A novel approach to calculate braiding of a large alluvial river

Lalit Saikia[1,3,*], Chandan Mahanta[1] and Suranjana Bhaswati Borah[2]

[1]Department of Civil Engineering,
Indian Institute of Technology Guwahati, Guwahati 781 039, India
[2]Department of Environmental Science,
Tezpur University, Tezpur 784 028, India
[3]Department of Earth Science, University of Science and Technology,
Meghalaya, Meghalaya 793 101, India

Braiding pattern in sixteen reaches of the Brahmaputra river in Assam, India is discussed. A new braiding index has been introduced incorporating a fraction of area covered by sandbars, number of mid-channel bars and maximum width of alluvial reach. Braiding parameters calculated using different formulae showed similar trend but higher values in 2014 compared to 1973. Increase of braiding in different reaches in 2014 was due to development of more sandbars and distributaries. The new index has shown comparable result with other approaches and better correlation with sinuosity.

Keywords: Alluvial river, braiding, sandbars, Brahmaputra.

BRAIDED channels consist of a network of river channels separated by small and often temporary islands. There are several indices to describe braiding intensity of a river based on different characteristics, e.g. bar dimensions and frequency[1–3], number of channels in the network[4,5] and the total channel length in a given river length[6,7]. Plan Form Index (PFI) ratio calculates degree of braiding by utilizing flow top width of mid-channels, overall width of the channel and number of braided channels[8]. All indices consider one or two parameters from a braided channel, e.g. length of bars, mid-channels, main-channel or centre line and number of channels in a cross section.

Different approaches for measurement of braiding indices can be grouped into two types: (i) counting the number of active channels or braid bars per transect across the channel belt, and (ii) calculating the ratio of the sum of channel lengths (in a reach) to a measure of reach length[9].

It is observed that, none of the methods to determine braiding index used number of mid-channel bar, which is a key factor of a braided channel. Hence, a new index has been introduced in the present study to calculate braiding of a large alluvial river using fraction of area covered by sandbars, number of mid-channel bars and maximum width of the reach.

*For correspondence. (e-mail: lalitsaikia@yahoo.com)

Braiding was studied for the Brahmaputra River in Assam (India). The Brahmaputra is an extremely dynamic and predominantly braided river in the world[10]. It has a peculiar drainage pattern, diverse geological setting, high sediment load and critical bank erosion problem[11]. In the entire course of the Brahmaputra, approximately 100 km reach known as Tsangpo gorge where the river abruptly bends southward, is a locus of extremely rapid and focused erosion[12–15]. Steep slopes of river and tributaries in the mountainous reaches led to high sediment generation and transportation. Sudden decrease in slope of the Brahmaputra results in a large amount of sediment deposition developing a prominent braided pattern near Pasighat in Arunachal Pradesh, where the slope is abruptly decreased (from 8.27 m/km in the reach between Pi in Tibet and India to 1.52 m/km in the reach between entry to India and Pasighat). The slope further decreases during the course of the river, showing a more prominent braided pattern in the plains.

Seven methods (Table 1) suggested by different researchers were used to calculate braiding. Different parameters were extracted from Landsat images of 1973 and 2014 (Table 2) using remote sensing (ERDAS Imagine) and GIS techniques (ArcGIS 10.1). The years 1973 and 2014 were selected due to availability of satellite images and to study the changes in a 40-year period.

Images were procured for the same season of the year to minimize inconsistencies in data. Post-monsoon data were used due to low cloud cover and proper channel and sandbar definition available during this season. Raw data consisting of individual bands of each satellite image were combined in ERDAS Imagine image processing software to create a composite image. The images were then pre-processed with image enhancement techniques like haze reduction, brightness and contrast to make the process of information extraction easier. Images were then stitched to create a single seamless mosaic image for the entire stretch of the river which was utilized to interpret and extract the bank line, river centre line, main channel, braided channels and sandbars in ArcGIS 10.1. The Brahmaputra River in Assam was divided into 16 reaches, each with a length of 40 km. These were numbered

Table 1. Satellite dataset used

Sensor	Path/row	Date of acquisition	Spatial resolution
MSS	145/41	15 November 1973	60 m
MSS	146/41	16 November 1973	
MSS	147/41	5 December 1973	
MSS	147/42	22 November 1973	
MSS	148/42	21 February 1973	
OLI	135/41	27 November 2014	30 m
OLI	136/41	18 November 2014	
OLI	136/42	18 November 2014	
OLI	137/42	9 November 2014	
OLI	138/42	2 December 2014	

