid dynamics, (including velocity, discharge, roughness, and shear stress), channel character or channel configuration (including channel width, depth, and material) [4]. Riverbank erosion has significant ramifications for short as-well-as long-term channel adjustment, development of plan form, braiding, sediment dynamics of river basin, and d/s sedimentation issues [5]. Understanding the etiquette through which river channels have moved through time is critical to handle many geomorphic and river management problems, in light of large size, such as rates of change is necessary to measure and monitor channel migration [6]. A better understanding of morphological changes of alluvial rivers, bankline migration due to erosion and deposition process as well as technique to identify the pattern can be suitable for management of alluvial environments [1].

Majority of studies related to the morphology of Brahmaputra river system focuses on the main river channel of Brahmaputra [1, 7-13]. Sedimentation study of the char bars of the Brahmaputra river was analyzed by [14-16]. Erosion rate and bankline migration of the Brahmaputra river have been analyzed by [1, 7-8, 17-18] in Assam. Danish Hydrological Institute (DHI) has set-up the river morphological model, real-time flood forecasting and early warning model, and embankment breach prediction model in Brahmaputra river for Flood and Riverbank Erosion Management Agency of Assam (FREMAA) under Assam Integrated Flood and Riverbank Erosion Risk Management Investment Program (AIFRERMIP) [19]. [20] have carried-out the morphology and channel width study at Bogibeel bridge, Assam.

Bogibeel bridge is a structure of national importance. It provides a better connectivity within the state for the transport of goods and people. With its proximity to the border, the bridge is also highly significant for India's defence system. Therefore, it is of utmost importance that the structural and functional integrity of the bridge is not affected by the fluvial processes in Brahmaputra river. It is also important to examine the consequences of the construction of the bridge on the morphology of Brahmaputra river. Construction of any structure on a river affects its flow and morpho-dynamics. And for a river like Brahmaputra, which carries high volume of flow and sediment, the repercussions can be huge. Therefore, a morphological study understanding the impact of a structure on the river is also needful.

The present paper focusses on the morphology and morpho-dynamics of Brahmaputra river near the Bogibeel bridge. The aim is to investigate the effect of the bridge on the river morphological behaviour and to inspect any attack on the structure of the bridge and its components (guide bunds, embankments, abutments) by the river. The specific objectives of this study are: (i) study the morphology of Brahmaputra near Bogibeel bridge, (ii) examine the effect of the bridge on the morphology of the river.

2. Study Area

Brahmaputra is one of the largest (by discharge) alluvial rivers in the world, having a total length of 2,880 km and a total basin area of 580,000 Km^2. It originates in China in a glacier in the Kailash range of the Himalayas. The river runs through Assam for a length of 640 Km. In its course, the river discharge is augmented with contributions from more than 100 tributaries [1], the largest of which are 15 from the north bank and 10 from the south bank. There is a large variation in the gradients of the river within Indian territory, from 4.3 to 16.8 m / Km near the gorge to 0.1 m / Km near Guwahati. With the milder slopes in the Assam region, the river forms a very wide (1.23 to 18 Km) braided channel and divides the state into North and South Assam. Several bridges have been constructed over Brahmaputra to connect north and south Assam (Table 1).

Table 1. Details of Bridges on Brahmaputra River.

Bridge	Connected Districts	Length (Km)	Type
Dr Bhupen Hazarika Setu	Tinsukia	9.15	Road Bridge
Bogibeel Bridge	Dibrugarh and Dhemaji	4.94	Road - Rail Bridge
Koli-Bhomora Setu	Sonitpur and Nagaon	3.02	Road Bridge
Naranarayan Setu	Bongaigaon and Goalpara	2.28	Road - Rail Bridge
Saraighat Bridge	Kamrup	1.49	Road Bridge

The Bogibeel bridge situated 17 Km downstream of Dibrugarh. The bridge is located just over 20 km away from the Assam-Arunachal Pradesh border and is thus expected to act as an alternative to the Koli-Bhomora Setu, Tezpur, in providing connectivity to nearly five million people residing in upper Assam and Arunachal Pradesh. Bogibeel bridge is the longest combined railway bridge and road bridge above water in India and the second longest bridge across Brahmaputra river. The construction of the 4.94 Km long bridge started in 2002 and it was completed in December 2018. Bogibeel bridge connects Dhemaji district in north Assam with Dibrugarh District in south Assam. The location map of Bogibeel bridge is shown in Figure 1.

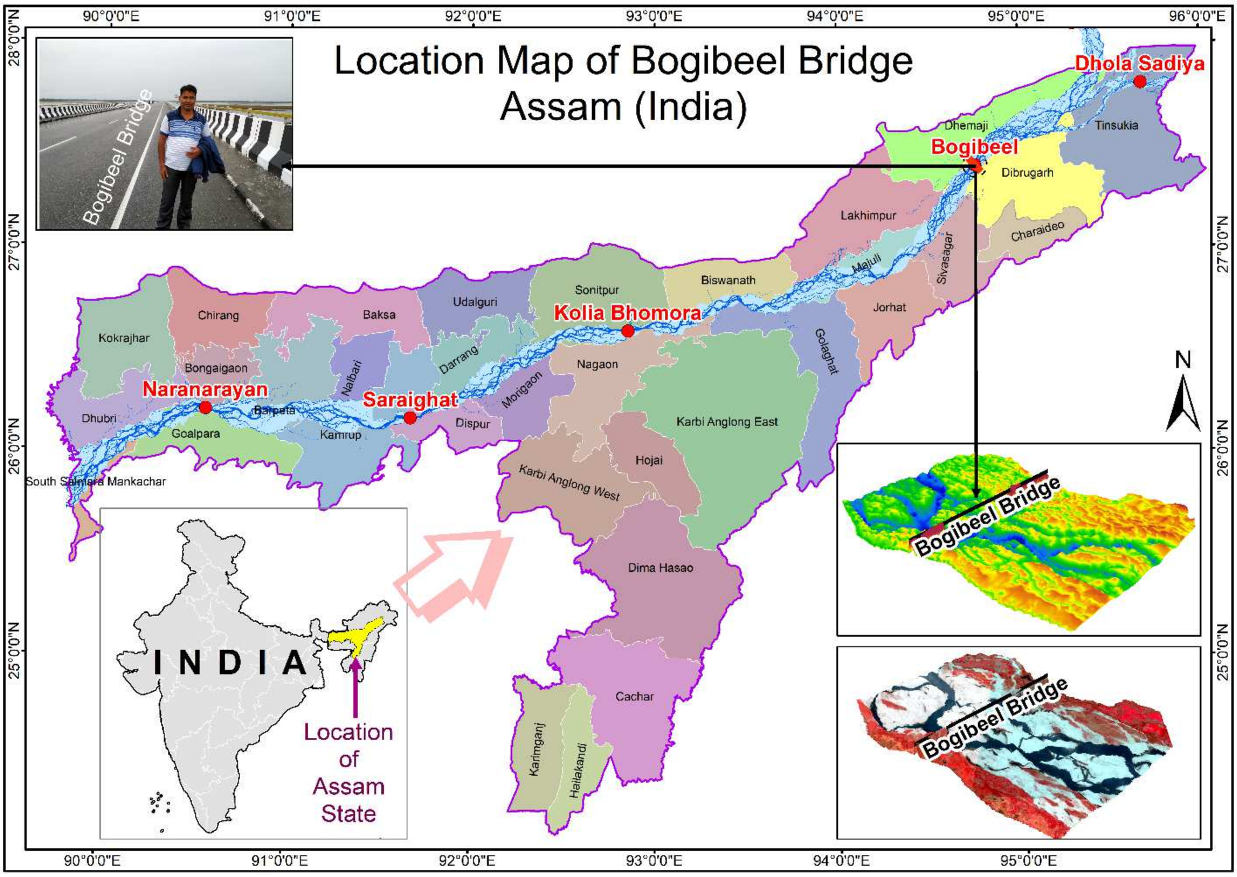


Figure 1. Location Map of Bogibeel Bridge, Assam (India).

