Need assessment and detailed planning for a harmonious hydrometeorology system for the Sundarbans

1. Study Area

- Sundarbans, the coastal part of Ganga-Brahmaputra Delta (GBD), is located on the western side of the delta and was covered previously in totality by mangrove forest, spreading over India and Bangladesh. However, since 1770, it was partly reclaimed for human habitation and agriculture in both the countries.

- Sundarbans have been best described by O'Malley in the District Gazetteer of 24-Parganas District. 'The Sundarbans are a network of tidal channels, rivers, creeks and Islands. Some of these islands are mere swampy morasses, covered with low forest and scrub wood jungle, but those to the north, which are embanked grow rich crops of rice. As one approaches the coast, the land gradually declines to an elevation which throughout many hundred square miles is scarcely raised above high-water mark. This seaboard area is a typical specimen of new deltaic formation. It exhibits the process of Land-making in an unfinished state, and presents the last stage in the life of a great river – the stage in which it emerges through a region of half land, half water, almost imperceptibly, into the sea.' (O'Malley, 1914).

- The 'low forest and scrub wood jungle' is the mangrove forest not properly reflected in the above description of O'Malley. At present, the mangrove forest part of this landscape is around 10,000 km^2, distributed over two countries and is the habitat for famous "Bengal Tigers".

- It has been well described as "a sort of drowned land, broken up by swamps, intersected by a thousand river channels and maritime backwaters, but gradually dotted, as the traveller recedes from the seaboard, with clearings and patches of rice land" (Hunter, 1875)
- Indian Sundarban extends from 21^0 40' 04" N to 22^0 09' 21" N latitudes and 88^0 01' 56" E to 89^0 06' 01" E longitudes. Ichhamati–Raimangal River marks the eastern boundary of Indian Sundarban while Hugli River is the western boundary. It is bounded by Bay of Bengal in the south and the Dampier-Hodges' line in the North.

- Indian Sundarbans consists of 104 islands of which 54 deltaic islands are inhabited (Danda et al, 2011) and rest 48 islands are forested islands. However, it is now having 102 islands. Two islands namely Lohachhara and Suparibhanga have already submerged and people migrated to other islands (Guha Indrila et. al, 2012).

- Indian part of Sundarbans extends over 9630 km^2 area out of which around 4260 km^2 area is under reserve mangrove forest. Out of this, about 55% is under land vegetation and the balance 45% is under water cover / inter-tidal zone.
- Nearly 40% of the Sundarban mangrove forest in India has been brought under Protected Area (PA) network : (a) Sundarban National Park = 1330 km^2, (b) Sajnekhali Wildlife Sanctuary = 362 km^2, (c) Lothian Wildlife Sanctuary – 38 km^2 and (d) Haliday Wildlife Sanctuary = 6 km^2.
- The rest 5370 km^2 part of India Sundarbans is inhabited in nature. As per 2011 census, altogether 4.42 million people live in 19 comprehensive development blocks distributed in North 24 Parganas (6 Blocks) and South 24 Parganas Districts (13 Blocks).
- The Sundarban landscape is characterised by a network mesh of tidal water systems. The average tidal amplitude is between 3.5-5 metres, with the highest amplitudes in July-August and the lowest in December-January and is a classic example of tide dominated delta (Ghatak & Sen, 2010).
- Altogether 6 (six) major rivers/ estuaries operating in Indian Sundarbans. The branches and creeks coming out of these six rivers are creating the network of rivers. These six rivers are Hooghly/ Muriganga, Saptamukhi, Thankuran, Matla/ Bidya, Goasaba and Raimangal/Ichhamati. Of the 6 rivers that dominate the landscape, only the Hugli-Muriganga and Ichamati-Raimangal carry freshwater flow of some significance (Danda, 2007). Being the moribund part of the lower delta plain of the GBM system, the Indian Sundarban is experiencing both declining freshwater supplies and net erosion, as has been recorded since 1969 (Hazra, 2010).
- The Indian Sundarban is also facing degradation due to natural and anthropogenic causes. Degradation of this littoral tract is manifested in terms of frequent embankment failures, submergence & flooding, beach erosion, siltation within embayment, saline water intrusion in the agricultural field etc (Hazra et al. 2002).
- Indian Sundarban being situated in Ganges-Brahmaputra estuary is also vulnerable to anthropogenic perturbations due to high nutrient loads from riverine discharge, increasing human population density and rapid economic growth (Seitzinger SP et al, 2005; Biswas H. et al, 2010)
- A huge quantity of leaf litter is loaded to the estuarine water from surrounding mangrove forests in Sundarbans. Land mass washes during monsoon and

effluents from shrimp culture farms also contribute to this huge nutrient load. (Chaudhuri Kaberi et al, 2012)

