6. HARNESS

Tapping the River

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THE YARLUNG Tsangpo Brahmaputra Jamuna river system provides water for irrigation, and domestic use along the entire length of the river system, supporting the water-dependent livelihoods of riparian communities such as agriculture and fisheries. In some sections of the river system, water is used in industries and for power generation as well.

Infrastructure systems, such as hydropower stations, inland waterways, and ports have been gradually developed to harness such benefits provided by the river

In the Yarlung Tsangpo basin, recent trends show increasing water usage for industrial and domestic purposes. Due to a small population and limited development in the Tibetan region of China, water quality is relatively pristine in the upper reaches of the river system while the water quality can be seen to deteriorate downstream with increasing human activities. In the Brahmaputra and Jamuna basins, the river also provides a wide range of other benefits that are important to riparian social economies, such as inland water transport. Hydropower production is gaining increasing appreciation in the upper hilly regions. Most of the water withdrawn from the river in Brahmaputra and Jamuna basins is used for agricultural purposes.

Infrastructure systems, such as hydropower stations, inland waterways, and ports have been gradually developed to harness such benefits provided by the river. While the river presents a natural barrier for connectivity between two banks, the acceleration of bridge building has overcome such barriers and significantly increased the connectivity in the basin, which also plays a fundamental role in the social and economic development of the riparian communities.

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Water uses for irrigation, industrial and domestic purposes

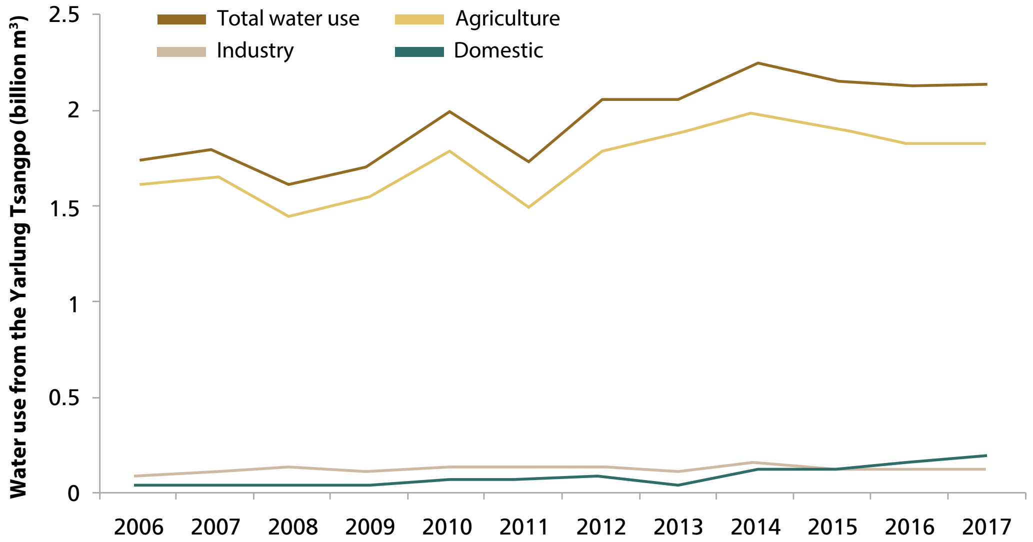
RTI International & ELMS[1]

YARLUNG TSANGPO River is an important source of water for the Tibetan Region in China. Water supply from Yarlung Tsangpo on average makes up about 60 percent of the total water supply in the Tibet Autonomous Region, rising from 40 percent in 2008, indicating the increasing importance of the river to the social economy of Tibet.

Even so, water use from the upstream Yarlung Tsangpo remains low compared to the volume of water available from the river. From 2006 to 2017, total water use increased from 1.76 billion cubic meters (bcm) to 2.14 bcm, peaking at 2.25 bcm in 2014. (Figure 1). Although agriculture is the largest user of water, the share of agricultural water use has decreased from over 92 percent in 2006 to just above 85 percent in 2017. Domestic water use has increased by the largest margin, by over 230 percent, from 2006 to 2017, compared to 60 percent for industrial water uses and only 12 percent for agricultural water uses.

The share of industrial water uses increased from 5 percent in 2006 to over 8 percent in 2011 and then decreased and stabilized at around 5 to 6 percent in recent years. The share occupied by domestic water uses have almost tripled from 3 percent to nearly 9 percent during the last decade.

Figure1: Historical water use change in the Yarlung Tsangpo from 2006 to 2017[2]



In the Brahmaputra and Jamuna basins, surface water irrigation is mainly confined to the flat and fertile lands of the valley, though small-holder irrigation also occurs in the hilly upstream terrain of the Brahmaputra and Teesta basins. Large-scale irrigation is supported by several barrages, including India's Teesta Barrage, which regulates the discharge for nearly 1 million hectares in India and about 150,000 hectares in Bangladesh. This infrastructure could irrigate 750,000 hectares in Bangladesh[3]. Surface water irrigation in these zones is highly water intensive and three rice crops are commonly grown (*aus, amman*, and *boro*); the first two depend heavily on floods, while the *boro* crop, which achieves by far the highest yields, is planted as floods recede. Risks of crop failure during the early monsoon are highest; a large flood event can destroy those crops and does so with regularity. In the Jamuna basin, some 80 percent of irrigation originates from groundwater, particularly for the cultivation of *boro* rice[4], which has been an important driver for attaining food self-sufficiency in Bangladesh in the last two decades.

Currently, there are more than 1,270 Flood Control Drainage and Irrigation (FCDI) schemes in the country, developed by the Bangladesh Water Development Board (BWDB) and the Local Government Engineering Department (LGED) and covering more than 6 million hectares. From 1995 to 2015, LGED developed around 720 small-scale water resources sub-projects that improved water management for around 450,000 hectares of land. In addition, there are four barrages across the Teesta, Tangon, Buri-Teesta, and Manu rivers, which are used as diversion structures for supplementary irrigation. Irrigation development, accompanied by high yielding value crop development, particularly *boro* rice, and making use of the abundant groundwater resources, has shown spectacular results in the country.

Due to climate change and unregulated groundwater use, less water is available for irrigation during the dry season in a large part of the Jamuna basin. Therefore, a well-planned irrigation management system is essential for gradually increasing crop intensity as well as yield. Irrigation efficiency needs to be improved with modern water management technologies to enhance food productivity through optimal use of available water resources. As part of the climate change strategy, creation of water reservoirs and rainwater harvesting in rain-fed/coastal/hilly areas will be encouraged, and small-scale water resources systems may be developed.

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Domestic and industrial water uses in the Jamuna basin are mostly derived from groundwater sources. The pumping of groundwater has increased with increasing population in the basin. As a result, land subsidence has become a growing concern, and has pushed urban water managers to more strongly consider a substantial switch to surface water sources. Owing to concerns about water quality, such a switch would require higher water treatment costs, and could exacerbate the competition for water in the dry season, inducing tradeoffs with agricultural and navigational water uses. More targeted and managed groundwater recharge during wet periods could help offset these rising pressures but has not previously been practiced in a systematic way.

The importance of water resources for the industrial sectors in Bangladesh, an important engine for the country's growth during the last 10 to 20 years, is growing rapidly. Whereas water demand is still low compared to the agriculture sector, industrial use is expected to grow by 440 percent by 2050. Water resources are particularly important for the textile, fertilizer, and leather industries, both in terms of consumptive needs and in view of the pollution pressures caused. Water is also used in thermoelectric power generation both as a cooling agent and for steam generation used for power generation. The textile sector accounts for more than 85 percent of all export earnings, more than 10 percent of GDP, and provides direct employment to more than 4 million workers. Both textile and leather sectors have high growth rates projected for the next 20 to 30 years.

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WATER QUALITY

Yarlung Tsangpo river

Qu Bin

GENERALLY, THE Yarlung Tsangpo had an alkaline aquatic environment: pH in the Yarlung Tsangpo basin was between 8.3 to 9.0 with an average of 8.8. TDS (total dissolved solids) varied greatly from 66 mg L-1 to 265 mg L-1 with an average 157 mg L-1 in the mainstream channel, which was higher than that of the world average. The water chemical characters of the Yarlung Tsangpo vary along the whole river system, and are significantly shaped by the different geology, meteorological and anthropogenic conditions within the river basin[5].

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The Tibetan Plateau is the youngest and highest plateau in the world, where weathering and physical erosion take place at a fairly high rate[6]. Solutes in the Yarlung Tsangpo river waters have multiple sources, deriving from physical, chemical and biological processes in the drainage basin such as weathering of rocks, groundwater supplication, precipitation transportation, and as well as anthropogenic input[7]. It has been proposed that the majority of the dissolved solids in the Yarlung Tsangpo are mainly derived from various rock weathering (namely, carbonates, evaporates, silicate) as well as numerous geothermal springs and mineral-rich alpine lakes distributed in the Sothern Tibetan Plateau[8].