3. Data Used and Methodology

This study of the reach of Brahmaputra river near Bogibeel bridge has been carried-out using the Cross- section data, bathymetry data, and Landsat satellite imageries collected from Earth Explorer, US Geological Survey.

Table 2. Data Used and their Sources.

S. No.	Data Types	Data Sources
1.	Elevation Data	Shuttle Radar Topography Mission (SRTM) DEM data has been downloaded from NASA & USGS EROS Data Centre. 1. Spatial Resolution: 30 m 2. Source: http://glcfapp.glcf.umd.edu:8080/esdi
2.	Cross-Section Data, and Bathymetry Data	Cross-section data, and bathymetry data has been collected from a Govt Organization. They have surveyed the bed levels of Brahmaputra river for about 9 Km u/s and 7 Km d/s of the bridge. The following information was in the data. 1. AutoCAD files of river cross sections for 2004, 2007 and annually from 2009 to 2017. 2. Excel files with cross-section data for each transect. 3. Latitude and longitude of Survey of India reference pillars.
3.	Landsat Series Satellite Imageries	Landsat Satellite Imageries from 2004 to 2021 were downloaded from Earth Explorer, USGS. 1. Landsat-5 TM Data: 2004 to 2011. 2. Landsat-7 ETM+ Data: 2012 to 2015 3. Landsat-8 OLI Data: 2016 to 2021. 4. Spatial Resolution: 30 m 5. Source: https://earthexplorer.usgs.gov 6. These satellite imageries have been used for validation of bathymetry data and to interpret morphological changes in the river.

3.1. Pre-Processing of Bathymetry Data

The data received was not geographically referenced and was not in ready to use GIS format. The cross- section spreadsheets were in chainage and elevation format and latitude and longitude of transect endpoints were missing. Data pre-processing consisted in:

1) Georeferencing using Survey of India reference pillars.

2) Extraction of cross-section transects from the

georeferenced drawing

3) Generation of chainage points and addition of elevation values for all transects.

The coordinates and elevation values of the generated points were later converted to an XYZ shapefile.

3.2. Bathymetry Development

The bathymetry was developed as a raster from the generated XYZ points. The point shapefiles in XYZ format are converted to raster (tiff) using the tool "Topo to Raster"- an interpolation method of Spatial Analyst in ArcGIS[1]. The bathymetry (raster) was developed with the resolution of output cell of 5m × 5m.

4. Geomorphic Features of Brahmaputra River

Morphological dynamics of rivers are affected by any natural and anthropogenic perturbation in the system. The effect of any structure can be seen in the morphological changes in the river system pre and post- construction. It is, therefore, necessary to familiarize with the major geomorphic attributes of Brahmaputra river. Notable morphological features of Brahmaputra are braided planform, bedforms and sediment transport.

4.1. Braided Planform

Brahmaputra river is a braided river with braid plain widths of up to 18 Km. Total braided width of the river course through Assam has increased from 6 Km to 9 Km over the past century [8]. Degree of braiding of highly braided river can be measured by plan form index (PFI), which has been developed by [21]. This can be measured by ((T/B) x 100) / N, where: T = flow top width, B = overall width of the channel, and N = number of braided channels.

Plan form index (PFI) indicates to the fluvial landform disposition with regard to an allotted water level and its smaller value is represent of a higher degree of braiding. [21] has also proposed a broad range of classification of the braiding phenomenon based on the PFI values. According to him if PFI value is less than 4, then river is highly braided; if PFI values are ranging between 4 and 19, then river is moderately Braided, and if PFI value is more then 19, then river is low braided.

The newer braiding indicator PFI has been adopted for the study to analyze the braiding behavior of Brahmaputra river near Bogibeel bridge. A thirteen KM river reach, 6.5 Km of u/s and d/s of Bogibeel bridge has been selected for this study. The PFI has been measured at 27 cross-sections (at every 500 m Interval) of Brahmaputra river by using multi-temporal satellite remote sensing data from 2004 to 2021. Mean plan form index (PFI) of the Brahmaputra river near to Bogibeel bridge is given in Table 3.

Table 3. Mean Plan Form Index (PFI) of Brahmaputra River near Bogibeel Bridge.

S. No.	Reach	Construction Period (2004-2017): Mean PFI	Post-Construction Period (2018-2021): Mean PFI
1.	Upstream (u/s) of Bogibeel Bridge	15.53	17.86
2.	Downstream (d/s) of Bogibeel Bridge	14.38	16.03

The mean plan form indexes of Brahmaputra River near Bogibeel bridge with u/s and d/s; and during the construction period and post construction period are ranging from 14.38 to 17.86, which is corresponding to moderately braided of Brahmaputra river in that reach.

4.2. Bedforms

Brahmaputra river has the third highest sediment load in the world [22]. The river yields huge volumes of sediment load annually, estimated at between 387 and 650 million tons [23]. Large scale bedforms (bars and islands) and micro-scale bedforms (ripples and dunes) are important riverbed features. These bedforms induce resistance to flow, and thus influence discharge, water level, bed shear stress and sediment transport.

In Brahmaputra river, braid bars, dunes and ripples are in abundance. Braid bars are the most common features in Brahmaputra. These bars grow due to flow divergence at the bar head and enhances growth around bar margins. Lateral growth is enhanced by the development of secondary current in the anabranches. Vertical growth develops from the successive superimposition of moving ripples and dunes. Local flow structures, their distribution, and erosion-deposition processes become further complicated due to the longitudinal movement of these bars; bars can travel up to 100 m/day in Brahmaputra [23].

Ripples and dunes are also dominant in Brahmaputra. The flow in Brahmaputra almost always remains in the lower flow regime, i.e., in the subcritical regime (Fr <1). Plane bed, ripples and dunes develop at the lower flow regime; dunes wash away at transitional flow. Dunes are the main driver of bedload transport, and responsible for the formation of local bed morphology, and initiation of bedforms.

4.3. Riverbank Erosional and Depositional Area Analysis

Multi-temporal satellite remote sensing data of Landsat-5 TM (30 m), Landsat-7 ETM (30 m), and Landsat- 8 OLI (30 m)

1There are numerous interpolation and raster generation tools available in ArcGIS. The "Topo to Raster" tool is chosen due to its applicability in elevation value interpolation. It ensures a hydrologically correct digital elevation model.

have been used to digitize bank lines from 2004 to 2021 (18 years) (Figure 2). The area of erosion and deposition between each cross-sections line (at 300 m interval) on left bankline and right bankline along the Brahmaputra river around Bogibeel bridge were calculated and mapped using ArcGIS 10.7 software. Year wise (2004-2021) total erosion and deposition statistics on left bankline and right bankline of Brahmaputra river around Bogibeel bridge is given in Table 4 and shown in Figure 3. Negative values are used for erosion and positive values are used for deposition.

Table 4. Right-Left and Upstream-Downstream Erosional and Depositional Area in Km^2 (2004-2021).