Table 2. Different approaches for calculation of braiding indices

Braiding index (BI) or braiding parameter (B)	Reference
BI = 2 (sum of length of all the islands or bars in a reach)/centre line reach length	2
BI = Average number of channels in several cross-valley transects	4
B = Sum of the braid lengths between channel thalweg divergences and confluences/mean of the meander wavelength in a reach of the channel belt	3
BI = Total length of the channels/length of main channel	6
BI = Average number of active channels per cross-valley transect	5
B = Sum of the mid-channel lengths of all the segments of primary channels in a reach/mid-channel length of the widest channel through the reach	7
Plan Form Index (PFI) = (T/B) × 100/N where, T = flow top width; B = overall width of the channel; N = number of braided channel	8

Table 3. Length of the centre line, the widest channel, mid-channels and sandbars

	Length (km)							
	Center line (C)		Widest (main) channel (M)		All mid-channels (s)		Sandbars (b)	
Reach no.	1973	2014	1973	2014	1973	2014	1973	2014
1	33.4	40	35	52	314	377	175	272
2	40.5	40	46	47	406	616	223	391
3	40	40	46.5	50	294.5	358	183	210
4	40.3	40	45.4	46	285.4	248	139	150
5	41	40	45	50	247	461	109	295
6	40.3	40	49.3	47	323.3	382	152	254
7	39.6	40	45.3	52	233.3	255	104	133
8	41.9	40	46.1	47	202.1	245	78	129
9	39.6	40	43.5	47	315.5	301	154	173
10	40.9	40	49	50	279	455	148	257
11	40.6	40	47.7	43	153.7	168	58	91
12	39.9	40	52.2	43	181.2	412	83	240
13	40.1	40	45.2	47	328.2	486	159	306
14	40.7	40	45.9	42	259.9	390	112	261
15	40.7	40	47.8	46	286.8	374	137	192
16	36.6	38	48.1	48	237.1	454	143	275
Whole River	636	638	738	757	4347	5225	2157	3629

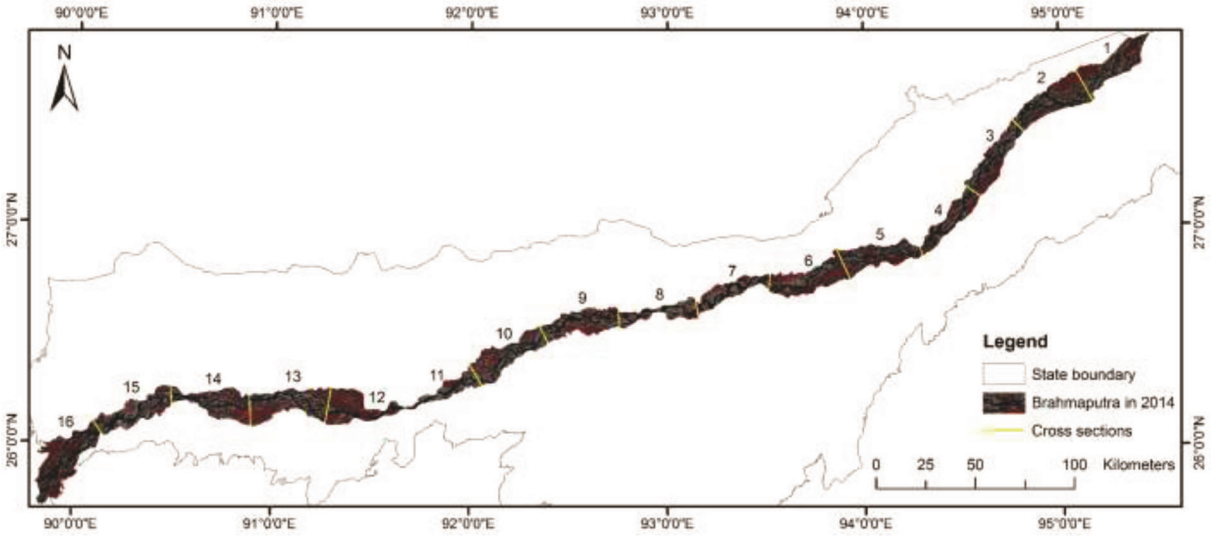

Figure 1. Map showing different reaches of the Brahmaputra River in Assam, India.