Major ions (Ca^{2+}, Na^{+}, K^{+}, Mg^{2+}, Cl^{-}, HCO^{3-}, SO_4^{2-}) in the mainstream of Yarlung Tsangpo fluctuated but with a general underlying steady trend from the source to the downstream. When compared with other rivers in the world, concentrations of most ions in the mainstream of the Yarlung Tsangpo were higher than the world average. For instance, concentration of SO_4^{2-} in the mainstream of Yarlung Tsangpo was 37.4 mg L^{-1}, almost four times higher than that of the global average (Figure 2).

Besides the precipitation and weathering supply, the evaporation along the upper reaches of the river basin significantly exceeds rainfall because of the abundant annual global radiation[9], both of which could lead to the high ion concentrations (e.g., Ca^{2+}, Na^{+}, Mg^{2+}, HCO^{3-}, SO_4^{2-}) in the Yarlung Tsangpo. Differently, ions K^{+} and Cl^{-} in waters of the Yarlung Tsangpo had a lower concentration than the world average level.

It is claimed that K^{+} in waters of the global river is primarily from the silicate minerals leaching, and in small amounts from other sources that often include one or more among evaporite minerals, fertilizers, rain waters and the decay of land plants[10]. Therefore, with few fertilizers or decay land plants along the Yarlung Tsangpo basin, the concentrations of K^{+} presented relatively low levels. It has been widely accepted that Cl^{-} in surface waters of rivers contributed by the cyclic salts is expected to decrease with increasing distance from the sea[11].

With the major contribution of the rainfall during the monsoon season to the annual discharge of the Yarlung Tsangpo[12], water chemistry is inevitably affected by the precipitation which is dominated by the India monsoon. However, as the roof of the world, the high elevation Himalaya blocks most of the water vapor flux from the Indian Ocean to the Tibetan Plateau and declines the precipitation in this area[13]. As a result, the concentration of Cl^{-} in the Yarlung Tsangpo was lower than most rivers in the world.

Majority of the dissolved solids in the Yarlung Tsangpo are mainly derived from various rock weathering as well as numerous geothermal springs and mineral-rich alpine lakes

Figure 2: Average concentrations of major cations of the mainstream of the Yarlung Tsangpo and rivers in the other regions in the world. (Modified from Qu et al.[14])

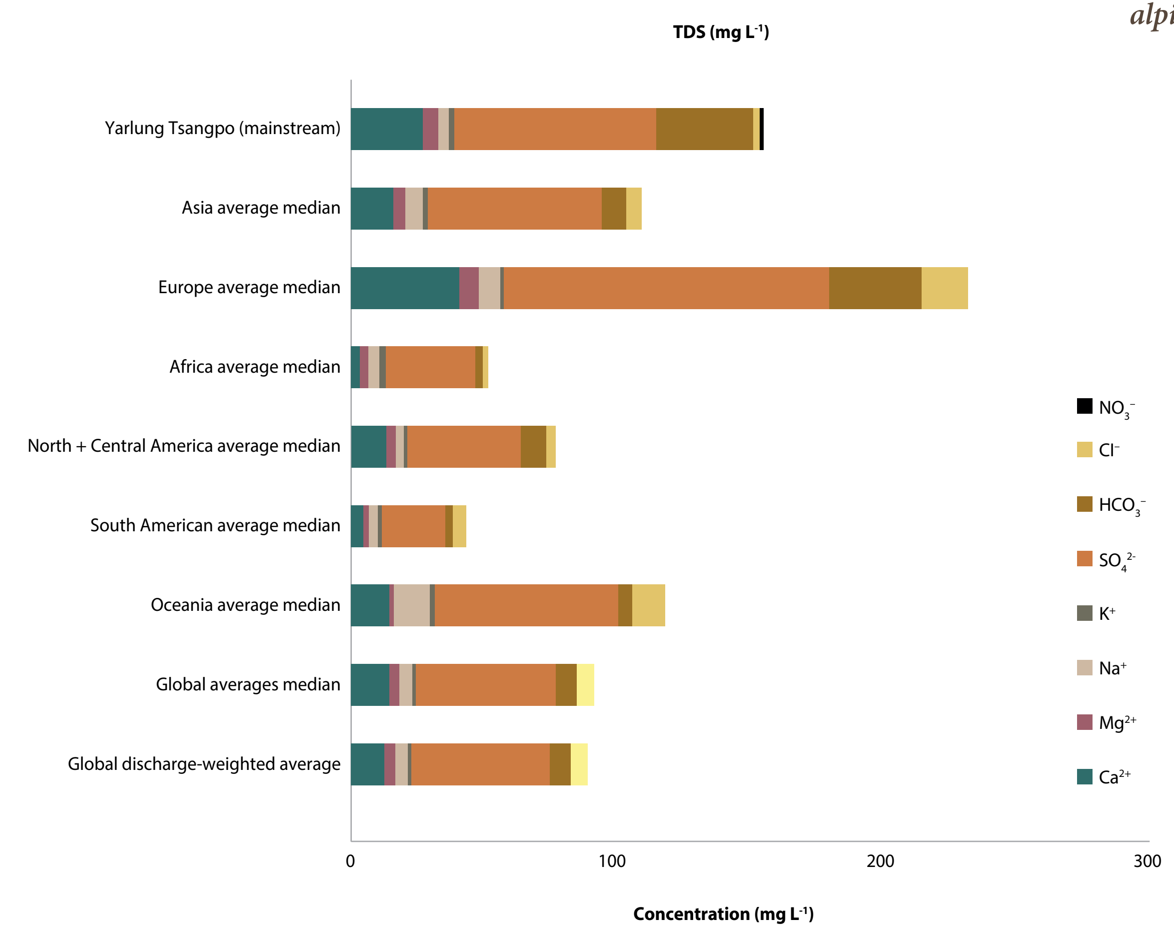

Table 1: Chemicals of health significance as described by international guideline (WHO) and China national guideline (GB) for drinking-water quality. Concentrations in Yarlung Tsangpo were presented in range and average, repectively

Parameter	Unit	Concentrations in Yarlung Tsangpo[15]	WHO[16]	Remark	GB5749[17]	Remark
pH		8.3-9.0, 8.8		Optimum: 6.5–8	6.5–8.5	
TDS	mg L^{-1}	66-265, 157 [18]	NA	Optimum: <1200	1000	
Turbidity	NTU	14.2-62.4, 26.1	5		NA	
Aluminum	µg L^{-1}	3.1-128.8, 43	200		200	
Antimony (Sb)	µg L^{-1}	1.7-18.4, 4.8	20		5	
Arsenic (AS)	µg L^{-1}	0.2-80.2, 20.2	10			
Barium (Ba)	µg L^{-1}	5.6-28.7, 15.1	700		700	
Bicarbonate (HCO_3^-)	mg L^{-1}	28.1-92.1, 68.0	NA	Optimum: <600	NA	
Cadmium (Cd)	µg L^{-1}	0.2-14.2, 2.7	3		5	
Calcium (Ca^{2+})	mg L^{-1}	12.3-46.3, 27.5	NA	Optimum: <250	NA	
Chlorine (Cl)	mg L^{-1}	0.4-5.8, 2.3	5 (C)	For total chlorine	4	For total chlorine
Chromium (Cr)	µg L^{-1}	0.2-4.1, 3.3	50(P)	For total chromium	50	For Cr(+6)
Copper (Cu)	µg L^{-1}	0.3-7.4, 2.2	200		100	
Fluorine (F^-)	mg L^{-1}	0.1-0.2, 0.16	1.5		1	
Potassium (K)	mg L^{-1}	0.2-1.2, 0.9	NA	Optimum: <250	NA	
Lead (Pb)	µg L^{-1}	1.6-55.7, 12.4	10		10	
Magnesium (Mg^{2+})	mg L^{-1}	1.3-12.5, 4.7	NA	Optimum: <150	NA	
Manganese (Mn)	µg L^{-1}	0.8-265, 40.7	400(C)		100	
Molybdenum (Mo)	µg L^{-1}	0.6-2.0, 1.3	70		70	
Nitrate (NO_3^-)	mg L^{-1}	0.1-2.9, 1.1	10	For nitrogen (N)	10	For nitrogen (N)
Sodium (Na^+)	mg L^{-1}	1.2-9.1, 5.2	NA	Optimum: <200	200	
Sulfate (SO_4^{2-})	mg L^{-1}	11.0-112.8, 38.7	NA	Optimum: <500	250	
Uranium (U)	µg L^{-1}	0.7-4.2, 2.2	30 (P)		NA	
Zinc (Zn)	µg L^{-1}	2.2-60.6, 17.0	NA	Optimum: <3	1	

Note: NA= no health based guideline value is provided; According to WHO Drinking-water Quality 4th edition (2011):
A = Provisional guideline value because calculated guideline value is below the achievable quantification level;
C = Concentrations of the substance at or below the health-based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints;
D = Provisional guideline value because disinfection is likely to result in the guideline value being exceeded;
P = Provisional guideline value because of uncertainties in the health database;
T = Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

Most of the concentrations of the elements are at low level in river waters of the Yarlung Tsangpo compared with the global average[19]. It should be noted that high concentrations of manganese (Mn), copper (Cu), cadmium (Cd), lead (Pb) and zinc (Zn) were found in parts of the socio-economically developed regions in the Yarlung Tsangpo river basin. The trace element in waters of the Yarlung Tsangpo are mainly governed by the weathering of bedrocks followed by up-concentration due to high aridity, human activities might also have an effect on the water chemistry over the region. Notably, in the Yarlung Tsangpo near the Yangbajing, high levels of arsenic (As) were observed, which is mainly due to the distribution of arsenic-rich springs within the basin[20,21,22].