Year	Right Bankline and u/s		Right Bankline and d/s		Left Bankline and u/s		Left Bankline and d/s	
	Deposition	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition	Erosion
2004	0.11	-0.05	1.29	-0.01	0.09	-0.46	2.21	-0.12
2005	0.05	-0.12	0.00	-0.19	0.12	-0.19	0.00	-0.01
2006	0.00	-0.24	0.00	-0.05	0.00	-0.45	0.00	-0.32
2007	0.23	-0.06	0.03	-0.15	0.23	-0.08	0.04	-0.23
2008	0.55	-0.05	0.01	-0.10	0.37	-0.14	0.12	-1.56
2009	0.14	-0.00	0.04	-0.02	0.73	-0.11	0.05	-1.07
2010	0.11	-0.08	0.01	-0.00	0.39	-0.02	0.00	-0.09
2011	0.92	-0.58	0.01	-0.45	0.15	-0.30	0.14	-0.92
2012	0.11	0.00	0.00	0.00	0.07	-0.09	0.12	-0.09
2013	0.01	-0.11	0.00	-0.10	0.00	-0.02	0.00	-0.04
2014	0.00	-0.00	0.00	-0.00	0.00	-0.00	0.00	-0.00
2015	0.40	-0.06	0.21	-0.00	0.00	-0.09	0.00	-0.10
2016	0.18	-0.00	0.01	-0.00	0.00	-0.06	0.00	-0.25
2017	0.00	-0.06	0.00	-0.05	0.00	-0.05	0.00	-0.03
2018	0.83	-0.11	0.64	-0.14	0.02	0.00	0.00	-0.04
2019	0.00	-0.06	0.01	0.00	0.00	0.00	0.00	0.00
2020	0.10	-0.01	0.00	-0.01	0.09	-0.15	0.06	-0.18
2021	0.22	-0.09	0.13	-0.07	0.13	-0.13	0.16	-0.30

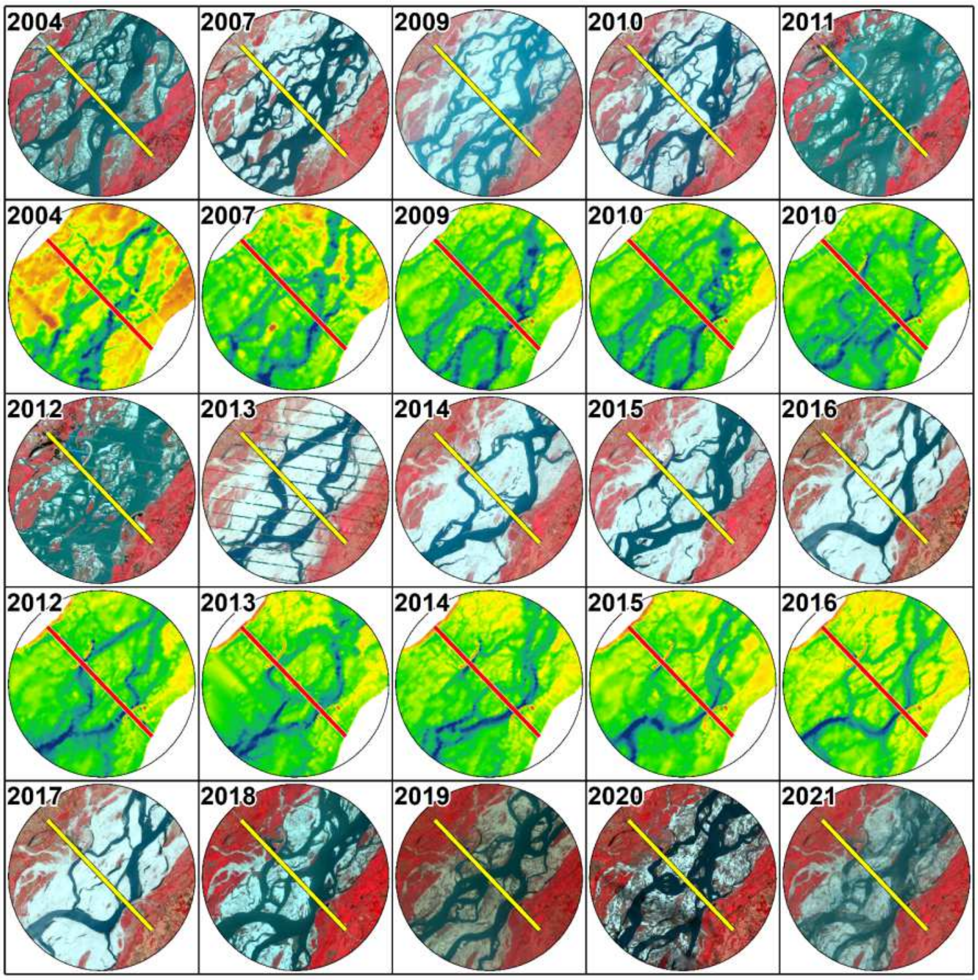


Figure 2. Bathymetry Data (2004-2016), and Satellite Imageries (2004-2021) Map of Bogibeel Bridge, Assam.

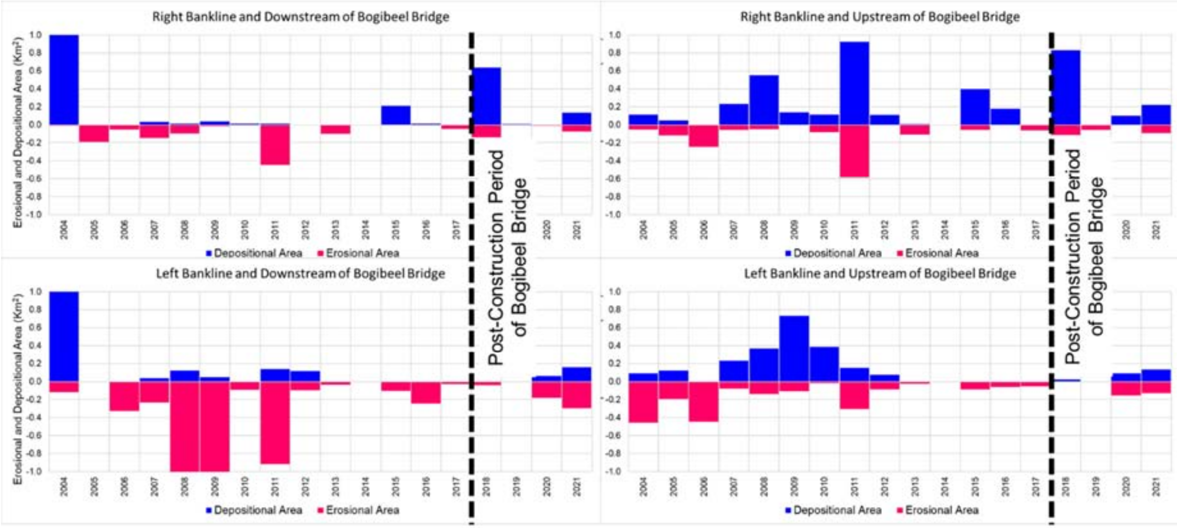


Figure 3. Right-Left and Upstream-Downstream Erosional and Depositional Area Graph.

Overall deposition of the Brahmaputra river reach (within 13 Km) nearby Bogibeel bridge from 2004 to 2021 exceeds overall erosion. The depositional areas on right bankline and left bankline is 6.36 Km^2, and 5.30 Km^2 respectively, while erosional areas on right bankline and left bankline is 3.02 Km^2, and 7.68 Km^2 respectively. In comparison to upstream of Bogibeel bridge, downstream is more active for erosional process. The average depositional area from 2004 to 2021 (18 years) on right bankline and left bankline is 0.35 Km^2, and 0.29 Km^2 respectively, while average erosional area from 2004 to 2021 (18 years) on right bankline and left bankline is 0.17 Km^2, and 0.43 Km^2 respectively. From these statistics it is clear that left bankline is more active then the right bankline. Referring to Figure 3, the erosion and deposition pattern of Brahmaputra river reach nearby Bogibeel bridge is showing a decreasing trend, which corresponds to the good river training work and flood management in that area over the last few years.