- In contrast, 6000 km^2 of mangrove forest in Bangladesh is only known as Sundarbans. Out of this area, about 1890 km^2 is under water cover / inter-tidal area. It extends from Baleswar River in the east to the Harinbhanga and Raimangal Rivers along the border with India in the west. Bangladesh Sundarban lies between the latitudes of 21^0 48' N to 22^0 41' N and the longitudes of 89^0 28' E to 90^0 08' E.
- The total area of the Bangladesh Sundarban is 9610 km^2 (which is slightly bigger than Cyprus having an area of 9,250 km^2), of which, the impact zone covers 3,641 km^2 (IUCN Bangladesh, 2014). The rest lies in the Sundarban Reserve Forest area.
- Bangladesh part of Sundarbans is distributed over three districts, namely Satkhira (Shyamnagar Upazila), Khulna (Koyra and Dacope Upazilas) and Bagerhat (Mongla and Sarankhola Upazila).
- Out of these three districts, 'high vulnerabilities in terms of insecurity of food, income, water, health and poverty are prominent in Bagerhat and Satkhira Districts (BBS et al. 2009; GoB 2006, Dasgupta et al. 2014)
- Total population of in these five Upazilas is around one million as per 2001 census, thus altogether more than one million people live within Bangladesh part of Sundarbans.
- Further, some 8 million people live on the edge of the Bangladesh Sundarbans - the largest mangrove forest in world. For generations, they have depended on nature, and lived as woodcutters, honey collectors, fishermen and subsistence farmers.
- It needs to be understood that total population of Sundarbans is more than population many European countries like Sweden, Switzerland, Portugal etc.
- Thus, importance of Sundarbans is not only from the point of biodiversity conservation, but also due to the fact that it supports life and livelihood of around 15 million people living in this landscape over generations.

2. Objectives

- The focus of the study is to make a harmonious hydrometeorology system for Sundarban landscape covering both the parts namely India and Bangladesh so that continuous real time measurements of different hydrodynamic parameters like tidal range fluctuations, waves, currents, sediment loads, saline water ingress along the rivers / creeks in different seasons and in varied tidal regimes, freshwater input (especially for Bangladesh Part) etc. can be carried out in future for preparation of a robust database for this otherwise fragile landscape due to climate change and Sea Level Rise.

- A framework designing so as to understand the actual components of different parameters contributing to Relative Sea Level Rise (RSLR), especially land subsidence due neo-tectonic movements and/or due to compaction of sediments.

- To suggest a robust network of meteorological observatories, both surface and sea surface, so as to estimate different weather parameters like rainfall, flood level, wind speed and direction, humidity, soil moisture etc. continuously with a pixel size of maximum 30 kilometres and to transmit that on real time basis to feed into the micro-level weather models for generation of operational forecasting

- To suggest logistic arrangements for proper dissemination of the micro-level forecasting within the community at local level to help in decision support system of the local bodies.

- Probable Locations for installations of these instruments / equipment with a possible Standard Procedure of Operations and institutional mechanism will need to be worked out.

3. Scope of the Work and Limitation

In order to carry out this work in the limited available time, it was decided to depend upon secondary data as available from various sources. The scope of the work thus includes the collection of appropriate data, both in the form of statistics and written documents as well as in maps and integrating them together to form an overall document useful for the study. Research Papers published in the different International Journals and as available in the web have been extensively accessed and used for carrying out this study. Information as available in the official websites different agencies / organisations have also been searched and used for this report. Data contained in the PSMSL website and the locations of different tide gauge stations have also been used in preparation of the document. The block-wise statistics of population was extracted from Census Report of 2011. The Tide Charts as published by Survey of India for Kolkata Port and the tide information as published by BITWA, BWDB etc. for different ports of Bangladesh have also been utilised.

Limited interactions with the concerned officials of several organisations like Kolkata Port Trust, IMD, IWAI etc. were also made to collect information from different agencies. Information was also collected through various communication media e-mail, Whats App messages including personal phone calls from different agencies of Bangladesh, which were highly beneficial for the preparation of this document.

A comparative analysis of the existing hydro-meteorological systems with those of Mekong Delta and Danube Delta has also been attempted here in Part-II of the document. In all cases, the secondary data and reports have only been utilised.

The work does not envisage collecting any firsthand data based on any direct observation and/or experimentation and fieldworks, which may be considered as a limitation to this study.

Hydromet Assessment Along Sundarbans

Importance of Hydro-Meteorological Services

The Evolutionary history of this planet has pointed out to the fact that weather on a short-term and Climate on a long-term basis have always played a key role in sustenance and proliferations of different elements of the biosphere, irrespective of geological time scale. History of human civilisation has clearly indicated that rise and fall of different civilisations like the Harappan Civilisation of the Indus Valley, Mesopotamia, ancient Greek and Roman Civilisations etc were all dependent on natural systems and thereby influenced by climate and weather. Even with notable development of science and technology in 21st Century, weather and climate still play a major role in development of human civilisation in any part of the globe. Thus, weather and climate have always influenced human activities and natural systems (Anonymous, 2007).