Watercourse within the Yarlung Tsangpo River can be generally considered pristine

River water chemistry is highly variable by natural environment conditions such as basin lithology, hydrology and climate. Based on the pH and ions study, waters in the Yarlung Tsangpo river basin were characterized by high alkalinity due to the high concentrations of Ca^{2+} and HCO_3^-. TDS was ~157 mg L^{-1} in the basin fluctuated from 66 mg L^{-1} to 265 mg L^{-1}, which was in a common level compared to other rivers in the world. The ionic characteristic study of river water chemistry of the Yarlung Tsangpo was mainly controlled by natural processes, such as weathering of carbonates, silicates, and evaporites, and drainage from geothermal waters and saline lakes. By comparison with the standards from WHO and GB for drinking water, all ions were within the maximum desirable limits and concentrations of most elements were under the guideline of WHO. Watercourse within the Yarlung Tsangpo River can be generally considered pristine.

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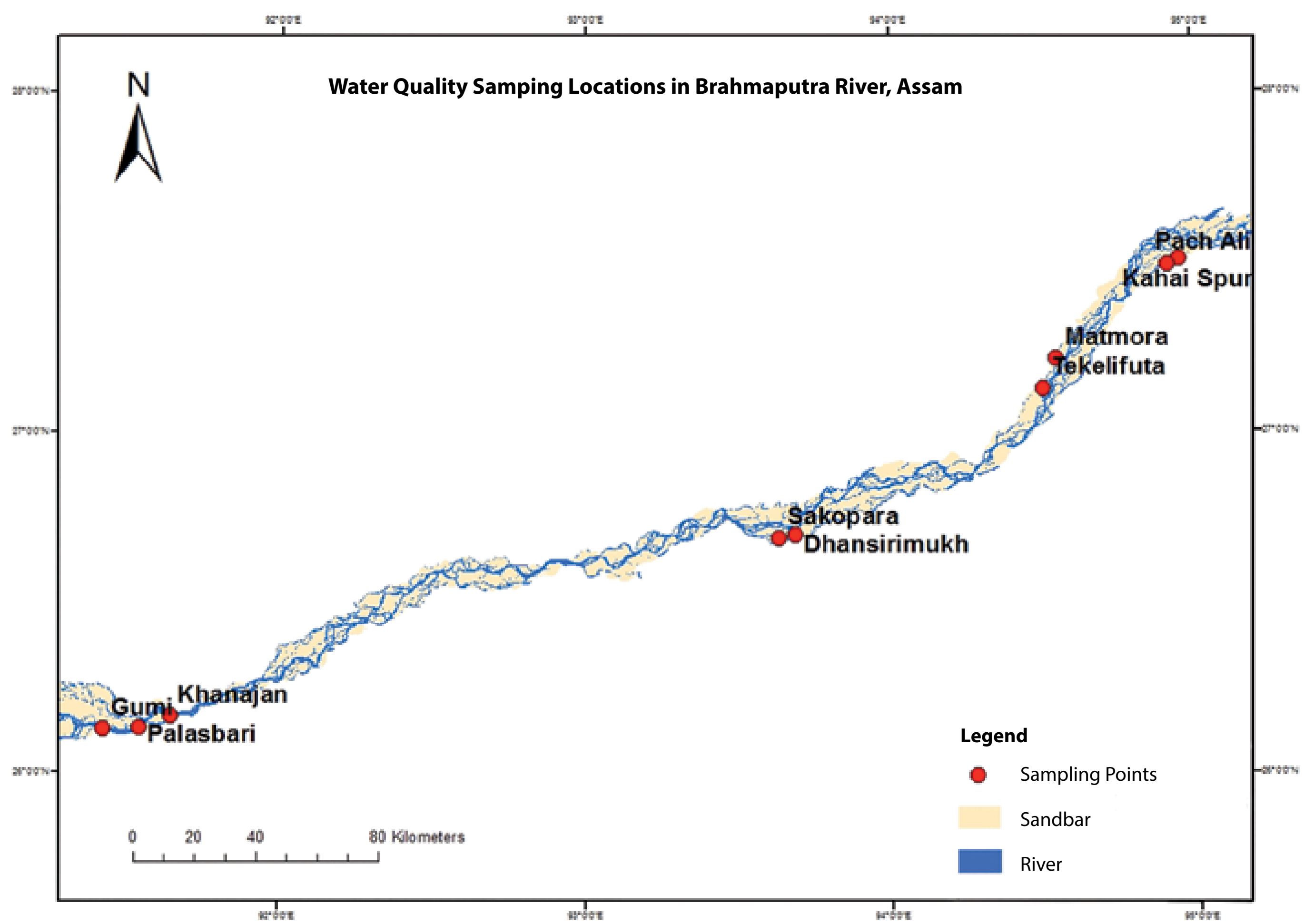
Brahmaputra River

Minakshi Bora

BRAHMAPUTRA RIVER plays an important role in the life and livelihood of the riverine population apart from supporting unique watershed ecology and therefore its water quality assessment is pivotal. Unfortunately, proper water sampling and laboratory-based water quality assessment covering the entire length of the river is largely missing in case of Brahmaputra River. Hence, the establishment of a detailed and scientific field-based water quality database for the river is very much essential for deploying and strengthening a proper water quality management plan. An attempt has been made to analyze an already existing database procured by Prof Dulal C Goswami under the Northeastern Integrated Flood and Riverbank Erosion Management project (Assam) sponsored by Asian Development Bank during the year 2007[23]. Unlike other water quality studies done so far on the Brahmaputra, the advantage of this study is that it covers the entire length of the river in Assam in the upper, middle and lower reaches

Figure 3: Map showing the sampling sites



Like all other Indian rivers, coliform contamination is considerably high in the Brahmaputra river along major locations at the vicinity of human habitation

each with multiple sampling points. The sampling sites are namely Pach Ali, Kahai Spur, Matmora, Tekelifuta, Dhansirimukh, Sakopara, Khanajan, Palasbari and Gumi (Figure 3).

A total of 24 different water quality parameters viz. color, odour, temperature, pH, electrical conductivity (EC), total suspended solids (TSS), total dissolved solids (TDS), total hardness, calcium, magnesium, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), chloride, sulfate, nitrate, ammonical nitrogen, phosphorus, arsenic, iron, manganese, lead, fluoride, total coliform and fecal coliform were analyzed by following the standard protocols given by Trivedy and Goel[24] and APHA[25]. Based on the collected data an overview of the water quality status has been obtained and the results are presented in Table 2 given below and are discussed in the subsequent paragraph.

Table 2: Water Quality of Brahmaputra River at selected sampling sites

Parameters	Kahai Spur	Pach Ali	Matmara	Tekelifuta	Dhansirimukh	Sakopara	Khanajan	Palasbari	Gumi
Color	Colorless	Colorless	Colorless	Colorless	Colorless	Colorless	Colorless	Colorless	Colorless
Odor	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Temperature	20	18	22	20	21	22	24	22	19
pH	7.5	5.8	7.4	6.2	7.1	6.9	6.7	6.7	7.7
EC	3400	800	2000	1800	2400	2600	3100	3000	3600
TSS	172	189	137	169	180	197	193	183	229
TDS	13.6	15.7	12.9	12.1	14.2	17.1	17.4	16.9	18
Total Hardness	64	42	46	50	52	42	52	48	50
Calcium	12.02	14.43	12.83	16.83	13.6	14.4	13.07	12.02	15.23
Magnesium	51.97	27.572	33.18	33.17	38.4	27.6	38.93	35.98	34.77
DO	6.49	8.91	8.91	12.16	8.1	9.7	7.41	9.73	10.54
BOD	4.2	4.6	3.6	3.9	4.2	3.2	3.46	3.25	3.96
Chloride	34.02	25.56	22.72	29.82	27.4	24.1	27	27	26
Sulphate	7.44	4.69	10.78	12.11	6.7	8.4	10	10	10
Nitrate	3.91	4.32	4.21	2.76	2.3	1.8	3.14	3.26	BDL
Ammoniacal Nitrogen	3.8	4.5	1.2	1.8	3.1	2.8	2.8	2.4	2.1
Phosphorus	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Manganese	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Iron	0.87	0.9	0.91	0.86	0.76	1.12	1.84	1.12	0.9
Fluoride	1.4	1.07	1.33	1.6	1.4	1.07	1.27	1.46	1.37
Arsenic	0.002	0.003	0.01	0.012	0.002	0.001	0.004	0.001	0.002
Lead	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Total Coliform	9	12	7	9	9	11	9	9	11
Fecal Coliform	1	2	1	1	1	0	1	0	1

N.B: All the parameters are in mg/l except temperature (˚C), pH, electrical conductivity (µS/cm) & Arsenic (ppb); BDL-Below Detection Limit

Source: Field monitoring and analysis done by Department of Environmental Science, Gauhati University

Out of the 24 parameters examined, six parameters, that is, pH, electrical conductivity (EC), magnesium, fluoride, iron and coliform count were observed to have crossed either the desirable or the permissible limit given by various standardization agencies such as BIS and ICMR. The survey indicates that surface water quality of the Brahmaputra River is acceptable in terms of mineral content and organic matter. However, like all other Indian rivers, coliform contamination is considerably high in the Brahmaputra river along major locations at the vicinity of human habitation. River Bharalu, a tributary of Brahmaputra which drains through the Guwahati

city reports very high coliform count in the recent past (Central Pollution Control Board report). Notably, bacteriological quality of the Brahmaputra River water is generally worst during May and June when a lot of surface runoff occurs during the early monsoon outbreaks.