5. Morphological Analyses

The morphological analysis of the study reach has been done for a change in river slope, change in the mean riverbed in a reach, followed by quantification of the erosion and deposition. These analyses have provided the overall first-hand information of the general behaviour of the river, geometry, and fluvial dynamics, pre and post construction of the bridge.

5.1. Thalweg Profile Analysis

The thalweg is the line connecting the deepest bed levels of successive cross-sections of a river. The deepest bed elevations in all the available cross sections of a year were plotted to understand the bed elevation trend between the years. In wide multi-channel rivers like Brahmaputra, these deepest points can switch from one channel to another from one transect to another within a year, and between two successive years. Therefore, the changes in the thalweg profile do not give us a definite value of rising or fall in a channel, but an average representation of changes in the bed of the channel. The thalweg profiles from 2009 to 2017 have been generated by using River Bathymetry Toolkit (RBT) and shown in Figure 4. The changes in the bed profiles for the period 2009 to 2017 are shown in Figure 5.

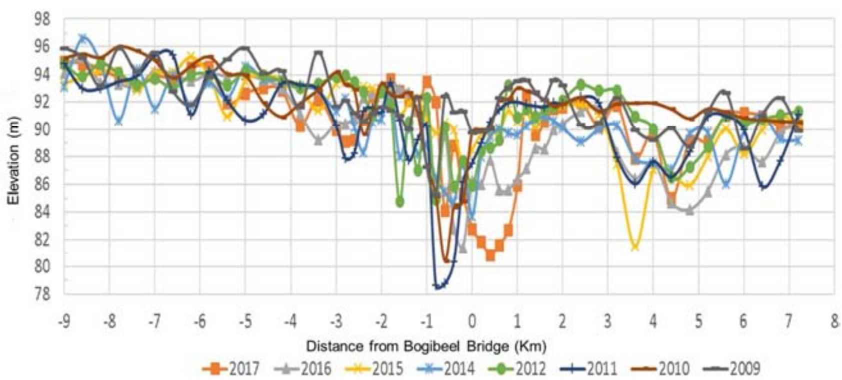


Figure 4. Thalweg Profiles from 2009 to 2017.

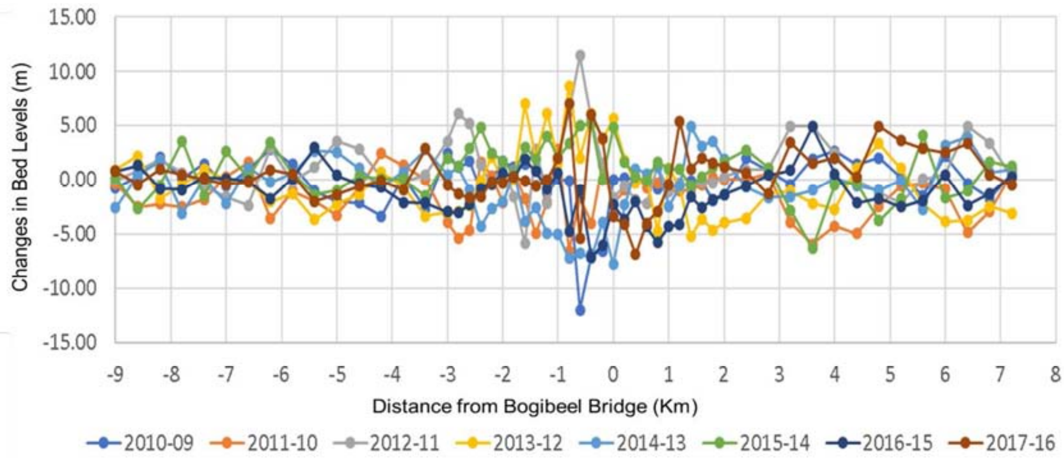


Figure 5. Changes in the Deepest Bed Levels in Consecutive Years.

The analysis of change in the riverbed levels gives the following results: (i) the river is highly dynamic in the entire reach, (ii) the average change in the riverbed level is found to be -0.20 m (fall of 0.20 m), (iii) maximum fall in the bed level was found to be 1.15 m from the year 2010 to 2011, (iv) standard difference was found to be of 2.75 m, (v) the major bed level changes were observed up to 1.6 Km upstream of the bridge, and (vi) maximum rise (11.54 m) and maximum fall (11.99 m), both were observed 600 m upstream of the barrage.

5.2. Riverbed Slope

The slope of the deepest channel of the study reach of the river is also calculated. The values of the slopes are given in Table 5. The average slope of Brahmaputra River in this 13 Km reach is found to be nearly 0.35 m / Km (Figure 6). In the trend analysis of the riverbed slope, the results reveal that there is a fall in the slope of the overall channel at a rate of 0.01 m / Km per year, i.e. the slopes are getting steeper. The trend in the riverbed slopes is shown in Figure 7.

Table 5. Riverbed Slopes Estimated from Cross-Sections.

Year	Study area		U/S of the Bridge		D/S of the Bridge	
	Reach (Km)	Slope (m / Km)	Reach (Km)	Slope (m / Km)	Reach (Km)	Slope (m / Km)
2004	13	-0.2903	6.5	-0.2	6.5	-0.4
2007	13	-0.239	6.5	-0.3	6.5	-0.1
2009	13	-0.2861	6.5	-0.6	6.5	-0.3
2010	13	-0.2871	6.5	-1.1	6.5	-0.2
2011	13	-0.3372	6.5	-1.1	6.5	-0.5
2012	13	-0.3052	6.5	-0.8	6.5	-0.09
2013	13	-0.4224	6.5	-0.2	6.5	-0.2
2014	13	-0.3708	6.5	-0.8	6.5	-0.1
2015	13	-0.4311	6.5	-0.4	6.5	-0.3
2016	13	-0.5195	6.5	-0.8	6.5	0.1
2017	13	-0.3719	6.5	-0.6	6.5	0.8

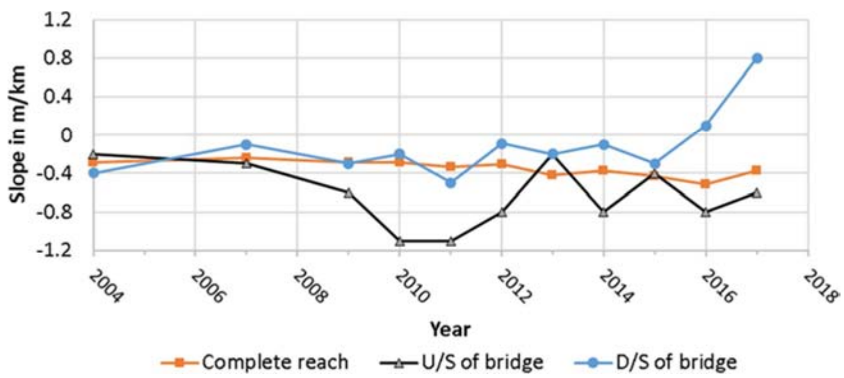


Figure 6. Trend of Riverbed Slope in Various Stretches.