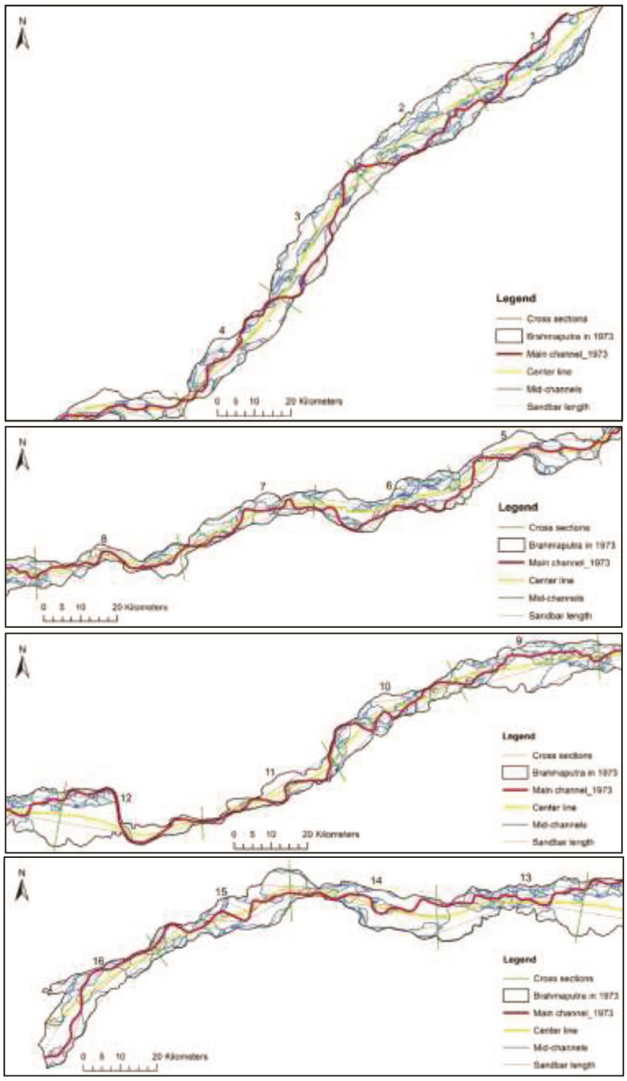

Figure 2. Main channel, centre line, mid-channels and sandbar length in different reaches in 1973.

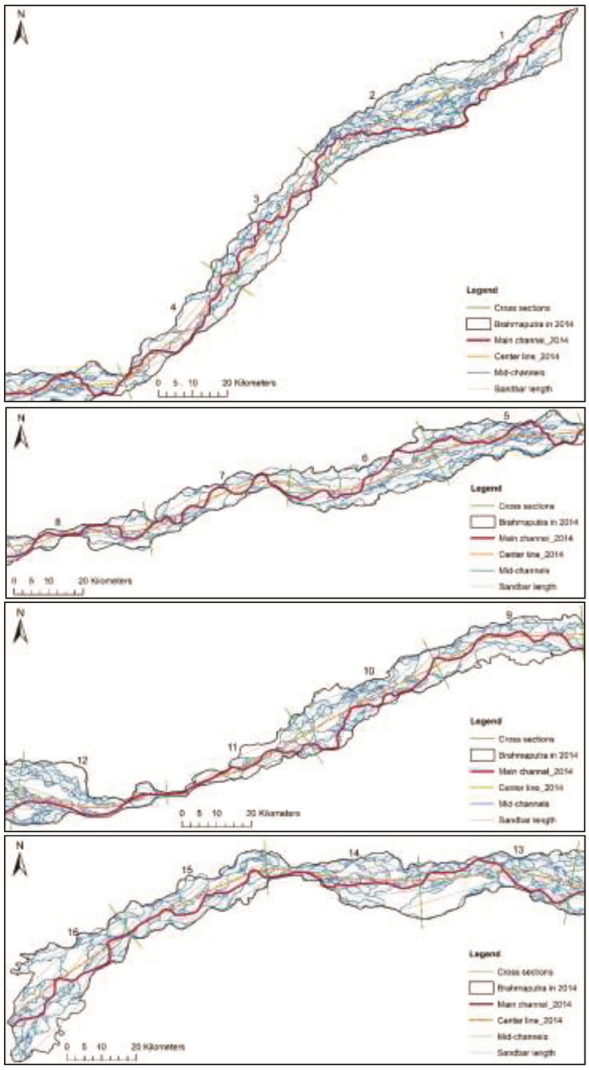

Figure 3. Main channel, centre line, mid-channels and sandbar length in different reaches in 2014.

from 1 (upstream) to 16 (downstream) as shown in Figure 1. Braiding values in 1973 and 2014 were calculated for each reach.