Besides, another water quality parameter, that is, turbidity, which was not monitored during the present study, is also of major concern in the river. According to a report by East Siang Public Health Engineering Department during the year 2017, turbidity level as high as 425 NTU was recorded in the Siang river which is a major contributor of the Brahmaputra river. The excessive suspended sediment load during rainy seasons is responsible for the high turbidity levels in the river water. Excessive turbidity of the Brahmaputra river in the recent times is also related to the geological instability of the region. As the river valley and its adjoining highlands lies in geologically unstable and seismically active Eastern Himalayan belt, it experiences frequent earthquakes. These earthquakes trigger massive landslides and the debris thus generated in turn increases the turbidity of the river water[26].

Excessive turbidity of the Brahmaputra river in the recent times is also related to the geological instability of the region

Furthermore, in order to attain a broader perspective about the overall water quality status, a water quality index (WQI) calculation was also performed using *Weighted Arithmetic Index method*[27]. WQI aims at assigning a single value to the water quality of a source by translating a list of parameters and their concentrations present in a sample into a single value[28]. A pioneer work by Brown *et al*[29] stated that according to the range of WQI values, five water quality status categories can be classified: 0 to 25 is *excellent*; 26 to 50 is *good*; 51 to 75 is *poor*; 76 to 100 is *very poor*; and finally, above 100 is *unsuitable for drinking and fish culture*. The WQI values calculated in the current study ranged from a minimum of 29.8 to a maximum of 74.5. Out of nine sampling sites, four sites, namely, Pach Ali, Tekelifuta, Sakopara and Palasbari exhibited good water quality status with WQI values less than 50. While the remaining five sites, Kahai Spur, Matmora, Dhansirimukh, Gumi and Khanajan, exhibited poor water quality status with WQI values ranging between 50 and 75. Proper treatment is suggested prior to any use of the water falling under poor category.

Fortunately, direct pollution sources are mostly absent in the Indian stretch of the Brahmaputra River channel and moreover, owing to the huge amount of water discharge carried by the river, the pollutants added to it easily gets dispersed or diluted with time and space. However, a concerning fact about the overall water quality of the Brahmaputra river is that some of its tributaries like Dibru, Bhugdoi, Dhansiri, Gelabil and Bharalu are considered to be very polluted which in turn are contaminating the otherwise pristine water of the Brahmaputra river to a great extent. The present set of data will provide valuable insights in designing a suitable and holistic water quality management scheme in the Indian part.

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From a river to a drain: the Bharalu river

Shahnaj Laila

Originating in the Khasi Hills of India's north-eastern state of Meghalaya, the nearly 13 kilometers long Bharalu river starts off as the Bahini/Bihini near the Basistha Ashram at its foothills. According to Puranic legends, Lord Brahma's son, the great sage Basistha, meditated at this very site to rid himself of a curse given by one King Nimi. On Lord Vishnu conferring him with a boon of salvation, the sage brought down the three streams (Tridharas) of the celestial Ganga, namely, Sandhya, Lalita, and Kanta, to this point and absolved himself of all sins by taking a ritual bath there. Herein, the combined tridharas came to be known as the Basistha Ganga. On the banks of this river sprang up an ashram attributed to sage Basistha and is both a holy place as well as a popular picnic spot today. In 1764 C.E., the Ahom King Rajeswar Singha built the Jogeswar Shiva Temple within the ashram complex, surrounded by the Garbhanga Reserve Forest which is a rich elephant habitat.

A few kilometres from this point, the river bifurcates into two rivulets – the Basistha flowing towards the Ramsar site, Deepor Beel (Beel is an Assamese word for a lake); and the Bahini, meandering through Guwahati city before emptying into the Brahmaputra at Bharalumukh (mouth of the Bharalu literally).[30] It flows through areas like Beltola, Ganeshguri, R.G Baruah Road, before taking a sharp turn from the Assam State Zoo, whereon it comes to be known as the Bharalu. The river passes through some of the densest population clusters of the city including Ulubari and Sarabhatti before it meets the Brahmaputra.[31]

Historically, riverine transport was the preferred medium of movement of people and goods in Assam since it was inexpensive and the topography difficult. With the establishment of British rule in 1826 C.E., the necessity of an all-weather road for the purpose of facilitating military transport was strongly felt by 1836 C.E. By 1865 C.E., some steps were taken to construct such a road.[32] In order to sustain a large workforce, supply chains had to be maintained, especially the supply of firewood for fuel. With a sanction from the Bengal government in 1872 C.E., the Bhoraldhap forest area near Rani, adjacent to the Deepor Beel, was identified as a suitable site for felling timber, from which the tree-logs would be floated to Guwahati by the river Bharalu.[33] This is one example of the use of the Bharalu as a waterway.

However, this entire stretch of the river has been polluted today due to rampant urbanisation and the unchecked disposal of waste into its waters, rendering it unfit for human consumption. It has become a sewer and sections of it are known as the Mora Bharalu (Mora is Assamese word for dead), with putrefying stench wafting through the air. The river's catchment areas of central Guwahati are urban sprawls, and the prescribed width of its channel (40 feet) has been reduced to only 5-10 feet at many points due to encroachment. The Bharalu has been named as one of the 71 most polluted rivers in India by Central Pollution Control Board. Such problems have led to flash floods inundating many areas annually during monsoon. Moreover, the dangerously high levels of diarrhea causing fecal coliform bacteria make the water unsafe for drinking.[34]

In 2013, the Pollution Control Board of the Government of Assam, following the guidelines of the National River Conservation Directorate of the Ministry of Environment and Forests, Government of India, came up with a Detailed Project Report to clean up and restore the Bharalu.[35] A Feasibility Report of the Guwahati Development Department of Assam Government has also listed the Bharalu as one of the priorities of Guwahati Smart City development project involving a number of measures. It remains a mammoth task and needs proper planning and execution.[36]

Jamuna River

M Niamul Naser

THERE ARE quite a few cities and urban areas situated on the banks of the Jamuna and its tributaries, but there are no major industrial zones along the river. Pollution usually originates from domestic waste and agricultural sources along the river. The water quality parameters are within national standards as can be seen from Table 3 and water quality improves during monsoon as any pollution is flushed away by the river.

Table 3: Physicochemical condition of the Brahmaputra and Jamuna river system of Bangladesh

River System	Year	pH	DO mg/l	BOD mg/l	TDS mg/l	Chloride mg/l	References
Brahmaputra R	2016	7.18-7.78	5.8-7.6	1.0-2.2	52.2-168.0	4.0-12.0	DOE 2017
	2012	6.63-8.1	5.4-9.4	2.0-4.2	71-163	2.0-8.5	DOE 2014
	2010	6.82-7.28	4.0*-6.6	1.8-12.4*	62-120	4-8.5	DOE 2012
Jamuna R	2016	6.76-8.19	6.4-8.5	1.2-4.2	62.2-125.3	4.0-10.0	DOE 2017
	2012	7.2-8.46	5.9-8.5	2.8-11.0*	63.1-165.6	1.5-8.5	DOE 2014
	2010	6.16*-8.7	4.6*-7.4	2.0-5.0	66.0-170.0	3.0-14.5	DOE 2012
Meghna R	2016	6.08-7.09	0.8*-7.1	0.2-8.4*	28.1-228.0	2.0-30.99	DOE 2017
	2012	6.24*-7.6	5.2-7.2	0.3-3.4	45.0-150.0	3.0-11.0	DOE 2014
	2010	6.75-7.3	5.0-12.0	6.9*-20.2*	26.0-195.0	2.5-18.0	DOE 2012
Tista	2016	7.24-7.54	6.45-7.55	1.9-3.2	65.0-255.0	NA	DOE 2017
EQS** values for Bangladesh		6.5 – 8.5	≥5	≤6	1000	150-600	DOE 2017

** Values indicating the anomalies from EQS given by Department of Environment (2017)*
*** EQS, Environmental Quality Standard of Department of Environment (2017)*

Comparing the river water qualities, in 2010, 2012 and 2016, the total dissolved solids (TDS) and chlorides content were in good values of ranges for the DOE (2017) environmental quality standards (EQS). The pH, dissolved oxygen (DO) and Biological Oxygen Demand (BOD) have always been a challenge for the rivers of Bangladesh (see * values). In 2010, the pH values of Jamuna and in 2012 in Meghna fell slightly below the standard values. The slight alkalinity of water could be due to soil pH or for domestic and agricultural wastes disposed in the banks of the river. The DO, in 2010, falls slightly below the EQS values in Brahmaputra and Jamuna rivers, while in 2016, it was far below in Meghna river system. For the Brahmaputra and Jamuna rivers this may be due to low water flow and for Meghna river due to industrial effluents in the lean water flow period. The BOD indicates that the sewage contamination was earlier due to sporadic issues in both Brahmaputra and Jamuna rivers; but common in Meghna river system. Looking at the values of the upper riparian segments of Teesta river along with the Brahmaputra and Jamuna rivers, the northern rivers are in good aquatic state, especially for fishes. Further, the downstream Meghna river water quality is recently getting altered. There is a lack of detailed biological productivity and elements like plankton and benthos in the river ecosystem.