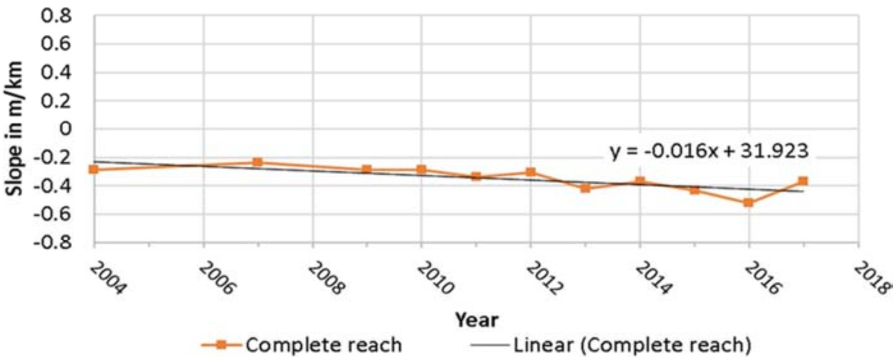


Figure 7. Trend Line Fit for Bed Slopes of Complete Reach.

5.3. Cubature Study

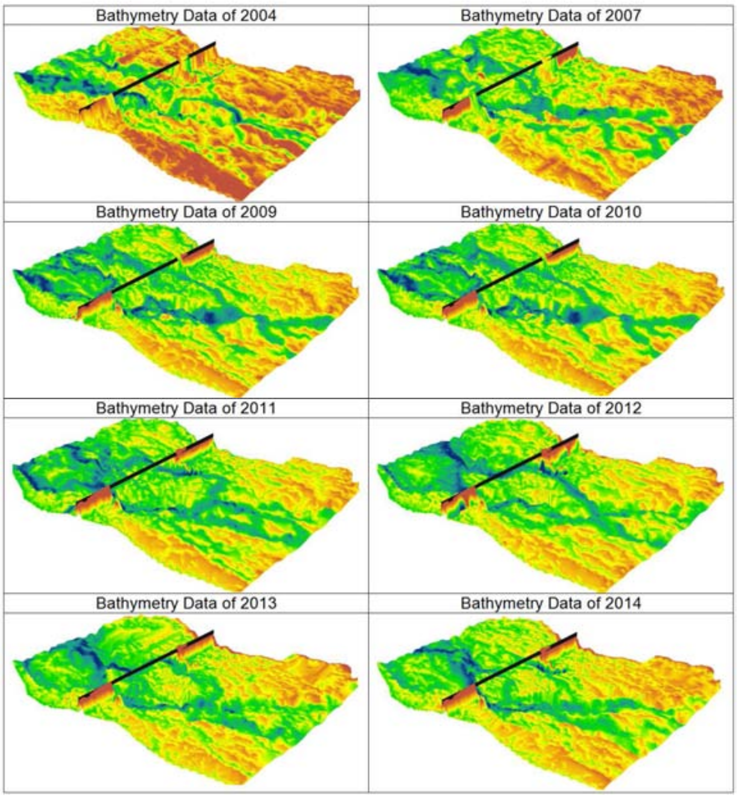
The concept of sediment balance is used in the cubature study of a river is shown in Figure 8. Consider a system with sediment inflow (S_1) and sediment outflow (S_2), then the total change in sediment storage (ΔS) within this reach is the difference between S_1 and S_2. This effective storage is equivalent to the difference between deposition and erosion within this reach. The same calculation is shown below.

Effective Sediment Storage (ΔS) = Sediment Inflow (S_1) - Sediment Outflow (S_2)

(ΔS) = Deposition-Erosion. If ΔS is positive, there is net deposition in the channel and if ΔS is negative, then there is net erosion.

Figure 8. Effective Sediment Storage in a System.

In this study, bathymetry data, produced from the cross-section data, is used to compute effective storage in the river reach. The bathymetry of one year was deducted from the bathymetry of its previous year to evaluate the net erosion and deposition in the system. The volumetric erosion, deposition and the spatial distribution of these changes have been computed by analysing the bathymetrical data (Figure 9). The rate of sediment deposition and erosion and volumetric sediment storage in the study reach are presented in Figure 10.



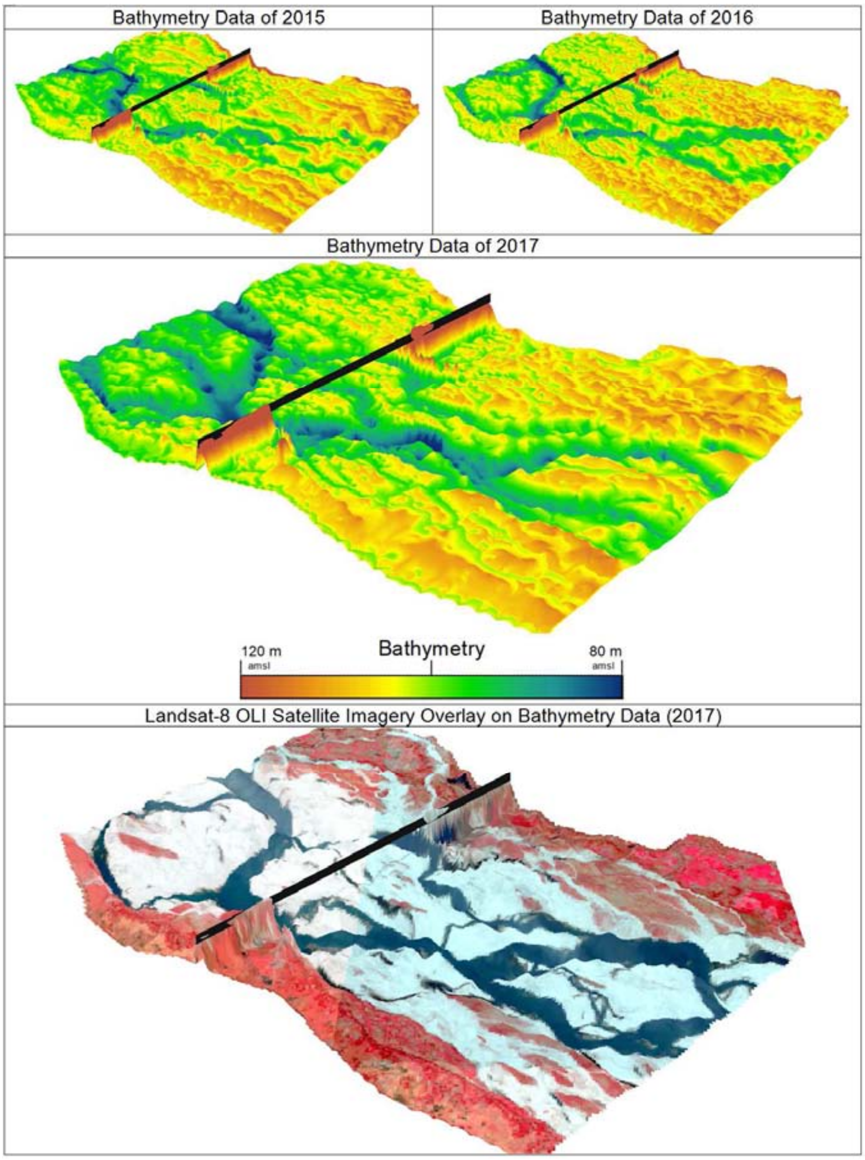


Figure 9. Bathymetry and Erosion-Deposition Maps (2004-2017).