Climate and increment in extreme weather conditions as a fallout of climate change are increasingly making impact and adversely influencing human safety, health and security, food productions, food security, livelihood options and thereby the life of the individuals. Changes in rainfall pattern, frequency and amount are now eminent in different parts of the world resulting in shifting of the agricultural seasons and in many cases reducing the agricultural production leading to starvation and famine like situation. The situation has been further complicated in the coastal regions since the frequency and/or intensity of tropical cyclones have been increased to a large extent resulting in disasters and loss of life, property, live stocks as also livelihood during this century. Floods are now annual events and regular phenomena rather than occasional. Droughts and loss of harvest due to dry season and high temperature is also going on in different parts of the sub-continent. It is also interesting to note that when some part of the sub-continent is facing severe problem including loss of agricultural harvest due to drought, the other part is facing hardship and loss of property due to floods and water logging due to excessive rain or cloud burst, phenomena which can only be explained with the erratic behaviour or monsoon. Compounded with these hardships, vector borne and water borne diseases like Chikungunya, Malaria, Dengue, Diarrhoea etc. are found to be spreading like epidemic even in Metro Cities with 21st Century amenities, a phenomenon being explained as a fallout of climate change and climatic condition.

Accelerated Sea Level Rise (SLR) has made the coastal people more vulnerable. The increased amplitude of the coastal waves and currents are leading to erosion of the embankments in a faster manner leading to breaching of embankments and saline water inundation along the vast coastal tract of the sub-continent. Salt water ingression is no more a theoretical consideration but is being experienced in day to day life by the coastal population. Saline water inundation coupled with salt water ingression is making vast agricultural land along the coast unusable for agricultural practices and thereby telling upon the livelihood of the coastal community leading to large scale migration. Frequent disasters and climatic hazards are also affecting the tourism sectors in coastal areas.

As per the IPCC Fifth Assessment Report, 2014 these adverse situations are going to accelerate in the coming days due to climate change even with sufficient interventions and mitigation measures to decrease emission of GHG on a world-wide scale. In such a scenario, when the people will be compelled to live with frequent disasters like situation, the only option is to get ready beforehand regarding any adverse situation. Hydro-meteorological predictions and forecasts including the nowcasts and other information among all sections of people are now getting appreciated by all sections of people. All types of transportation, namely land, naval and especially aviation are utilising weather forecasts especially the prior knowledge regarding severe weather conditions and warnings for safe journey. Agriculture and food productions ministries and departments are using long-term weather forecasting for Crop Production modelling which is entirely dependent on precise and timely climate forecasts. Any country can get prepared beforehand to ensure sufficient food grain stock through planned import to prevent from a situation of 'distress buying' at the time of shortage of food grain. The entire process of disaster preparedness depends on precise forecasting and prior information on climate hazards. Disasters can be managed effectively with planned approach through precise forecasting which may in other words save the life and properties of the citizens from severe exposures. Similarly, public health is another sector where prior information regarding climate advisories may help the public health practitioners to reduce the exposure of communities to climate sensitive diseases and so on.

There is thus, a growing demand for tailored, accurate and reliable forecasts and warnings issued in a timely manner and in a user-friendly and easy-to-understand language. Since in the coming days, the impact of climate change is going to be increased, it is expected that the existing agencies in different countries of this sub-continent carrying out hydro-meteorological forecasts will be faced with increasing challenges and demands for providing more useful forecasts and other useful information to cater the needs of the various sectors.

<u>Special Significance of Hydro-meteorological Services in Sundarban</u>

Vulnerability Assessment of Sundarbans from the Hydro-meteorological services

Vulnerability or susceptibility is related to the characteristics of the region and has to be studied in detail after dividing the study area into appropriate units (Anonymous, 2006). Since in the present study, Sundarban is located over two countries, hence Indian Sundarbans and Bangladesh Sundarbans have been treated separately while studying the vulnerability vis-à-vis the effect, although most of the issues are common to both parts and hence treated in a common way. It may be worth mentioning here that human population and settlements are the primary concerns in assessing vulnerability of any region and hence reported separately.

Vulnerability of the Sundarbans along with other reasons is primarily due to the fact that about 5 million people are dwelling within Indian Sundarbans and about 10 million people are living in the impact zone of Sundarbans in Bangladesh. Thus, life and livelihood of 15 million people are directly dependent on the climate and weather situation in Sundarbans. Details of population dependent on Sundarbans are given below:

Table – 1.1 : Population in Indian Sundarbans as per 2011 Census

Sl. No.	Name of the District	Name of the CD Block	Number of Household	Total Population	Total No. of Male Population	Total No. of Female Population
1.	North 24-Parganas	Haroa	46888	214401	111080	103321
2.	North 24-Parganas	Minakhan	43756	199084	101827	97257
3.	North 24-Parganas	Sandeshkhali – I	37344	164465	83925	80540
4.	North 24-Parganas	Sandeshkhali – II	37771	160976	81921	79055
5.	North 24-Parganas	Hasnabad	47739	203262	104019	99243
6.	North 24-Parganas	Hingalganj	46048	174545	88937	85608
7.	South 24-Parganas	Canning – I	64041	304724	155126	149598
8.	South 24-Parganas	Canning – II	49711	252523	128438	124085
9.	South 24-Parganas	Mathurapur – I	40602	195104	100093	95011
10.	South 24-Parganas	Mathurapur – II	45888	220839	113831	107008
11.	South 24-Parganas	Jaynagar – I	55734	263151	134966	128185
12.	South 24-Parganas	Jaynagar – II	50413	252164	128858	123306

13.	South 24-Parganas	Kultali	45099	229053	117562	111491
14.	South 24-Parganas	Basanti	70818	336717	171279	165438
15.	South 24-Parganas	Gosaba	58197	246598	125910	120688
16.	South 24-Parganas	Kakdwip	60201	281963	144120	137843
17.	South 24-Parganas	Sagar	43716	212037	109468	102569
18.	South 24-Parganas	Namkhana	41433	182830	93351	89479
19.	South 24-Parganas	Patharpratima	69641	331823	169422	162401
20.	**Total**		**955040**	**4426259**	**2264133**	**2162126**

Table – 1.2 : **Population in Bangladesh Part of Sundarbans as per 2001 Census**

Name of District	**Name of Upazila**	**Area (sq km)**	**Municipality**	**Union**	**Mouza**	**Village**	**Population**	**Density (per sq km)**
Satkhira	Shyamnagar	1968.24	-	13	127	216	313781	159
Khulna	Koyra	1775.41	-	7	72	131	192534	108
	Dacope	991.57	-	10	26	107	157489	159
Bagerhat	Mongla	1461.22	1	6	30	77	149030	102
	Sarankhola	756.61	-	4	12	45	114083	151
Total							**926917**	

Source : Bureau of Statistics as in website of Banglapedia; http://en.banglapedia.org/

Although there is no human settlements inside Bangladesh Sundarban, the impact zone of the forest is inhabited by about 8 million people, of which, about 28% are mainly engaged in livelihood generation from the forest, such as fishing, shrimp fry collection, collection of Golpata, honey, fuel wood, Non-timber Forest Produce etc (IUCN Bangladesh, 2014). Thus a large section of population living within Sundarban Impact Zone in Bangladesh is dependent on natural resources and their livelihoods are directly linked with climate and nature.

A detail account of boundary of Sundarban has been recently worked out (Bandyopadhyay, 2017) based on evolution and geomorphology. In India, the Dampier-Hodges Line which actually represents the extent of Mangrove wetlands during the time of survey of 1829-30 has been considered as the Sundarban, while in Bangladesh, the mangrove forest boundary is regarded as the Sundarban. 10 kilometres buffer from the northern extent of mangrove forest has been regarded as 'Ecologically Critical Area (ECA)'. ECA has also been accepted by the Government of Bangladesh and referred in the Government documents. However, in some literature, a 20 kilometre buffer around the northern fringe of the mangrove forest in Bangladesh, has been designated as 'Sundarban Impact Zone (SIZ)' although it has got no legal footing so far as acceptance by the Government of Bangladesh.

There cannot be any doubt in the fact that climate and weather situation in Sundarbans are not restricted in their imprint only on the population living within Sundarbans or in its Impact Region. It has its effect far behind and even upto Kolkata city In India and beyond and Jessore or Kusthia in Bangladesh. Although it has been considered in the government circle that Dampier Hodges line in India represent the extent of mangrove forest in Indian Sundarbans during 1829-30, but the old literature points to something contradictory. Mangrove forests and for that matter Sundarban was extended far inside over the land area and even in Kolkata City.

While describing Sundarbans in the old District Gazetteer of 24-Pargana District, it was mentioned "that this subsidence of the surface of the ground is not confined to the Sundarbans, seems to be confirmed by the fact that stumps of trees have also been found at Sealdah in Calcutta, at various levels down to a depth of thirty feet, or ten feet below the peat. These trees also were pronounced by the Superintendent of the Botanical Gardens to be *Sundri*, a tree of which the range is restricted to from two to about ten feet below high-water mark. It appears, therefore, that the deltaic tract stretching from Khulna to Calcutta must at some time have undergone a subsidence." (O'Malley, 1914). This clearly indicates that even in the recent past, Sundarban was extended upto Sealdah, which is being considered as the Central Kolkata now and far away from the present day Sundarbans. These areas in other words, the city of Kolkata, is also dependent on the climate and weather condition of the Sundarbans.

Embankments vis-à-vis vulnerability in Sundarbans

It has already been discussed that about 5 million people live within Indian Sundarbans. The term 'Sundarbans' is used in Bangladesh to define the area of natural mangrove forest in the seaward area of the Brahmaputra delta and excludes the landward reclaimed areas; however, in India the term is used to include both the mangrove forest and the reclaimed delta area (Bhattacharyya et al, 2013). In case of Indian Sundarbans, the reclamation of Sundarbans has started long back exactly from the year 1782 or 1783.