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NAVIGATION

Inland navigation

Uttam Kumar Sinha

Yarlung Tsangpo river

In a region where water is predominantly used for irrigation and with seasonal variation in rainfall, along with higher level of urbanization, maintaining channels for navigation is inherently difficult. Frequent flooding during the monsoons makes inland navigation more arduous. However, if the policy directive is to maximize broader social, economic and environmental benefits, then the inland navigation projects could not only support greater and faster economic growth but also lead to higher cooperation among the riparian countries. Navigation channels on the rivers as they flow and cut across the territorial boundaries in the region should be designed to become "pathways for prosperity" by interfacing with the social and economic needs of the riverine communities rather than being narrowly implemented for transportation utility by moving large containers from one river port to another. The emphasis on transboundary river cooperation cannot be less highlighted. For example, careful site-selection and constructing more storage dams in the upper reaches of the rivers could provide the twin benefits of flood management and adequate water flows for navigation in the downstream plains. Upstream-downstream cooperation on inland navigation is not unique as such arrangements are witnessed in several basins like the Nile, Amazon, Rhine and the Danube with discernable social and economic benefits including mechanisms to protect the environment and ecology of the rivers.

China has the largest network of waterways and the highest inland waterways cargo movement (one tonne over one kilometre) in the world

Inland navigation on the Yarlung Tsangpo is not a priority for China like, for example, the Yangtze river, winding through 9 provinces from east to west, which is regarded as an economic super-zone or more commonly as the 'golden waterway' generating 40 percent of China's GDP. China has the largest network of waterways and the highest inland waterways cargo movement (one tonne over one kilometre) in the world. It considers inland port infrastructure critical to its global trade growth and has targets to improve the waterways with calls for strengthening shipping capacity, expanding roadway and railway networks, and building large-scale logistics centres. Even on the Mekong River, China plans to develop 500 tonnes shipping navigation capacity along the 630 kilometers stretch of the river from Yunnan province to Luang Prabang in Laos.

The middle reach of the Yarlung Tsangpo River is about 100 kilometers and the elevation changes from 3,993 to 2,780 meters above the sea level, with an average gradient of 0.13 percent. Annual precipitation in the middle reach of the Yarlung Tsangpo river decreases dramatically from 60 millimeters in Nyingchi, to 43 millimeters in Lhasa, to 28 millimeters in Gyantze. There are no significant inter-annual precipitation changes. Precipitations are concentrated from June to September, making up 90 percent of the annual total. The inflow of the middle reach of the Yarlung Tsangpo river mainly depends on precipitation, ice melting and groundwater recharge. Inter-annual flows are relatively stable[37]. Since 1962, there have some been short-distance transport around the Milin County. However, due to the large elevation change and high altitude, the potential for inland waterway development in Tibet has largely remained unutilised.

River transportation

Along with the development of modern infrastructure such as roads and railways, the river system is still a major mode of transportation for goods and people in India and Bangladesh. Waterways can be a cost efficient, environment-friendly mode of transport with huge potential to enable diversion of traffic from over-congested roads and railways.

Brahmaputra River

India, on the other hand, has 14,500 kilometers of recorded inland waterways. As compared to other means of transport, inland waterways are the least capital-intensive and with relatively low infrastructure costs, it is best suited to carry over-dimensional cargo (ODC). Despite such advantages, waterways trade in India constitutes less than 4 percent of the total inland cargo movement.

At various stages in the history of the Indian sub-continent's economic growth, waterways helped to create economic wealth. In probably the most authentic physical account of the Indian frontier, the *Imperial Gazetteer of India* (1909) describes the Brahmaputra basin as the "great highway" of the Himalayas from the plateau of Tibet to the plains of Assam. Like the Indus in the north-west, the bend of the Brahmaputra

Inland waterways are the least capital-intensive and with relatively low infrastructure costs, it is best suited to carry over-dimensional cargo

enfolds the Himalayas in the south-east and as the *Gazetteer* notes, "This magnificent natural outlet of the glacier and snow-fed drainage of the north is still a matter of speculative interest to geographers, although enough of it is known to justify the expectation that it may yet be recognized as one of the world's highways."

Romesh Dutt, the eminent economic historian had expressed, "Nature had provided India with great navigable rivers which had been the high roads of trade from ancient times. And the system of canals, fed by these rivers, would have suited the requirements of the people for cheaper although slower transit, and would have at the same time increased production, ensured harvests and averted famines." He went on to describe how narrow commercial considerations prevented the state's involvement in river navigation, while road and rail enjoyed continuous state support during the British rule. Despite extension of the Assam-Bengal Railway from Guwahati to Tinsukia in 1902 and to Lumding and Dibru-Sadiya in 1903; 98 percent of the weight of the trade was carried by the Brahmaputra in the Assam valley during the time.

With the partition and the ensuing politics, the significance of inland waterways in the stream of development thinking remained much neglected in the region since 1947.

This is fundamentally changing now with the realisation that waterways can be a cost efficient, environment-friendly mode of transport with huge potential to enable diversion of traffic from over-congested roads and railways. In 2016, through an Act

History of inland water transport on the Brahmaputra[38]

Brahmaputra in Assam has served as a means of transport and communication of merchandise and people from and to Assam. Long before the advent of the railway system into Assam, the river maintained the link with other parts of the country through the network of its waterways and hundreds of boatmen were employed in its services. It was the lifeline of Assam.

The modem steamship service between Assam and Calcutta was first introduced by a Calcutta-based British-owned river transport company, the India General Navigation and Railway Company Ltd, which was founded around 1844. Another British-owned company which started operation was the River Steamer Company that was founded in 1867 and subsequently renamed as River Steam Navigation Company. Later on, both these companies came to be known as the Joint Steamer Companies. In 1967 the Central Inland Water Transport Corporation, a Government of India undertaking, became the legal successor of the joint steamer companies, in Calcutta. The river service was well organized, an infrastructure developed on the riverine route, and it became one of the world's most flourishing internal trade routes.

The river was the bulk carrier of Assam's tea and jute to Calcutta, two of the country's most valuable foreign exchange earners. The steamer services from and to Calcutta were finally closed down during the Indo - Pakistan conflict of September 1965 and the century old, checkered history of the inter-state trade and commerce came to an end.

The main exports of Assam, tea, leather, and jute have to find their way to Calcutta for internal distribution in India and export overseas. These have necessarily to be carried by the inland waterways. Tea has to be carried by the river route not only because the railways cannot carry the entire traffic, but because the waterway is quicker than by rail and the tea warehouses in Calcutta are so located that they can mostly be used in conjunction with water transport." Imports into Assam from Calcutta were food grains, foodstuffs, salt, mustard oil, iron and steel materials, cement, cloth, textiles, etc.

Bangladesh has over 24,000 kilometers of rivers, rivulets and canals of which one-fourth are navigable during the monsoon and nearly one-sixth during the dry periods

of Parliament, India designated 111 rivers as national waterways and signalled a strong stake in harnessing its network of rivers for inland navigation.

In addition to the 111 rivers already identified for development of waterways, there are about 116 rivers, that can provide 35,000 kilometers of navigable stretches. By overlooking these natural waterways, the logistics cost in India today runs very high at about 18 percent. Comparatively in China it is 8 to 10 percent and 10 to 12 percent in most European countries. Inland waterways transport is cost effective when compared to rail and road transport. Calculations suggest that the cost of transporting cargo by waterways is one-fourth the cost of transport by rail and one-sixth the cost of transport by road. In an age of environmentally sound approaches, trade on waterways leaves a small carbon footprint. Estimates suggest that 1 horsepower can carry 4,000 kilograms load in water but only 150 kilograms by road and 500 kilograms by rail. One litre of fuel can move 105 tons weight per kilometer by inland waterways but only 85 tons per kilometer by rail and 24 tons per kilometer by road. India has a vision plan on the Brahmaputra section of the river called the National Waterways 2 (NW2) and is currently focused on the route from Dhubri to Sadiya in Assam.

Jamuna River

Bangladesh has over 24,000 kilometers of rivers, rivulets and canals of which one-fourth are navigable during the monsoon and nearly one-sixth during the dry periods. About 50 percent of Bangladesh's cargo traffic moves through these waterways along with nearly one-quarter of all the passenger traffic. Most of the freight transported by waterways in Bangladesh is bulk cargo including construction materials, petroleum products, fly-ash, fertilizers and food grains. There are over 22,000 registered vessels engaged in trade and passenger movement. In addition, there are more than 750,000 local or country boats for transport of goods and people. These are the lifelines for the poorest communities. Bangladesh is emphasizing strongly on regional inland waterways transport with its Connectivity Project Phase 2. The focus of these initiatives will be largely on long-distance trade and transport, bulk cargo, connecting the sea ports and the National Waterways 1 (NW1) to National Waterways 2. It is developing large number of waterways as a national priority. Some of them will connect with those in India to facilitate transboundary navigation.