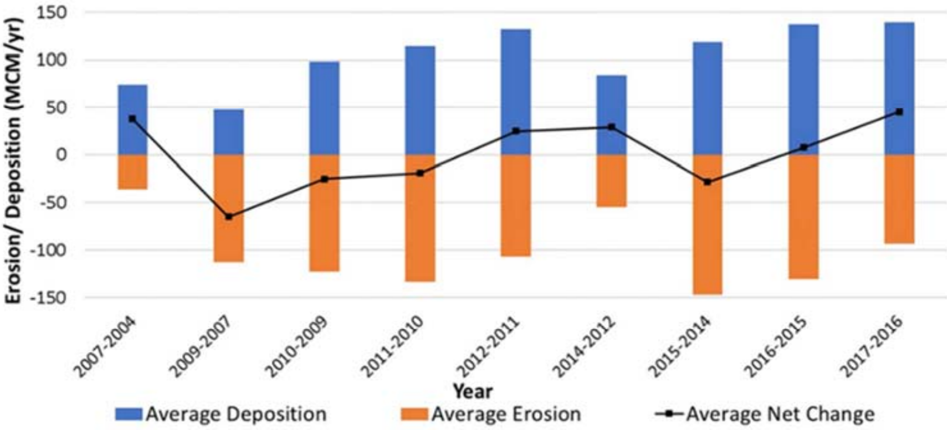


Figure 10. Erosion and Deposition along the Entire Study Reach from Cubature Study.

The spatial distribution of erosion-deposition or bed level changes are mapped and shown in Figure 10. The position of the rivers for the respective years are also shown for better illustration. In the maps, negative values represent erosion and positive values represent deposition. Brahmaputra is one of the world's most dynamic river. Formation of new channels, abandonment of old channels, formation of sandbars is observable in this river system. The results of the cubature study are detailed in Table 6.

Table 6. Analysis of Erosion Deposition Maps and their Result.

S. No.	Period	Deposition (MCM)	Erosion (MCM)	Effective Sediment Storage (MCM)	Results from erosion-deposition maps
1	2007-2004	222.33	109.00	113.33	1. At BCL: the high values of elevation may be due to the construction of bridge abutments 2. Formation of new channels: near US28 to US17 3. Abandonment of old channel: US21 to US11 4. Widening of existing channel: DS17 to DS23 5. Growth of Island: just downstream of bridge (DS01 to DS11) 6. Formation of sandbars: DS08 to DS11, US30-29 7. The river shows higher deposition than erosion in the entire reach.
2	2009-2007	96.30	226.22	-129.92	1. The river shows very high erosion in the entire reach. 2. Formation of sandbars: US30-28, US 20, DS01-03, DS06-9, DS19-20 3. Abandonment of channel: US19-17 4. Formation of channel: US20-03 5. Widening of existing channel: US27-25, DS13-14 6. Bank erosion: DS10-13 (South bank)
3	2010-2009	98.17	123.18	-25.01	1. Moderate erosion and deposition are observed 2. Abandonment of old channel: US14-09 3. Formation of new channel: US26-25, US09-04 4. Widening of existing channel: US28-27, US25, US20-16, DS14-15 5. Erosion: at South bank-US30-28, US03-DS01 (near guide bund), DS10-15, DS20 and at North bank: US30-26, DS12, DS14-15, and of island at DS12-14
4	2011-2010	114.37	133.44	-19.07	1. Formation of new channel from US30-21, DS11-15 are observed. 2. Abandonment of channel is also observed at US28-27 near north bank and US25-21 near south. 3. Huge deposition just upstream of bridge US06-04 is found. 4. Bank erosion: at north bank: US13-07, DS07-10, DS12, DS16-17 and at south bank DS13-19.
5	2012-2011	132.41	107.47	24.94	1. Deposition is observable from the map. 2. Abandonment of channel: US30-26, US25-20 (near S), US17-10 (near N) 3. Deposition: US18-08 4. Growth of sand bar: US25, US11-01, DS02-12 5. Erosion of north bank observed at US30-29, US02-DS03 and of Island d/s of bridge DS16-22 6. Formation of new channel: US28-21, US15-07
6	2014-2012	167.99	109.38	58.62	1. Major Deposition is observable from map. 2. Abandonment of channels at US30-28, US18-15, US19-07 3. Growth of sand bar: US26-22, US01-DS05, DS07-13 4. Formation of bars: DS15-17 5. Erosion of sandbars: BCL-DS13, US26-22, US23-20 6. Erosion of north bank observed at US30 and BCL
7	2015-2014	118.50	146.66	-28.17	7. Erosion of north bank observed at US30-26 and BCL and south bank DS07-12 8. Widening of channel: US26-25, US11-05, DS12-18 9. Deposition near north bank: US26-22
8	2016-2015	137.51	130.04	7.47	1. Erosion of north bank observed at US30-29, US27 20 and along south bank DS12-22 2. Widening of channel near US28-25 and DS15-23 near north bank. 3. Formation of cut-off from US02-DS02 4. Abandonment of channel: US15-08 and DS16-30 5. Overall river shows deposition distributed throughout the reach.
9	2017-2016	139.44	93.91	45.53	1. Deposition is observed in old reaches US30-29, US28-26, US16-04. 2. Widening of channel US17-11 due to formation of sandbars in the middle 3. DS12-30: North bank retreat of a channel of river and over all deposition in the old channel. There is also abandonment and formation of channel in this reach.

6. Field Assessment

Author has done the field assessment survey in area around Bogibeel bridge. Author has selected two location for survey. 1st is Amguri Bali Village of Dhemaji district, which is situated in upstream and round 1.7 Km far from Bogibeel bridge. 2nd is Dalani Gaon of Dibrugarh district, which is located in downstream and around 3.5 Km away from Bogibeel bridge. The field assessment data of Amguri Bali Village and Dalani Gaon is given in Table 7, and Table 8 respectively.

Table 7. Field Assessment Data of Amguri Bali Village.

S. No.	Details of Field Assessment Form	
1	General Information	
1.1	Village name	Amguri Bali
1.2	CD block name (according to census of India)	Sissiborgaon
1.3	District name	Dhemaji
1.4	State name	Assam
1.5	Latitude (degree decimal-DD) 'Y'	27.44919
1.6	Longitude (degree decimal-DD) 'X'	94.743136
1.7	Elevation (Above mean sea level, m)	104 m
2	River Bankline	Right bankline (north bank)
2.1	River flow direction	NNE to SSW
2.2	River width (Km)	7.4
3	Lithological, Slope and Soil Information	
3.1	Stratigraphic classification	Sedimentary rock
3.2	Lithological information	White to greyish sand, silt, pebble and clay
3.3	Slope (surrounding area)	Gentle
3.4	Soil primary classification	Younger alluvial soils
3.5	Soil texture	Sandy clay, heavy clay
4	Physical Attributes of Riverbank	
4.1	Riverbank material	Sand
4.2	Riverbank modification	None
4.3	Riverbank features	Vegetated mid-channel bar
4.4	Riverbank profiles - natural / unmodified	Composite
4.5	Riverbank profiles - artificial / modified	Set-back embankment
5	Physical Attributes of Channel	
5.1	Channel bed material	Sand, clay
5.2	Channel flow-type	No perceptible flow
5.3	Channel modifications	None
5.4	Channel features	Vegetated mid-channel bar
5.5	Valley form (within the horizon limit)	Braided channel
6	Geomorphic Features	
6.1	Out-of-channel - geomorphic features	Anabranch, active floodplain
6.2	In-channel - geomorphic features	Braided river, non-sinuous braided river, mid-channel bar
7	Landuse / Landcover (within 100 m of vulnerable area)	
7.1	Land cover	Scrub land and shrubs, open field and river
7.2	Land use	Agricultural crop land, agricultural fallow land, rural area, school, clinic, religious and transportation
8	Any infrastructure (nearby the vulnerable area)	Embankment (breached in 1998)
9	Major impacts from vulnerable area	Transportation (road), residential area (rural), agricultural area (crop/fallow), fishing and erosion
10	Evidence of recent management	Embankment
11	Flood related Information of the Village nearby the Vulnerable Area	
11.1	About the Village	
11.1.1	Name of village	Amguri Bali
11.1.2	Approx. population of the village	500
11.1.3	Major occupation of the village	Farming, fishing
11.1.4	How long have community been living here?	More than 100 years
11.1.5	Majority of construction material	Tin-shed, khas
11.2	Flood Occurrence and Severity	
11.2.1	How many times did community experience flood while living at this village?	Flooded every year during the monsoon season (2019)
11.2.2	What was the maximum water level and duration of flood entering your village?	
11.2.2a	Flood year	2019
11.2.2b	Flood depth	6 feet
11.2.2c	Duration	15 days
11.3	Flood Emergency Response	
11.3.1	Just before the flood, how did your community first become aware that flood waters might reach your home?	Observing the river water level
11.3.2	Did share the warning with others?	Yes
11.3.3	How many hours were there between the time your community became aware that flooding might reach your village until the water actually reached to your village?	2 hours
11.3.4	What is the minimum warning time would your community need to move all your transportable contents to a safe location?	1 hours
11.3.5	What is the shortest distance between your village and river?	2 Km
11.3.6	Do your community have a safe place to move in case of flooding?	Yes (On embankment)
11.3.7	How far is it from your village?	150 m
11.4	Flood Impact on Infrastructure	
11.4.1	During the flood, water supply was interrupted?	No water supply
11.4.2	During the flood, the electric supply was interrupted?	Yes
11.4.3	During the flood, the telephone supply / mobile network was interrupted?	No
11.4.4	Was there any secondary source for water supply?	Yes (Another village, handpump)
11.4.5	Was there any secondary source for electric supply?	No
12	Flood Management Activities	