A new braiding formula was suggested:

$$\text{Braiding, } B = X \times N^* \times W/L,$$

where X is the fraction of area covered by bars, N^* the number of mid-channel bars, L the length of reach and W is the maximum width of the reach.

In the formulation of the method, the following points were considered: (i) River or reach with more fraction of area by bars has more braiding value. (ii) In case of same fraction of area by bars, the number of mid-channel bars will influence braiding value. (iii) Braiding of rivers or reaches with same fraction of area by bars and same number of mid-channel bars will differ by maximum width. (iv) Length is used in denominator to get a dimensionless value of braiding index.

The lengths of the centre line, main channel, sand bars and mid-channels in the sixteen reaches of the Brahmaputra River, needed for calculation of braiding parameters, were obtained from Landsat images of 1973 and 2014 (Figures 2 and 3, Table 3) using GIS tools. Fraction of area covered by bars, number of mid-channel bars and maximum width and length of reaches in 1973 (Table 4) and 2014 (Table 5) were used to calculate the new braiding parameter suggested in the present study.

Braiding values obtained for different reaches of Brahmaputra are shown in Table 6 and Figure 4. Despite variations in braiding values using different approaches, similar trend was observed in all reaches. Lower values of PFI were observed in braided reaches because PFI value and braiding are inversely proportional to each other. Ten reaches, i.e. reach nos 1, 2, 3, 4, 6, 9, 10, 13, 15 and 16, had greater braiding values in 1973 than the average value for the entire Brahmaputra River in Assam. In 2014, nine reaches, i.e. reach nos 1, 2, 5, 6, 10, 12, 13, 15

Table 4. Fraction of area covered by bars, number of mid-channel bars and maximum width and length of reaches in 1973

Reach no.	Total area of the reach or river in km^2 (R)	Area of bars (B)	Fraction of area covered by bars ($X = R/B$)	No. of mid-channel bars (N^*)	Max. width in km (W)	Reach length in km (L)	Braiding, $B = X \times N^* \times W/L$
1	365.4	281.7	0.8	77	11.4	33.4	20.3
2	411.0	322.0	0.8	92	13.1	40.5	23.3
3	349.3	265.2	0.8	58	9.7	40	10.7
4	271.9	187.2	0.7	66	9.5	40.3	10.7
5	280.6	156.9	0.6	48	9.5	41	6.2
6	317.4	216.0	0.7	79	10.8	40.3	14.4
7	222.6	118.7	0.5	38	7.9	39.6	4.0
8	206.3	100.7	0.5	37	7.0	41.9	3.0
9	370.2	251.9	0.7	61	13.3	39.6	13.9
10	270.2	167.1	0.6	62	9.5	40.9	8.9
11	159.0	101.3	0.6	22	6.6	40.6	2.3
12	306.1	225.9	0.7	25	15.8	39.9	7.3
13	381.0	270.0	0.7	68	12.4	40.1	14.9
14	320.3	235.3	0.7	48	11.1	40.7	9.6
15	330.1	246.3	0.7	51	11.5	40.7	10.8
16	344.0	251.6	0.7	46	11.6	36.6	10.6
Whole river	4905.6	3397.7	0.7	878	15.8	41.9	10.7

Table 5. Fraction of area covered by bars, number of mid-channel bars and maximum width and length of reaches in 2014