The Bangladesh Inland Water Transport Authority (BIWTA) established 21 inland river ports and 380 landing stations in the country through 2014. In 2013–14, BIWTA recorded 87.40 million passengers and 35.18 million tons of cargo for the nine major river ports. Inland water transport is mainly used for the transport of bulk, dry bulk, and liquid bulk of construction materials, food grains, fertilizer, clinker, petroleum products, and other products. A large fleet of about 10,000 inland vessels are engaged in the carriage of goods and passengers. There are also approximately 750,000 boats powered by pump engines operating mainly in the rural waterways.

BIWTA's ongoing activities include dredging of waterways, procurement of dredgers and ancillary crafts, development of an inland container terminal at Ashuganj, improvement of inland ports and landing stations, development of landing stages in rural areas, and development of waterways around Dhaka city. An inland container terminal has been developed through a joint venture project of BIWTA and Chittagong Port Authority with an annual handling capacity of 116,000 TEUs[39], which is to be followed by another four inland container terminals under construction by the private sector.

About 50 percent of Bangladesh's cargo traffic moves through these waterways along with nearly one-quarter of all the passenger traffic

Despite being the cheapest mode of transport, the popularity of inland waterways transport as a mode of passenger and cargo transportation has been declining. The modal share of inland waterways transport fell from 16 percent passenger and 37 percent cargo in 1975 to 8 percent passenger and 16 percent cargo in 2005[40]. Much of the competition came from the road transport system. Inland waterways transport has suffered because many rivers of the country have been deteriorating both from natural, morphological processes and from withdrawal of water from the rivers causing decreased dry season navigability. This was further aggravated by poor or no maintenance of navigability, weak regulations and safety standards, low allocation of budgetary funds, and general under-investment by both public and private sectors. Tables 4 and 5 below illustrate the declining share of inland-water transportation (passenger and cargo) from 1975 to 2005, and Table 6 shows that almost all the existing routes fall in the basin area.

Table 4: Modal share of passenger and cargo

	Passenger Traffic (billion passenger-km)						
	Total	Road	%	Rail	%	IWT	%
1975	17.0	9.2	54%	5.1	30%	2.7	16%
1996	66.0	52.0	79%	3.9	6%	10.1	15%
Annual Growth 1996-2005	7.1%	6.6%		0.7%		1.3%	
2005	111.5	98.4	88%	4.2	4%	8.9	8%

	Cargo Traffic (billion ton-km)						
	Total	Road	%	Rail	%	IWT	%
1975	2.6	0.9	35%	0.7	28%	1.0	37%
1996	10.7	6.9	63%	0.8	7%	3.0	30%
Annual Growth 1996-2005	6.9%	8.6%		0.8%		0.1%	
2005	19.6	15.7	80%	0.8	4%	3	16%

Source: World Bank (2007)

Table 5: Employment in Inland Water Transport (IWT)[41]

IWT Employers	Employed	IWT Employers	Employed
Public Sector		Private Sector	
Bangladesh Inland Water Transport Authority	4,000	Landing Stations	668,000
Bangladesh Inland Water Transport Corporation	5,000	Inland Vessels	75,000
Department of Shipping	60	Dockyards	101,000
		Country boat and Mechanized country boat	5,500,000
		County boat yard	10,000
Total	6,363,000		

Table 6: Existing Navigation Routes in Bangladesh

Route	Length (km)	Remarks
Alaipur-Raita-Laxmipur	32	During lean period the minimum depth remains 1.5 m
Paksey-Lauskandi-Ghoramara	7	
Talbaria-Shantigram-Sengram	25	
Sengam-Habaspur-Stabaria	3	
Nazirganj-Durgapur	6	
Padma-Jamuna confluence	14	
Sub total	87	
Alaipur-sarda	14	Hydrographic survey never carried out
Sardu-Rajshahi	15	
Premtali-Godagari	6	
Sub total	35	
Total	122	

Source: Mishra et al. 2012[42]

Sand quarrying

Sand quarrying is an important source of livelihood in India and Bangladesh; but needs to be monitored in order to alleviate the negative impacts

International navigation

Uttam Kumar Sinha

INLAND WATERWAYS transport on the Brahmaputra is particularly promising between India and Bangladesh. The protocol agreement between these two countries remains a stable framework for transit and trade. The Bangladesh-India joint communiqué, published in January 2010 during the visit of the Prime Minister of Bangladesh to India, showed that an understanding had been reached to introduce transit trade through Bangladesh to connect mainland India and its northeast. This was considered as a breakthrough attempt to re-align Bangladesh's long-term development strategy with neighboring India. The India-Bangladesh Protocol on Inland Water Transit and Trade (PIWTT) signed in 2015 allows for inland vessels of one country to transit through specified routes of the other country with each country providing facilities of 'ports of call'.

The waterways connectivity presents to Bangladesh an opportunity to sell its commodities like garments, pharmaceuticals, and leather to India, Bhutan, and even Nepal

The following year, a vessel from Kolkata traversed Bangladesh to the north-eastern Indian state of Tripura highlighting the value of the protocol routes in boosting the isolated markets of northeast India and allowing the region access to the industrial and market centres in India and Bangladesh. The 19th PIWTT Standing Committee meeting between the two countries in 2018 significantly improved the protocol routes with the inclusion of Rupnarayan river (NW-86) and expanded the number of 'ports of call' from five to six on each side by including Kolaghatin in West Bengal and Chilmari in Bangladesh. Standard-operating procedures for movement of passengers and cruise vessels on the inland routes were also agreed. Combining the services of the 1,620 kilometers NW-1 on the Ganga-Bhagirathi-Hooghly river system and the 891 kilometers NW-2 on the Brahmaputra between

the town of Dhubri on the Bangladesh border and Sadiya in Assam and the 71 kilometers NW-6 on the Aai river in Assam (through Bangladesh) will open up greater economic benefit in the region benefiting the Indo-Gangetic plains, Bangladesh and the north-eastern states of India, which suffer from huge logistic cost of essential supplies.

The waterways connectivity presents to Bangladesh an opportunity to sell its commodities like garments, pharmaceuticals, and leather to India, Bhutan, and even Nepal. Currently Bangladesh sources less than 10 per cent of import from India, and less than 1 per cent of exports. A situation that will rapidly change for the better as the navigational routes are further developed.

Table 7 shows that all inland water transportation protocol routes either origin or terminate in Chandpur, which is within the greater Ganges-Brahmaputra-Meghna basin with river ties to the entire Brahmaputra River system.

Table 7: Description of Protocol International Routes with India

Route			Shoal			Year of Survey
Name	Class	Distance (km)	#	Length (km)	Min. depth (m)	
Raimangal-Chandpur route						
Raimangal-Chalna	II	119	2	1.7	1.6 and 2.2	2010
Chalna-Mongla	I	16	1	0.5	2.1	2010
Mongla-Ghasiakhali	I	31	1	20.0	0.5	2010
Ghasiakhali-Chandpur	I	200	-	-	-	2004
Chandpur-Daikhawa route						
Chandpur-Aricha	II	119	-	-	-	2006
Aricha-Sirajganj	II	92	6	6.0	(-)1.3-(+)1.8	2010
Sirajganj-Bahadurabad	II	88	5	5.0	(-)1.3-(+)1.0	2010
Bahadurabad-Chilmari	II	62	5	5.0	(-)1.2-(+)2.2	2010
Chilmari-Daikhawa	II	37	3	3.0	0.1 -1.5	2010
Chandpur-Zakiganj route						
Chandpur-Bhairab Bazar	I	123	NA		-	2002,2006
Bhairab Bazar-Madna	III	63	1	10.0	1.2	2010
Madna-Ajmiriganj	III	47	1	23.0	(-)1.0	2010
Ajmiriganj-Sherpur	III	71	-	-	-	2010
Sherpur-Zakiganj	III	115	1	1.5	1.5	2010

Source: Mishra et al. 2012[43]

In addition, Bhutan is also benefitting. Landlocked Bhutan can finally find access to the sea through downstream India and Bangladesh. For the first time in July 2019, using the Brahmaputra waterways from Dhubri in Assam to Narayanganj in Bangladesh, Bhutan was able to ship stone aggregates using India as a transit. The cargo was first transported by land routes from Phuentsholing in Bhutan to the Dhubri jetty covering a distance of 160 kilometers and thereon by ship to Narayanganj. The cargo capacity was 1,000 MT equivalent to 70 trucks on road. The development of Jogighopa in Assam as a logistics hub for movement of cargo to and from the north-eastern states and Bhutan gives fillip to the development of inland waterways on the Brahmaputra.