S. No.	Details of Field Assessment Form	
12.1	Which type of flood protection activities, planning, or mitigation your community need in that area.	New guide band
13	Significant Observations, and Conclusions	
	This site is situated nearby the Amguri Bali village of Dhemaji district. Embankment breach had been recorded in 1988 and 2007. Due to Bogibeel bridge (located 1.7 Km aerial space of d/s), increase in water level and frequency of flood in that village has been observed. A spur with boulder pitched has been installed. A new stream has been developed slowly near spur structure in the last 10 years. Erosion is further caused due to this stream. 50 houses have been washed-out in last 5 years.	
	  	

Table 8. Field Assessment Data of Dalani Gaon.

S. No.	Details of Field Assessment Form	
1	General Information	
1.1	Village name	Dalani Gaon
1.2	CD block name (according to census of India)	Barbaruah
1.3	District name	Dibrugarh
1.4	State name	Assam
1.5	Latitude (degree decimal-DD) 'Y'	27.355389
1.6	Longitude (degree decimal-DD) 'X'	94.767444
1.7	Elevation (Above mean sea level, m)	101 m
2	River Bankline	Left bankline (south bank)
2.1	River flow direction	NNE to SSW
2.2	River width (Km)	9.06
3	Lithological, Slope and Soil Information	
3.1	Stratigraphic classification	Sedimentary rock
3.2	Lithological information	Silt, sand and clay sequence with carbonized wood
3.3	Slope (surrounding area)	Gentle
3.4	Soil primary classification	Younger alluvial soils
3.5	Soil texture	Sandy, sandy clay, heavy clay
4	Physical Attributes of Riverbank	
4.1	Riverbank material	Sticky clay, sand
4.2	Riverbank modification	None
4.3	Riverbank features	Unvegetated mid-channel bar, vegetated mid-channel bar
4.4	Riverbank profiles - natural / unmodified	Composite
4.5	Riverbank profiles - artificial / modified	Set-back embankment
5	Physical Attributes of Channel	
5.1	Channel bed material	Sand, clay
5.2	Channel flow-type	No perceptible flow
5.3	Channel modifications	None
5.4	Channel features	Unvegetated mid-channel bar, vegetated mid-channel bar
5.5	Valley form (within the horizon limit)	Braided channel
6	Geomorphic Features	
6.1	Out-of-channel - geomorphic features	Anabranch, active floodplain
6.2	In-channel - geomorphic features	Braided river, non-sinuous braided river, side bar, mid-channel bar
7	Landuse / Landcover (within 100 m of vulnerable area)	
7.1	Land cover	Open forest, plantation, scrub land and shrubs, river and water bodies
7.2	Land use	Agricultural crop land, agricultural fallow land, rural area, school, religious and transportation
8	Any infrastructure (nearby the vulnerable area)	Bridge (u/s of that village), RCC porcupines, embankment
9	Major impacts from vulnerable area	Transportation (road), residential area (rural), fishing, agricultural area (crop/fallow), bridge, erosion
10	Evidence of recent management	Embankment, RCC porcupines
11	Flood related Information of the Village nearby the Vulnerable Area	
11.1	About the Village	
11.1.1	Name of village	Dalani Gaon
11.1.2	Approx. population of the village	1000
11.1.3	Major occupation of the village	Farming
11.1.4	How long have community been living here?	More than 100 years
11.1.5	Majority of construction material	Mud, khas
11.2	Flood Occurrence and Severity	

S. No.	Details of Field Assessment Form	
11.2.1	How many times did community experience flood while living at this village?	Never been flooded
11.2.2	What was the maximum water level and duration of flood entering your village?	
11.2.2a	Flood year	0
11.2.2b	Flood depth	x
11.2.2c	Duration	x
11.3	Flood Emergency Response	
11.3.1	Just before the flood, how did your community first become aware that flood waters might reach your home?	Observing the river water level
11.3.2	Did share the warning with others?	Yes
11.3.3	How many hours were there between the time your community became aware that flooding might reach your village until the water actually reached to your village?	Not flooded
11.3.4	What is the minimum warning time would your community need to move all your transportable contents to a safe location?	x
11.3.5	What is the shortest distance between your village and river?	x
11.3.6	Do your community have a safe place to move in case of flooding?	x
11.3.7	How far is it from your village?	x
11.4	Flood Impact on Infrastructure	
11.4.1	During the flood, water supply was interrupted?	No water supply
11.4.2	During the flood, the electric supply was interrupted?	x
11.4.3	During the flood, the telephone supply / mobile network was interrupted?	x
11.4.4	Was there any secondary source for water supply?	Yes (Handpump)
11.4.5	Was there any secondary source for electric supply?	x
12	Flood Management Activities	
12.1	Which type of flood protection activities, planning, or mitigation your community need in that area.	None.
13	Significant Observations, and Conclusions	
	This site is situated nearby the Dalani Gaon village of Dibrugarh district. Bogibeel bridge is located at the u/s of that village. The village has an embankment of 15 feet height so there is no record of flood. Moderate erosion is observed.	



7. Conclusion

The Bogibeel bridge is an important infrastructure for Assam state. A Govt Organization has carried out the geo-technical survey and pre-construction studies for the bridge. During these studies, the cross-section data was measured from 2004 to 2017 during construction phase. The construction of the bridge started in 2002 and the bridge was functional from December 2018. In this paper, the bathymetrical data is used to describe the river's morphological attributes like bed profile, riverbed slopes, aggradation, and degradation in different reaches; and Landsat satellite imageries is used for validation of bathymetry data and to interpret morphological changes in the river.

Based on bathymetry data, the impact of the bridge on the river morphology could not be established as pre-construction bathymetrical data is unavailable and since the bridge is recently completed, post-construction data is also not available, but based on Landsat satellite imageries from 2004 to 2021, and field assessment data, it has observed that due to Bogibeel bridge, the water level and frequency of flood is increase in u/s (within 6 Km) of Bogibeel bridge.