Reach no.	Total area of the reach or river in km^2 (R)	Area of bars (B)	Fraction of area covered by bars ($X = R/B$)	No. of mid-channel bars (N^*)	Max. width in km (W)	Reach length in km (L)	Braiding, $B = X \times N^* \times W/L$
1	418.2	316.6	0.8	203	12.6	40	48.6
2	480.3	357.9	0.7	246	17.6	40	80.7
3	379.4	286.4	0.8	104	11.0	40	21.5
4	302.4	230.2	0.8	69	10.7	40	14.0
5	396.6	286.3	0.7	133	12.1	40	29.1
6	440.0	334.1	0.8	74	11.9	40	16.7
7	264.9	185.3	0.7	56	8.5	40	8.3
8	243.7	154.2	0.6	36	11.0	40	6.3
9	401.9	306.4	0.8	62	13.8	40	16.3
10	430.6	296.6	0.7	124	15.9	40	34.0
11	205.4	121.9	0.6	37	8.6	40	4.7
12	389.9	254.3	0.7	48	17.6	40	13.8
13	500.3	365.5	0.7	114	14.6	40	30.4
14	411.3	281.8	0.7	110	16.0	40	30.1
15	403.3	250.8	0.6	72	11.7	40	13.1
16	590.1	372.4	0.6	148	20.5	38	50.3
Whole river	6258.3	4400.4	0.7	1636	20.5	638	36.9

and 16, had greater braiding values than the average value for the river in Assam. Higher braiding values were due to greater channel width with (i) more distributaries, i.e. increased mid-channel lengths, e.g. in reach nos 2, 5, 6, 12, 13, 14 and 16 in 1973 and reach nos 1, 2, 3, 4, 6, 9, 13 and 15 in 2014; (ii) more mid-channel bars, i.e., increased sandbar lengths, e.g. reach nos 1, 2, 3, 4, 6, 9, 10, 13, 15 and 16 in 1973 and reach nos 1, 2, 5, 6, 10, 12, 13, 14 and 16 in 2014.

Low braiding in three reaches, i.e. reach nos 7, 8 and 11 was due to comparatively narrower channel width with lesser number of distributaries and mid-channel bars. The values of the new braiding index suggested in the present study reveal higher braiding (than average) in reach nos 1, 2, 3, 4, 6, 13, 15 and 16 in 1973, and only in reach nos 1, 2 and 16 in 2014.

The suggested index shows result comparable with other approaches. All braiding indices are more or less sensitive to flow stage and the channel count index is more accurate because it is not sensitive to variations in channel sinuosity and orientation[16]. The new index has shown a relatively better correlation with sinuosity than braiding values obtained from other approaches (Table 7). Moreover, the new parameter has very good correlation (0.97) with number of sandbars.

Braiding classification was suggested by Sharma[8]: highly braided: PFI < 4; moderately braided: 19 > PFI > 4 and low braided: PFI > 19. With reference to braiding

Table 6. Braiding parameters of Brahmaputra River from different approaches

	Brice (1964) $BI = 2b/C$		Howard *et al.* (1970) BI = Average number of channels		Maximum number of channels		Rust (1978) $B = b/M$		Mosley (1981) $B = s/M$		Friend & Sinha (1993) $B = (s - M)/M$		Sharma (2004) PFI = $(T/B^*) \times 100/N$		Present work $B = X \times N^* \times W/L$	
Reach	1973	2014	1973	2014	1973	2014	1973	2014	1973	2014	1973	2014	1973	2014	1973	2014
1	10.5	13.6	7	8	8	11	5	5.2	9	7.3	8	6.3	4.7	2.6	20.3	48.6
2	11	19.6	9	11	10	16	4.8	8.3	8.8	13.1	7.8	12.1	2.8	2.6	23.3	80.7
3	9.2	10.5	7	7	8	8	3.9	4.2	6.3	7.2	5.3	6.2	4.3	4.3	10.7	21.5
4	6.9	7.5	5	5	5	6	3.1	3.3	6.3	5.4	5.3	4.4	8.1	6.3	10.7	14.0
5	5.4	14.8	4	11	5	14	2.4	5.9	5.5	9.2	4.5	8.2	9.6	6.7	6.2	29.1
6	7.6	12.7	6	9	7	11	3.1	5.4	6.6	8.1	5.6	7.1	4.6	4	14.4	16.7
7	5.3	6.7	4	4	5	5	2.3	2.6	5.2	4.9	4.2	3.9	8.5	4.9	4.0	8.3
8	3.7	6.5	4	4	6	7	1.7	2.7	4.4	5.2	3.4	4.2	24.5	7.7	3.0	6.3
9	7.8	8.7	6	6	7	7	3.5	3.7	7.3	6.4	6.3	5.4	7.5	4.8	13.9	16.3
10	7.2	12.9	5	7	6	9	3	5.1	5.7	9.1	4.7	8.1	12.7	2.8	8.9	34.0
11	2.9	4.6	3	3	4	7	1.2	2.1	3.2	3.9	2.2	2.9	25.6	18.6	2.3	4.7
12	4.2	12	3	8	5	16	1.6	5.6	3.5	9.6	2.5	8.6	6.8	6.6	7.3	13.8
13	7.9	15.3	5	11	6	13	3.5	6.5	7.3	10.3	6.3	9.3	4.8	3.9	14.9	30.4
14	5.5	13.1	5	6	6	8	2.4	6.2	5.7	9.3	4.7	8.3	11	10	9.6	30.1
15	6.7	9.6	5	6	6	9	2.9	4.2	6	8.1	5	7.1	5	8	10.8	13.1
16	7.8	14.5	4	7	6	10	2.9	5.7	4.9	9.5	3.9	8.5	8	3.3	10.6	50.3
River	6.8	11.3	5	7	10	16	2.9	4.8	5.9	7.9	4.9	6.9	9.3	6.1	10.6	36.9