The bilateral approach with India and Bangladesh on the Brahmaputra continues to outline its engagement. In the context, therefore, the lower-riparian cooperation on the Brahmaputra is of greater value. The sub-regional platforms like the Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation (BIMSTEC) which has transport and communication as one of the 14 sectors of cooperation and the Bangladesh-Bhutan-India and Nepal (BBIN) initiative to enable people and cargo movement across borders can act as a catalyst for cooperation on inland waterways.

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Enhancing navigation

Uttam Kumar Sinha

HAVING UNDERSTOOD the overall benefits of inland waterways and factored the cooperating actors in the equation, the question of how to enhance the scope of the Brahmaputra waterways becomes pertinent. The Brahmaputra has enormous potential to capture the regional aspiration but before it is fully realized it has a serious challenge to overcome and that being ensuring adequate water flows particularly during the dry months.

Storage dams: Building storage dams in the upper reaches of the Brahmaputra basin can provide multiple benefits notwithstanding the negative social and ecological impacts of building such structures. A cost-benefit analysis suggests that some of the negative impacts can be off-set by the positive gains.

For one, the storage dams will result not only in a perennial and reliable inland waterways transport but will also bring higher availability of water in the dry months for drinking water supplies, irrigation and industrial and commercial use. Second, it will enhance flood management capabilities leading to lower social and economic costs of floods and third with an all-season water transportation, climate change mitigation efforts will be strengthened.

It is estimated that for every tonne per kilometer of transportation on water GHGs emission is calculated to be 25 percent of that of transport by road. Fourth, development of water storage dams would require long-term planning, financial capabilities, sub-regional cooperation among the Brahmaputra-basin actors like Bangladesh and Bhutan and above all provincial or intra-state understanding in the north-eastern region of India. As a spin-off the overall benefits and gains from inland waterways transport can encourage water use efficiency in the water sectors. Significant water savings could further result in enhanced flows during dry season.

River dredging: Bangladesh has also taken a decision to dredge its rivers, and it will be advantageous for India to extend dredging services to Bangladesh. In fact, dredging work on Ashuganj-Zakiganj section on the Kushiyara river and Sirajganj-Daikhowa section on the Jamuna has commenced with India providing 80 percent of financial contribution. Once the work is complete, the river route, it is expected, will become navigable all year round for cargo vessels boosting further the connectivity and economic gains in the region.

As a spin-off the overall benefits and gains from inland waterways transport can encourage water use efficiency in the water sectors

Navigation services: Night navigation services for safe shipping and navigation between Pandu-Silghat stretch of the NW2 near the Bangladesh border has already been implemented and such systems and technologies like the river navigation information system or the differential global positioning system that India has installed at various locations on the NW2 should be offered to Bangladesh.

The technical and infrastructural advancement of the NW2 is driving hydrographic surveys and feasibility studies, many of them already completed, on a number of rivers meandering the north-eastern states. The total navigational length calculated is 1,213 kilometers of which the prominent ones connected to the Brahmaputra are the Subansiri (NW95), Dhansiri (NW31), Lohit (NW62), Aai (NW6), Beki (NW73), Dehing (NW30), Kopili (NW57) and Puthimari (NW82). The Aai and the Beki along with the Drangme Chhu or the Manas and the Mo Chhu or the Sankosh flow from Bhutan and empties into the Brahmaputra in Assam while the Wang Chhu confluences with the Brahmaputra in Bangladesh after traversing through West Bengal.

Inland water transport infrastructure: Particularly for Assam, the development of the inland waterways transport cannot be more critical. A vast populace both urban and rural need transport facilities and rely on small ferry services for their daily activities and livelihood. There are, however, operational limitations to these services.

The World Bank-funded Assam Inland Water Transport Project is a timely venture to help modernize the waterways transport services by building terminals, installing night navigational aids, connecting more areas and ensuing easy accessibility in all seasons. This has the potential to spur economic trade at one level and at another to facilitate education and health services to the riverine communities.

Furthermore, as Bangladesh is a cornerstone to enhancing inland waterways and any plans to expand India's ambitious national waterways will have to include trade to and through Bangladesh, given the recent traction in the bilateral relations Bangladesh is seeking Indian investment in almost 100 special economic zones (SEZs). India could take advantage of the proposal particularly in constructing cargo terminals, which are in shortage in Bangladesh. Additionally, Bangladesh could consider allowing Indian vessels to load/unload at all designated ports of call, a courtesy that India offers to Bangladeshi vessels, and adopt improved vessel standards.

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Bridges and connectivity

Xiawei Liao

BRIDGES CREATE connections. They allow safe passage where previously was not possible or was much more difficult. While the River and its tributaries are full of difficult topographies, many bridges have been built. A selection of the bridges in the basin is listed and illustrated here in this section.

Yarlung Tsangpo river

Qushui Bridge: The first modern highway bridge in Tibet
Qushui Bridge is located in the Qushui County in Tibet, 60 km to the Southwest of Lhasa. As the first modern highway bridge in Tibet, it entered into operation on August 1st in 1966. The bridge is 300 meters long and 10 meters wide.

Yarlung Tsangpo Bridge: The longest bridge on the Yarlung Tsangpo
The Yarlung Tsangpo Bridge, also called Cross Yarlung Tsangpo Bridge, is the longest bridge on the Yarlung Tsangpo until now. The construction started in April 2003 and started being used in August 2005. The bridge is 12 meters wide and 3,797 meters long with 108 openings. Each opening spans across 35 meters. The bridge is built on a total of 216 pile foundations.

Liuwu Bridge: The first multi-bridge flyover on the Lhasa River
Liuwu Bridge is the first modern flyover in Tibet located on the Lhasa River. Its construction was completed in 2007. The whole bridge is 29 meters wide and 1,660 meters long with the main bridge and two approaches, south and north. The design of the Liuwu Bridge has embodied many Tibetan cultural details such as the lotus shaped pier, which symbolizes luck.

Lhasa Bridge: The most scenic bridge on a tributary of Yarlung Tsangpo
Having been completed on July 1st, 2006, Lhasa bridge has become one of the most scenic spots in Tibet. The bridge is 940 meters long in total and located at an altitude of 3,700 meters above the sea level. It is only 2 kilometers from the Lhasa station and about 5 kilometers from the city center of Lhasa. The bridge is designed as flowy while *kha-btags* (traditional ceremonial scarf in Tibetan Buddhism) welcome guests from far away. The design also resembles snow mountains that are seen everywhere in Tibet.

Brahmaputra river

The mighty Brahmaputra river, flowing through the Assam valley is one of the longest rivers in India. Brahmaputra river is known as the lifeline of Assam state and separates the northeastern states from the rest of India. Six rail and road bridges have been constructed over the Brahmaputra in Assam and four new bridges are proposed.

Dholia Sadiya Bridge, Dhola Sadiya
Dhola Sadiya Bridge or Bhupen Hazarika Bridge across the mighty Brahmaputra river (Lohit River, a major tributary of the Brahmaputra River) at 9.15 kilometers, is the longest bridge in India and become operational in 2017. Prime Minister Narendra Modi inaugurated India's longest road bridge over Brahmaputra River on 26 May 2017.

Dhola Sadiya Bridge or Bhupen Hazarika Bridge across the mighty Brahmaputra river at 9.15 kilometers, is the longest bridge in India

A year after the Dhola-Sadiya Bridge was inaugurated, the Government of India announced plans for a longer bridge over the river Brahmaputra, which is likely to be completed by the year 2026-27. It will run between Dhubri in Assam and Phulbari in Meghalaya, close to the Bangladesh border. At 19.3 kilometers, the new bridge will be twice as long as the Dhola-Sadiya Bridge.

Bogibeel Bridge, Dibrugarh
Bogibeel Bridge across the Brahmaputra river in Dibrugarh is the longest road and rail bridge in India. The 4.94 kilometers long road-cum-rail bridge connects Dhemaji district and Dibrugarh district of Assam. This is also Asia's second longest rail-cum-road bridge, longest combined rail and road bridge in India and second longest bridge in Assam after Bhupen Hazarika bridge.

The Jamuna Bridge, also known as the Bangabandhu Bridge, is the longest bridge in Bangladesh. It has been named after the founder president of Bangladesh - Bangabandhu Sheikh Mujibur Rahman

Saraighat Bridge, Saraighat

Saraighat Bridge in Guwahati is the first rail-cum-road bridge over mighty Brahmaputra river in Assam. The Saraighat Bridge over the river Brahmaputra links the northeast region with the rest of the country.

Saraighat Bridge in Guwahati is the first rail-cum-road bridge over mighty Brahmaputra river in Assam

Kolia Bhomora Setu, Tezpur

Kolia Bhomora Setu (Bridge) is a 3.15 kilometers long road bridge over the Brahmaputra river near Tezpur, connecting Sonitpur with Nagaon. The bridge is one of the most important links between the northeastern states and rest of India.

Naranarayan Setu, Jogighopa

Naranarayan Setu is another important road-cum-rail bridge over the Brahmaputra river in Assam, connecting Jogighopa with Pancharatna. The 2.284 kilometers long double deck bridge is listed as one of the most impressive rail-cum-road bridges of India.

New Saraighat Bridge, Guwahati

The 1.49 kilometers long new Saraighat Bridge over the Brahmaputra river near old Saraighat rail-cum-road bridge was inaugurated in 2017. This is the second bridge on Brahmaputra river at Saraighat.