A detail history of reclamation of Sundarbans has been provided by W. W. Hunter (1875). There were some attempts of reclamation of Sundarbans under "…Muhamammadan Chiefs, such as *Khan Jahan*. The present attempts date from an early period of the history of British Administration of Jessor, and are due to Mr. Henckell, the First English Judge and Magistrate of Jessor, appointed in 1781, who was the founder of the system of reclamation which is now converting these forests into immense rice tracts." Apparently about 1782 or 1783, Mr. Henckell established three market-places in this inhospitable tract at Kachua, Chandkhali and at Henckellganj (later on known as Hingulgunge). "In all three places, clearances of jungle had to be made before the *gunj* (italics by Hunter, 1875) or market could be established, for they were all in the Sundarban forest. By degrees, the lands immediately around them were brought under cultivation.

On the 4th April 1784, Mr. Henckell submitted to the Board his scheme for the reclamation of the Sundarbans. He proposed granting allotments of land, on favourable terms, to people undertaking to reclaim them…… The Sundarban plan, as it was then called, was approved by the Board of Revenue, and speedily brought into operation, - Mr. Henckell being made 'Superintendent for cultivating the Sundarbans'. In 1787, Mr. Henckell already looked on the scheme as a 'great success' and reported that many *zamindars* (italics by Hunter, 1875) had come forward and taken grants, and that 7000 *acres*, or 21,000 *bighas* (italics by Mr. Hunter), were already under cultivation. He had largely interested himself in the plan and had even personally advanced money to *talukdars* (italics by Hunter, 1875) to carry it out."

The entire process of reclamation of Sundarbans depended on erection of embankments and closing of the mouths of the creeks so as to destroy the entire mangrove forests within the island area. It has been well described in the old literature. "Another feature in the reclamation and cultivation of those Sundarban lands is the embankment of water inlets. It is a characteristic of deltaic formations that the banks of the rivers are higher than the lands further removed from them; and the whole of the Sundarbans may be looked on as an aggregation of basins, where the higher level of the sides prevents the water coming in to overflow the interior. Many of these basins are so formed, that, left to themselves, they would remain under flood, as they communicate with the surrounding channels by means of *khals*, or small water-courses, which penetrate the bank; and a great part of reclamation work consists in keeping out the water, and thus bringing under cultivation the marsh land inside. (James Westland, 1874)

In employing this method, all the inlets from the surrounding channels are embanked, and smaller channels, called '*poyans*', are opened round their ends. The inlets themselves are too big to be kept under control, but these '*poyans*' can easily be so kept. This embanking is usually done in November, after the rivers have gone down. When the tide is low, the channels are opened and the water from the inside drains off; when it is high, the channels are closed. Much land can be rendered culturable by this means, which would otherwise be marsh, But here also a single year's neglect may take away at one stroke all that has been gained by many years' labour. The effect of the rains and the freshets of each year is to partially destroy all the embankments that were used the previous year and to flood the lands….. Unless the embankments are again renewed in November, the floods will not have ceased to cover the low lands by sowing time, the land will remain unsown, and jungle and marshy reed will take the place of the paddy". (James Westland, 1874)

"Large areas of marsh land in Sundarbans have been reclaimed and brought under tillage by means of embankments raised to keep out salt and brackish water" (O'Malley, 1914) pointing to fact that reclamation of major portion of Sundarbans was completed by the beginning of 20^{th} Century and perhaps it attained the present shape by that time.

During 18^{th} and early part of 19^{th} century concept of Coastal Zone management was simply unknown. Any possibility of change in climate due to deforestation was not envisaged. Concept of Carbon sequestration had not evolved. Carbon footprint was not even imagined. Mangrove wetlands were considered as a liability than asset. People use to look at mangrove forests of Sundarban as a wasteland. This was expressed in various literature of that time.

"The scenery in the Sundarbans possesses no beauty. The view even from a short distance is a wide stretch of low forest with an outline almost even and rarely broken by a tree rising above the dull expanse. In the forests, so far as I have seen them, there are few trees above 30 or 35 feet high, and few attain any considerable girth. This seems to be the result of the closeness with which they grow, and the poverty of the soil, which is impregnated with salt. But when a tree can get room enough to grow freely, it will attain a much greater size. The finest and largest trees I have seen have been almost invariably in places where the land had once been cleared; so that they had a good start before the jungle sprang up around them. There is little undergrowth in the forests, though here and there one may find cane-brakes and thickets of prickly scrub; and there is more of matted undergrowth and tropical luxuriance to be found in Sagar Island than elsewhere. Few of the forest trees display a handsome bloom, as far as I have noticed at all times of the year except during the rains; the prettiest is a species of *hibiscus* (not a mangrove plant – comment is of writer), which grows freely along the banks of the streams, and bears large yellow flowers which turn to crimson as they droop" (Pragiter, 1889). Thus even Hibiscus plants were considered important than mangroves which lead to wide scale destruction and reclamation of mangrove wetlands in Sundarbans.