The changes in the riverbed profiles during the construction phase were estimated by analysing thalweg values and riverbed slope and through a cubature study. Based on the thalweg analysis, it was found that there is net degradation of the channel from 2009 to 2017. The variation in bed levels just upstream of the bridge (0 to 1.6 Km) was very high ranging from - 11 m to +11 m. The bathymetry of the river is changing actively from 2.6 Km to 3.4 Km upstream of the bridge. Due to the multi-channel planform of Brahmaputra, thalweg in two consecutive years may or may not lie on the same position. Therefore, these bed level changes only represent a sense of change in the river profile. Riverbed slope analysis from year 2004 to 2017 shows that, there is a general trend of fall (0.01 m/Km/year) in the slope of the riverbed. This can be due to narrowing of the river near the bridge leading to active degradation of channel. The cubature analysis reveals that the river is highly active and that huge loads of sediment gets deposited and eroded from the channel. Brahmaputra river being highly braided and dynamic shows formation of new sand bars and abandonment of old channels on one hand due to high deposition and formation of new channels due to erosion. No trend is observed in the net erosion and deposition in the system. Aggradation is observed in 2007, due to hindrance to the flow of the river because of the training works (diversion) for the construction of the bridge which started shortly after 2002. This has been seen by comparing the bathymetries of year 2004 and 2007. High erosion is observed in 2009, due to the modified cross-section (narrower) due to the construction guide bunds and bridge abutments. The uppermost reach of the study area (us 30) exhibits persistent erosion of the north bank. The reach downstream of the bridge shows a tendency for erosion of the south bank.

The bridge is a high interference with the river system. The river is trained near the bridge by guide bunds and embankments. It is important to establish "baselines" on morphology and morpho- dynamics of the river against which impact of interventions can be modelled and monitored. For the entire river, the monitoring can only be carried out with low temporal and high-resolution satellite imageries. A higher resolution and frequency of monitoring should be established at critical points in the river (either high dynamics and/or at critical investments and interventions). These morphological studies are necessary while making management decisions like construction of a structure, protection, and training works. The study can be used as a baseline for future studies near the Bogibeel bridge, and similar studies may be carried-out for other constructed or upcoming bridges on Brahmaputra river.

Acknowledgements

Author is grateful to Managing Director, DHI (India) Water and Environment Pvt Ltd, New Delhi, India for providing the necessary facilities to carry out this work.

References

[1] Pareta K. 2021. Why Indian largest river island Majuli is shrinking: biophysical and fluvial geomorphological study through historical multi-temporal satellite imageries. American Journal of Geophysics, Geochemistry and Geosystems. Vol. 7 (1), pp. 38-52.

[2] Baishya SJ and Sahariah D. 2015. A study of bank erosion and bankline migration of the Baralia river, Assam, using remote sensing and GIS. International Journal of Current Research. Vol. 7 (11), pp. 373-380.

[3] Aher S, Bairagi S, Deshmukh P and Gaikwad R. 2014. River change detection and bank erosion identification using topographical and remote sensing data. International Journal of Applied Information Systems. Vol. 2 (3), pp. 1-7.

[4] Alam JB, Uddin M, Ahmed UJ, Cacovean H, Rahman HM, Banik BK and Yesmin N. 2007. Study of morphological change of river old Brahmaputra and its social impacts by remote sensing. Geographia Technica. Vol. 4 (2). pp. 1-11.

[5] Lawler DM, Couperthwaite J, Bull LJ and Harris NM. 1997. Bank erosion events and processes in the upper Severn basin. Hydrology and Earth System Sciences Discussions, Copernicus Publications. Vol. 1 (3), pp. 523-534.

[6] Yang X, Damen MCJ and Zuidam RAV. 1999. Satellite remote sensing and GIS for the analysis of channel migration changes in the active Yellow river delta, China. International Journal of Applied Earth Observation and Geoinformation. Vol. 1 (2), pp. 146-157.

[7] Sarma JN. 2004. An overview of the Brahmaputra river system. In: Singh VP, Sharma B, Shekhar C and Ojha P. (Eds.), the Brahmaputra Basin Water Resources. Kluwer Academic Publishers. pp. 72-87.

[8] Sarma JN. 2005. Fluvial process and morphology of the Brahmaputra river in Assam, India. Geomorphology. Vol. 70, pp. 226-256.

[9] Sarma JN and Phukan MK. 2006. Bank erosion and bankline migration of Brahmaputra river in Assam during the twentieth century. Journal of the Geological Society of India. Vol. 68, pp. 1023-1036.

[10] Sarma JN, Borah D and Goswami U. 2007. Change of river channel and bank erosion of the Burhi Dihing river (Assam) assessed using remote sensing data and GIS. Journal of the Indian Society of Remote Sensing. Vol. 35, pp. 93-100.

[11] Lahiri SK and Sinha R. 2012. Tectonic controls on the morpho-dynamics of the Brahmaputra river system in the upper Assam valley, India. Geomorphology. Vol. 169-170, pp. 74-85.

[12] Das AK, Sah RK and Hazarika N. 2012. Bankline change and the facets of riverine hazards in the floodplain of Subansiri-Ranganadi Doab, Brahmaputra Valley, India. Natural Hazards. Vol. 64, pp. 1015-1028.

[13] Sarker MH, Thorne CR and Aktar N. 2013. Morpho-dynamics of the Brahmaputra-Jamuna river, Bangladesh. Geomorphology. Vol. 215, pp. 45-59.

[14] McLelland SJ, Ashworth PJ, Best JL, Roden JE and Klaassen GJ. 1999. Flow structure and transport of sand-grade suspended sediment around an evolving braid-bar, Jamuna river, Bangladesh. In: Smith ND. (Ed.), Fluvial Sedimentology, International Association of Sedimentologists (Special Publications). Vol. 28, pp. 43-57.

[15] Best JL, Ashworth PJ, Bristow CS and Roden J. 2003. Three-dimensional sedimentary architecture of a large, mid-channel sand braid-bar, Jamuna river, Bangladesh. Journal of Sedimentary Research. Vol. 73, pp. 516-530.

[16] Gilfellon GB and Sarma JN. 2000. Markov chain analysis as applied to the modern bar-top sediments of the Brahmaputra river. Journal of The Indian Association of Sedimentologists. Vol. 19 (1&2), pp. 107-114.

[17] Sarma JN. 2002. A Study on pattern of erosion and bankline migration of the river Brahmaputra in Assam using GIS. Report Disaster Management in North-Eastern region, Dept. of Revenue, Govt. of Assam. pp. 50-53.

[18] Gilfellon GB, Sarma JN and Gohain K. 2003. Channel and bed morphology of a part of the Brahmaputra river in Assam, India. Journal of the Geological Society of India. Vol. 62 (2), pp. 227-236.

[19] Pareta K. 2020. Riverbank erosion and shifting determined from satellite images. DHI Internal Report prepared under Assam Integrated Flood and Riverbank Erosion Risk Management Investment Program (AIFRERMIP) Scheme for Flood and Riverbank Erosion Management Agency of Assam (FREMAA), 63801442-04.

[20] Sarma S and Talukdar BP. 2019. Effect of channel width contraction at Bogibeel bridge site on the morphology of the river Brahmaputra. Bulletin of Pure and Applied Sciences. Vol. 38F (2), pp. 128-140.

[21] Sharma N. 2004. Mathematical modelling and braid indicators. In: Singh VP (Ed.) The Brahmaputra river basin water resources. Dordrecht. Kluwer Academic Publishers. Vol. 47, pp. 229-260.

[22] Krishnaswami S and Singh S. 2005. Chemical weathering in the river basins of the Himalaya, India. Current Science. Vol. 89 (5), pp. 841-849.

[23] FAP24. 1996. Final report, main volume. Water Resources Planning Organisation, Dhaka, Bangladesh.