b, Length of sandbars; *C*, Length of centre line; *M*, Length of main (widest) channel; *s*, Length of mid-channels; *T*, Flow top width; *B**, Overall width of the channel; *N*, Number of braided channels; *X*, Fraction of area covered by bars; *N**, No of mid-channel bars; *L*, Length of reach; *W*, Maximum width of the reach.

Table 7. Correlation matrix of different braiding parameters

	No. of sandbars	Sinuosity	Brice	Howard	Rust	Mosley	Friend and Sinha	Sharma	Present work
No. of sandbars	1								
Sinuosity	0.36	1							
Brice	0.87	0.12	1						
Howard	0.74	0.12	0.91	1					
Rust	0.82	–0.01	0.97	0.90	1				
Mosley	0.77	–0.12	0.94	0.88	0.96	1			
Friend and Sinha	0.77	–0.12	0.94	0.88	0.96	1	1		
Sharma	–0.50	–0.23	–0.62	–0.56	–0.59	–0.58	–0.59	1	
Present work	0.97	0.25	0.88	0.72	0.84	0.81	0.81	–0.50	1

Table 8. Braiding pattern of different reaches of Brahmaputra in Assam

	Reaches		Number of reaches	
Braiding range	1973	2014	1973	2014
Highly braided	NIL	1, 2, 10, 13, 14, 16	0	6
Moderately braided	1, 2, 3, 4, 5, 6, 9, 10, 12, 13, 14, 15, 16	3, 4, 5, 6, 7, 8, 9, 12, 15	13	9
Low braided	7, 8, 11	11	3	1

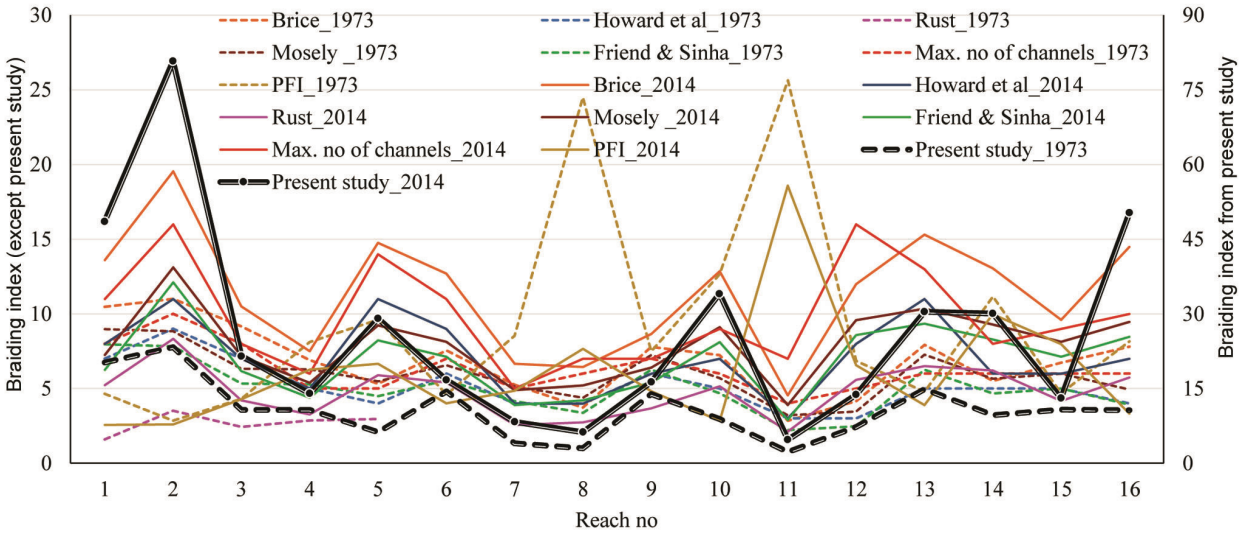

Figure 4. Braiding index of Brahmaputra River at different reaches calculated by different approaches.