In contrast, the reclamation of mangrove/ salt marsh in Bangladesh part of Sundarbans is a recent phenomenon. Densely populated area of southwest Bangladesh, referred to as Sundarban Impact Zone(SIZ) has experienced the embankments along the estuary channels in the late 20^{th} century. The Dutch term 'polder' was used here to describe areas, formerly of intertidal mangrove or salt marsh, that had been reclaimed through construction of embankments (Pethick & Orford, 2013). Altogether 10,000 km^2 of area was reclaimed with 92 polders created within 4022 km of embankment (Islam, 2006). However at the time of reclamation, these areas were mostly not under mangroves but under different types of wetlands, especially the floodplains of the adjoining tidal rivers.

Thus, embankments are crucial for the existence of human settlements in and around of the entire Sundarbans. With sea level rise, the adjoining water levels in rivers and creeks are increasing. The impact of this progressive increase in sea level on the height of the embankments are continuously being invalidated by regular maintenance and increasing the heights of the embankments, by the local people using in situ estuarine clay and silts; an arduous but cost-effective process (Pethick et al, 2014). Breaches in embankments, even temporarily, force change in livelihood pattern from land-based to water-based, which has significant bearing on the health of the ecosystem and that is why embankments have been described as ‘the very basis of human habitation in the Sundarbans’ (Danda, 2007).

The vulnerability in Sundarbans largely stems from the fragile embankments and the vast comparatively low lying areas of human inhabitation behind these embankments. The preceding discussions point to the fact that the land was reclaimed almost from the level of low water lines through construction of these embankments. Had there been no embankments, the sea water loaded with silt and finer sediments would freely flow over the islands on regular basis. A large part of these silts/ finer sediments would then be deposited on the islands, thus raising their levels. Since the embankments have stopped this flow, in the flood dominated estuaries of Sundarbans, these silts and finer sediments are getting deposited within the creeks and estuaries eventually raising the bed levels. With time, the creek beds rose higher than the low-lying reclaimed areas as a result of which even rainwater cannot get out of these islands simply due to invert level, turning those areas into vast stretches of permanent marshes (Mukherjee, 1969). It has already been mentioned that embankments, on the other hand, were erected to save the reclaimed lands turning into marshes once again. “The presence of embankments seals off the possibility of these tracts ever naturally maturing into lands habitable by humans” (Bhattacharyya, 1998; p. 93). This is the basic contradiction in the Sundarbans, an inherent incompatibility between the normal geomorphologic processes and human settlements in the delta (Danda, 2007). This inner contradiction has also increased the vulnerability of Sundarbans to a great extent.

Sea Level Rise and related issues

Sea Level Rise (SLR) and consequent submergence of the low lying Sundarbans is a matter of concern for quite some time. It was predicted long back that some part of Indian Sundarbans has been experiencing a relative sea level rise of 3.14 mm per year and it was projected that 15% of some islands of Indian Sundarbans is going to lose by 2020 due to SLR (Hazra et. al, 2002), which seems not to match exactly with the present scenario at ground level.

There is considerable uncertainty regarding future sea level rise since out of many things, the response of the large ice sheets of Greenland and West Antarctica is quite uncertain. Still, scientists are of the opinions that for an increment in temperature by 4^0 C or more over this century can cause a sea-level rise between 0.5 m and 2 m, although probability of high end rise has been judged to be quite low (Nicholis et al, 2011).

IPCC Fifth Assessment Report has further made a projection of Global Mean Sea Level Rise (GMSLR) by 2100 on the basis of Representative Concentration Pathways (RCPs) [four greenhouse gas concentration (but not emissions)] trajectories adopted by the IPCC for its fifth Assessment Report (AR5). It has been projected that GMSLR may vary from 0.28 – 0.61 m (RCP 2.6) to 0.53 – 0.98 m (RCP 8.5) with medium confidence level (Gregory J., 2013).

However, it has been clearly indicated that 'It is *very likely* that sea level will rise in more than about 95% of the ocean area. It is *very likely* that there will be a significant increase in the occurrence of future sea level extremes' (IPCC Fifth Assessment Report, 2013).

Based on a remote sensing based study over a period of 37 years, from the year 1973 to 2010, it has been calculated that the Sundarbans has undergone a net loss of 170 km^2 of mangrove area due to erosion as a consequence of sea level rise (Rahman et al, 2011, Ward et al, 2016). A similar study over 20-years period from 1989 to 2009 points to on an average net erosion of 20 m/year along the Bangladesh part of Sundarbans with 'little evidence that local devastation of the mangrove fringe by Cyclone Sidr in November 2007 had resulted in uncharacteristic long-term rates of retreat where it made landfall' (Sarwar & Woodroffe, 2013).Thus, such erosion has been attributed to Sea Level Rise only rather than any specific short-term event.