Jamuna river

The 18.5 meters wide and 5.63 kilometers long Jamuna Bridge, also known as the Jamuna Multi-Purpose Bridge, or the Bangabandhu Bridge, was opened in 1998 and is the longest bridge in Bangladesh. It has been named after the founder president of Bangladesh - Bangabandhu Sheikh Mujibur Rahman. The bridge connects the district of Bhuapur on the east bank of the river to the town of Sirajganj on the west bank. The bridge carries both road and rail traffic, as well as gas, electricity and telecommunications and was designed to bring the north-west region of Bangladesh into the country's mainstream economy and make inter-regional trade easier. It is part of the Asian Highway and the Trans-Asian Railway establishing a strategic link between the eastern and western parts of Bangladesh[44].

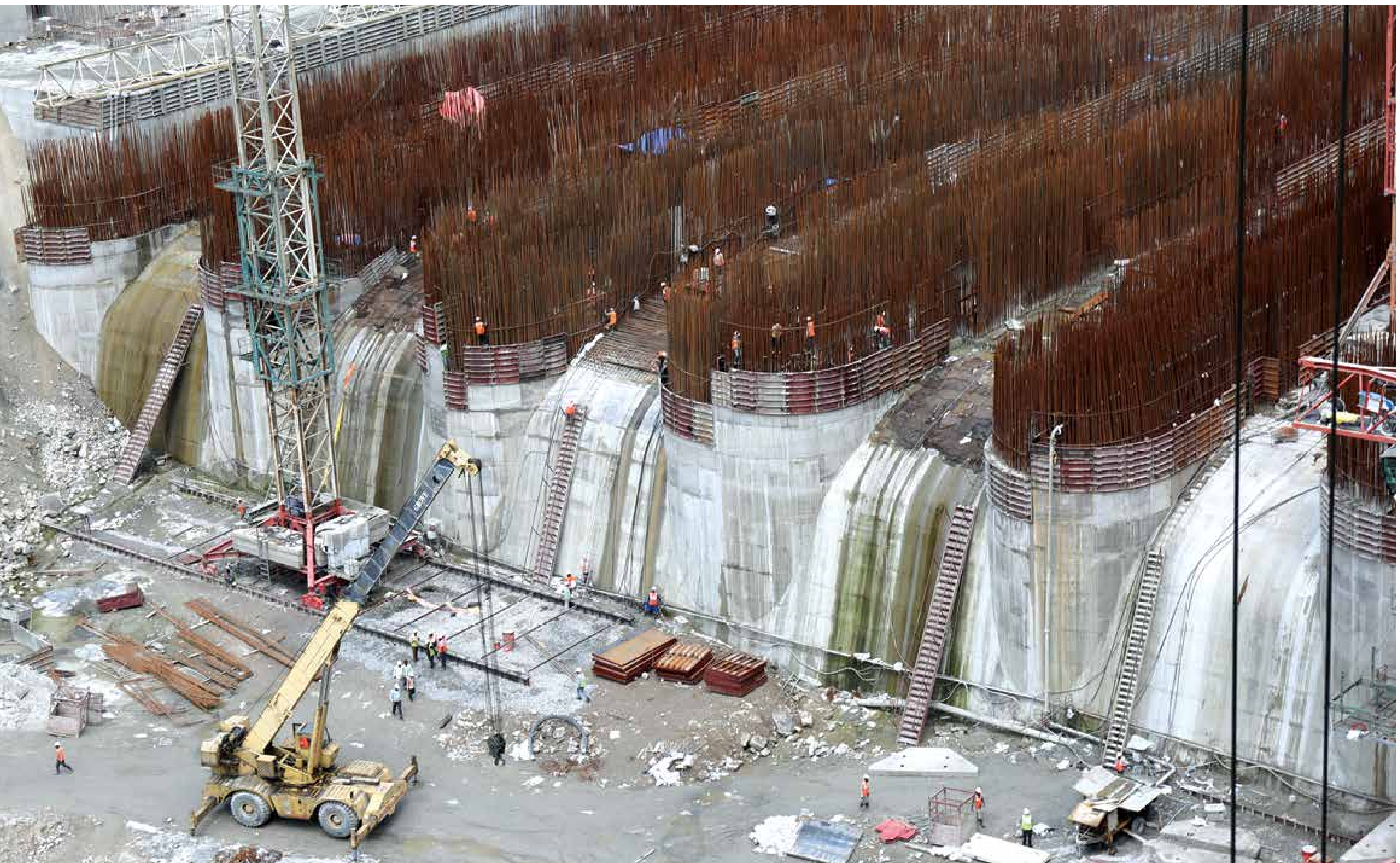
Using water power to make incense

Incense sticks are an important component of worship in Tibetan culture. Incense sticks are lighted in temples, homes, place of work and business and are an essential part of daily life. These pictures depict the process of using the power of flowing water to turn the wheels of the grinders for making a paste of the fragrant wood which is used to make the incense sticks.

Hydropower production

RIT International & EIMS

THE YARLUNG-Brahmaputra-Jamuna Basin has the potential for power generation from large storage dams as well as run-of-river and micro-hydro installations. Despite unmet demand for energy in the region, only a limited number of projects have been implemented to date[45]. The most important include the Zangmu Dam and several other storage projects in China[46], the aforementioned Teesta Barrage (which has a capacity of 67.5 MW), two other Teesta dams under construction in India (Low Dam III and IV), and several mid-sized structures on tributaries of the Brahmaputra in Bhutan.



Bhutan has seen improvements in development outcomes through investment in hydropower production and export. Analyses show that control infrastructures in this basin mainly advance energy production, except for the Teesta Barrage, which is mainly for irrigation. Dams far upstream in the basin may provide only limited flood protection due to modest storage-to-flow ratios and their inability to buffer against the heavy monsoon rainfall that falls in downstream portions of the basin[47]. Upstream dams, however, could have a major influence on augmenting dry season flows.

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The Zangmu hydropower station at the middle reaches of the Yarlung Tsangpo started operating in 2015. It is located next to the southern Tibetan county of Gyaca, which has a population of around 17,000. Located in a V-shaped valley at 3,200 meters above sea level, the Zangmu hydropower station is regarded as the highest in the world. The 510-MW plant is the largest in Tibet and equivalent to the entire existing hydropower-generating capacity of Tibet[48].

The Siang River is also endowed with rich hydropower potentials, amounting to more than 46 GW[49]. But it has been seen that hydropower development depends on various factors which include technical difficulties and political

The Brahmaputra basin provides scope for mutual benefit of the stakeholder countries with respect to energy generation

opposition, dearth of adequately investigated projects, land acquisition problem, environmental concern, regulatory issue, long clearance and approval procedure, the dearth of good contractor, and sometime law and order problem are the cause for the slow development of hydropower.

Although Assam has one of the lowest hydropower potentials in India's northeastern states, it has harnessed the maximum hydropower potentials in the region. Among all the northeastern states in India, Assam has harnessed maximum hydro potentiality, 55.14 percent, followed by Sikkim 15.6 percent and Meghalaya 11.78 percent. Currently, Assam has a capacity to produce 680 MW of hydro power, with another 275 MW capacity unexploited[50].

The Brahmaputra basin provides scope for mutual benefit of the stakeholder countries in respect to energy generation. India and Bhutan have hydropower potential, and both these areas have a list of planned hydropower plants. Bhutan and India have already signed agreements for distribution of power. Currently with only one hydropower plant of 230 MW, Bangladesh is yet to take part in the negotiations. Possibilities for inclusion for Bangladesh exist, as the country is already allowing India for trans-shipment of goods between Assam and Meghalaya and the Kolkata port of India.

India and Bhutan have enjoyed long and fruitful collaboration in the hydropower sector by providing clean electricity to India, generating export revenue for Bhutan, and further strengthening the bilateral economic linkages.[51] The two countries have successfully concluded several power sharing agreements. In 1961, India and Bhutan signed the Jaldhaka agreement, constructing the Jaldhaka project situated on the Indian side of Indo-Bhutan border in West Bengal. A major part of the power produced at Jaldhaka hydropower plant was exported to southern Bhutan. In 1987, Bhutan's first mega power project, the 336-MW Chukha Hydropower Project (CHP) was fully funded by the Government of India with a combination of grant and loan.

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Subsequently, the two countries also signed the Agreement on Cooperation in the Field of Hydroelectric Power (HEP) in July 2006, which outlines the framework for cooperation in the field of Hydropower. In 2008, the two countries further signed the Protocol to the 2006 Agreement and agreed to increase the export of electricity from Bhutan to India from 5,000 MW to 10,000 MW by the year 2020. Of these, three projects totaling 2,940 MW (1,200 MW Punatsangchu-I, 1,020 MW Punatsangchu-II and 720 MW Mangdechu HEPs) are under construction.

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In addition to hydropower, sources of cooling water are going to be a major issue for large-scale thermal power plants. Water is required in various processes at thermal power plants, primarily for cooling purposes. Significant volumes of water are used to cool down the steam exiting the steam turbines to dissipate the residual heat. Air cooling tower technology could be a solution if adequate water cannot be arranged from the respective rivers.

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