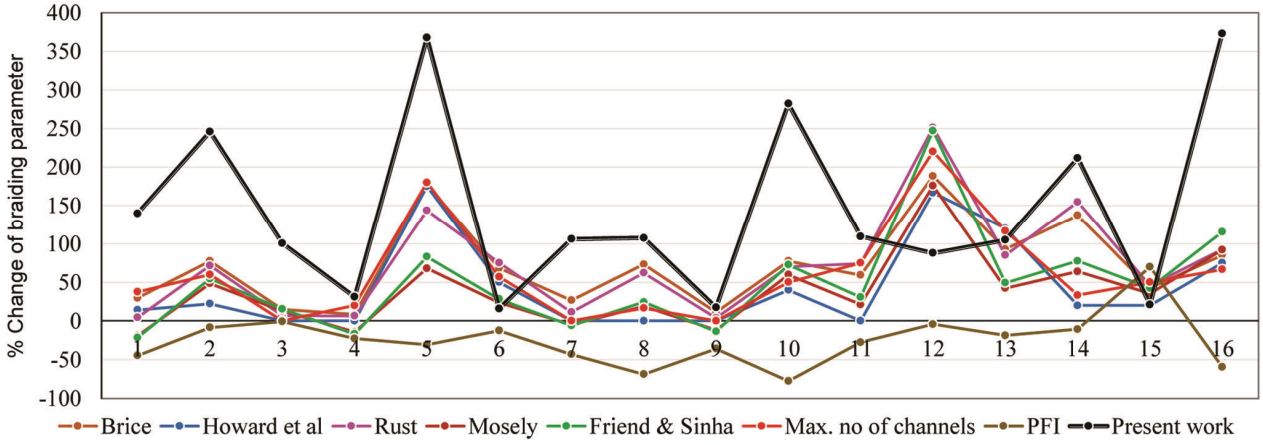

Figure 5. Percentage change of braiding parameters of Brahmaputra River during 1973–2014 at different reaches.

values for different reaches from different approaches, the following threshold values can be provided from the new braiding index (B) for a broad range of classification: highly braided: $B > 30$; moderately braided: $5 < B < 30$; and low braided: $B < 5$. On the basis of this classification, braiding pattern of different reaches of Brahmaputra in Assam during 1973 and 2014 can be summarized as shown in Table 8.

The reaches which were only low and moderately braided in 1973, became moderately braided and highly braided during the 40 years (1973–2014). Braiding value increased by more than 50% in reach nos 2, 5, 6, 8, 10, 11, 12, 13, 14 and 15 during 1973–2014. More than 100% increase in braiding was observed in reach nos 5, 12 and 14 (Figure 5). This increase was due to development of more sandbars and distributaries resulting in increased mid-channel lengths and sandbar lengths. Area of Brahmaputra River in Assam has increased from 4906 km^2 in 1973 to 6258 km^2 in 2014. Widening of the river resulted in loss of huge land area by bank erosion in many locations. But, the increased area of Brahmaputra in Assam is not linked solely to river bank erosion. Increase in area (28%) of Brahmaputra during 1973–2014 was also due to bifurcation of streams without loss of land in addition to river bank erosion.

This paper has introduced a new braiding index for a large alluvial and braided river like the Brahmaputra using the number of mid-channel bars/river islands, which is a determining parameter of braiding. The suggested braiding index shows result comparable with other established approaches. One utility of the new index is that it has shown better correlation with sinuosity. River or reach with more fraction of area by bars has more braiding value. The number of mid-channel bars influences braiding value in case of same fraction of area by bars. Rivers or reaches with same fraction of area by bars and the same number of mid-channel bars will differ in braiding value by maximum width.