SLR in Indian part of Sundarbans has been estimated to be 8 to 12 mm/year based on tide gauge data along Hooghly Rivers (Hazra, 2010, Danda, 2011). The figures of SLR as reported by different authors for Bangladesh part of Sundarbans are generally points to a figure of 3 mm per year to 6 mm per year (CEGIS, 2006; Bhuiyan and Dutta, 2012). Maximum relative SLR rate of 3.65 mm/year has been estimated in Bay of Bengal during over the last 9,000 years (Mitra 2003). SLR was estimated to be 4.0 and 6.0 mm/year at Hiron Point and Char Changa (Hatiya), respectively based on the analysis of recorded data over the years from 1977 to 1998 (SMRC 2000a). However, considerable departure from this figure has been observed in Khulna in Bangladesh Sundarbans wherein a rise in 17.2 mm per annum has been reported, although it has been reported that high water levels in the polder zone have been increasing at an average rate of 15.9 mm per annum (Pethick & Orford, 2013), which is really alarming.

Thus, the present studies in Sundarbans points to a considerable rate of SLR, in contrast to other parts of the subcontinent which has also been attributed by several authors due to land subsidence along Sundarbans.

<u>Land subsidence along Sundabans vis-à-vis increment in RSLR</u>

Subsidence along the southern part of undivided Bengal including Sundarbans have been noted long back, although has not been explained properly.

While describing Sundarbans, it was pointed out that "the most remarkable fact connected with the geological formation is that there are reasons for believing that there has been subsidence of the country. This is apparent from the discoveries made 50 years ago by Colnel Gastrell, who wrote 'What maximum height the Sundarbans may have ever formerly attained above the mean tide level is utterly unknown; that they ever were much higher than at present is, I think, more than doubtful. But that a general subsidence has operated over the whole extent of the Sundarbans, if not the entire delta, is, I think, quite clear from the result of examination of cuttings or sections made in various parts, where tanks were being excavated. At Khulna, about 12 miles north of the nearest Sundarbans lot, at a depth of eighteen feet below the present surface of the ground, and parallel to it, the remains of an old forest were found, consisting entirely of *sundri* trees of various sizes, with their roots and lower portions of the trunks exactly as they must have existed in former days, when all was fresh and green above them; whilst alongside them lay the upper portions of the trunks, broken off and embedded in a thick stratum of old half-decomposed vegetable mould, nineteen inches in depth, from which, when first exposed, leaves, grasses and ferns could readily be separated and detached. Below this were other thinner strata of clays and vegetable mould corresponding to the Calcutta peat, whilst above was a stratum of argillaceous sand passing into stiff blue clay containing numerous shells. One of the trees was found projecting far into the upper stratum of blue clay. Many of the trees were quite decomposed, whilst in others the woody fibre was nearly perfect" (L. S. S. O'Malley, 1914).

The rate of increase in Effective Sea Level Rise (ESLR) is due to a combination of deltaic subsidence, including sediment compaction, and an enhanced eustatic sea level rise in Sundarbans compared to other coastline has also been predicted (Pethick & Orford, 2013).

Based on primarily the changes in the river courses of the Ganges and Brahmaputra rivers in the recent geological period, 'presence of a subsiding structural trough' and consequent neo-tectonic movement along Ganges – Brahmaputra Plain in their lower reaches was reported long back (Morgan & McIntire, 1959). Unfortunately, specific study directed towards estimating the rate of subsidence has not yet been carried out and as such the predicted estimates vary widely from 2 to 18 mm/year (Goodbred and Kuelhl, 2000; Syvitski et al., 2009; Hanebuth et al., 2013). Such subsidence has also been confirmed based on seismological data of the earthquakes that took place in Bengal Basin during 1918 to 1989 (Khan & Chouhan, 1996).

It has been pointed out that eustatic sea level rise due to climate change and global warming in any particular area of the world must take into account the local factors also, especially the subsidence of the ground, since the ESLR is also dependent on such effects. Thus, proper estimation of the land subsidence in Sundabans needs to be considered as an essential step for predicting future SLR of the area and consequent assessment of vulnerability and formulation of adaptation planning (Pethick & Orford, 2013).

Thus, the land subsidence as a whole in Sundabans is a force agent for increasing vulnerability of the region and thereby needs to be quantified and estimated properly.

<u>Cyclones and Storm Surges</u>

Cyclones, which hit Sundarbans and for that matter the coasts of India and Bangladesh are technically called Tropical Cyclones. These storms belong to a storm system with a closed circulation around specific centres of low pressure, which are created by the release of heat when moist air rises towards the upper atmosphere and get condensed. The origin of these cyclones are in the tropics and has an anticlockwise circulation in the northern Hemisphere (Anonymous, 2006). These cyclones can produce high speed winds, torrential rains and drive up the ocean and sea water against the coasts resulting in storm surges. Thus, the vulnerability due to storm surges in the coastal areas is totally dependent on the tropical cyclones.