1. Brice, J. C., Index for description of channel braiding. *Geol. Soc. Am. Bull.*, 1960, **71**, 1833.
2. Brice, J. C., Channel patterns and terraces of the Loup Rivers in Nebraska. *Geol. Surv. Prof. Pap.*, 1964, 422-D.
3. Rust, B. R., A classification of alluvial channel systems. In *Fluvial Sedimentology*. *Can. Soc. Petrol. Geol.: Alberta*, 1978, 187–198.
4. Howard, A. D., Keetch, M. E. and Vincent, C. L., Topological and geometrical properties of braided streams. *Water Resour. Res.*, 1970, **6**, 1674–1688.
5. Ashmore, P. E., Laboratory modelling of gravel braided stream morphology. *Earth Surf. Proc. Land.*, 1982, **7**, 201–225.
6. Mosley, P. M., Semi-determinate hydraulic geometry of river channels, South Island, New Zealand. *Earth Surf. Proc. Landf.*, 1981, **6**, 127–137.
7. Friend, P. F. and Sinha, R., Braiding and meandering parameters. In *Braided Rivers* (eds Best, J. L. and Bristow, C. S.), The Geological Society, London, 1993, pp. 105–112.
8. Sharma, N., Mathematical modelling and braid indicators. *The Brahmaputra Basin Water Resources*, Water Science and Technology Library, Kluwer Academic Publishers, Dordrecht, The Netherlands, 2004, vol. 47, pp. 229–260.
9. Bridge J. S., Alluvial Channels and Bars. *Rivers and Floodplains: Forms, Processes, and Sedimentary Record*, Blackwell Science Ltd, Oxford, UK, 2009, p. 151.
10. Coleman, J. M., Brahmaputra River: channel processes and sedimentation. *Sediment. Geol.*, 1969, **3**, 129–239.
11. Mahanta, C. and Saikia, L., The Brahmaputra and other rivers of the North-east. In *Living rivers, Dying Rivers* (ed. Iyer, R.), Oxford University Press, New Delhi, 2015, p. 155.
12. Finlayson, D. P., Montgomery, D. R. and Hallet, B., Spatial coincidence of rapid inferred erosion with young metamorphic massifs in the Himalayas. *Geology*, 2002, **30**, 219–222.
13. Finnegan, N. J., Hallet, B., Montgomery, D. R., Zeitler, P. K., Stone, J. O., Anders, A. M. and Liu, Y., Coupling of rock uplift and river incision in the Namche Barwa – Gyala Peri massif, Tibet, China. *Geol. Soc. Am. Bull.*, 2008, **120**, 142–155.
14. Stewart, R. J., Hallet, B., Zeitler, P. K., Malloy, M. A., Allen, C. M. and Trippett, D., Brahmaputra sediment flux dominated by highly localized rapid erosion from the eastern most Himalaya. *Geology*, 2008, **36**, 711–714.
15. Larsen, I. J. and Montgomery, D. R., Landslide erosion coupled to tectonics and river incision. *Nature Geosc.*, 2012, **5**, 468–473.
16. Egozi, R. and Ashmore, P., Defining and measuring braiding intensity. *Earth Surf. Proc. Landf.*, 2008, **33**, 2121–2138.

ACKNOWLEDGEMENTS. This paper is part of the Ph D (awarded) thesis of the first author in the Department of Civil Engineering at Indian Institute of Technology Guwahati, India. The author acknowledges assistance received from the Department of Civil Engineering, Computer Centre and Lakshminath Bezbaroa Central Library of the Institute during his Ph D work.

Received 30 January 2018; revised accepted 6 June 2018

doi: 10.18520/cs/v115/i6/1179-1185

Screening and enhancement of anaerobic germination of rice genotypes by pre-sowing seed treatments

Dhonada Doley, Meghali Barua*, Debojit Sarma and Purna K. Barua

Department of Plant Breeding and Genetics,
Assam Agricultural University, Jorhat 785 013, India

In the present study, 243 lowland rice genotypes were screened for anaerobic germination (AG) under 10 cm of flooding in plastic trays. Forty three genotypes showed anaerobic germination. Pre-sowing seed treatments of the genotypes by soaking, priming with water, 1% KCl and 5% PEG each for 24 h revealed enhanced AG and other seed germination parameters under flooding compared to control. Priming could

*For correspondence. (e-mail: meghalibarua@aau.ac.in)