The vulnerability out of cyclones in a populated area like Sundarbans may be catastrophic. Based on contemporary literature and records, it has recently been pointed out that although historically earthquake in 1737 in the then Calcutta was thought to be responsible for loss of 3,00,000 lives, but actually a cyclonic storm in the night of 11th October, 1737 which occurred on the same night of the earthquake, had caused a huge wave to rush up the River Hooghly (reportedly 40 feet high) and destroyed many fishing boats and ships causing such loss of life and property (Bilham, 1994). It is really a relief that this kind of cyclonic devastation has not been experienced by Kolkata since then, but it may be presumed that such an event could have been one of an extreme kind in which the cyclone track had been coincident with the path of the River Hooghly. This might explain the huge upsurge of a wave and devastation of houses by winds. It is possible that the waves penetrated 60 leagues (nearly 300 kms) inland from the mouth of the bay beyond even Bandel where some ships were also destroyed due to such cyclone.

Historical data also points to some other cyclones also. As for example, the fatality of a severe tropical cyclone in 1864 in Southern part of the then Unified Bengal was about 60,000 people, which has been considered as one of the India's deadliest disasters in the known history (Anonymous, 2011). The wind speed of the cyclonic event in October 1942, as recorded in Sagar Island, has been recorded to be as high as nearly 165 km per hour. A similar severe cyclone in November 1970 had devastated the coast of Bangladesh (The then East Pakistan) and the causality was tremendous – reportedly 5,00,000 dead and 1,00,000 missing which made this one of the worst natural disaster of the modern times (Anonymous, 2006). The Calcutta Cyclone of 1737 and the "Bhola Cyclone" of 1970 figure in the ten number of World's Deadliest Disasters (Anonymous, 2011). Further, Bangladesh cyclone of 1991 which caused a total death of estimated 1,39,000 people has been included in the list of ten deadliest disasters of the last century (Center for Research on Epidemiology of Disasters (CRED) EM-DAT, Belgium).

Thus, cyclones along with simultaneous storm surge can play a very devastating condition along Sundarbans. The most devastating effects of a tropical cyclone occur when it crosses the coastline. India Meteorological Department (website: http://www.imdmumbai.gov.in/cycdisasters.htm), described that there are three elements associated with a cyclone, which cause destruction. These are:

- Cyclones are associated with high-pressure gradients and consequent strong winds. These, in turn, generate storm surges. A storm surge is an abnormal rise of sea level near the coast caused by a severe tropical cyclone; as a result, sea water inundates low lying areas of coastal regions drowning human beings and livestock, eroding beaches and embankments, destroying vegetation and reducing soil fertility.

- Very strong winds may damage installations, dwellings, communication systems, trees, etc. resulting in loss of life and property.
- Heavy and prolonged rains due to cyclones may cause river floods and submergence of low lying areas by rain causing loss of life and property. Floods and coastal inundation due to storm surges pollute drinking water sources.

All these three factors mentioned above occur simultaneously creating tremendous devastations. In the backdrop of climate change and sea level rise, such events are likely to increase in the near future as explained in the following table:

Table – 1.3 : Events of Disasters globally between 1900 - 2009

Disaster Types	Decades											
	1900-09	1910 – 19	1920 – 29	1930 – 39	1940 – 49	1950 – 59	1960 – 69	1970 – 79	1980 – 89	1990 – 99	2000 – 09	Total
Hydro meteorological	28	72	56	72	120	232	463	776	1498	2034	3529	8880 77%
Geological	40	28	33	37	52	60	88	124	232	325	354	1373 11.9%
Biological	5	7	10	3	4	2	37	64	170	361	612	1275 11.1%
Total	73	107	99	112	176	294	388	964	1900	2720	4495	11528

(Source : Centre for Research on Epidemiology of Disasters (CRED) as mentioned in the Report on Disaster Management in India, Government of India published in the year 2011)

From, the above table, it may be noticed that disasters are on increase. Number of disasters events which was 73 in 1900-09 has increased to 4494 during 2000-2009. The rise in disastrous events in between the decade of 1990-99 and the period of 2000-09 has been more than 73%, which is a phenomenal increment in number of disasters. It may be noted that the Hydro-meteorological events corresponds to more than 77% of the disasters and thereby is the main concern for vulnerability particularly in any coastal zone.

It has been estimated that for a storm surge under 2 °C Sea Surface Temperature (SST) rise and 0.3 m SLR, flood risk area would be 15.3% greater than the present risk area and depth of flooding would increase by as much as 22.7% within 20 km from the coastline in Bangladesh (Karim et al, 2008).

Thus, any systematic planning for vulnerability reduction for saving the life and property of the population of Sundarbans as also safeguarding the natural resources to the extent possible depends on advance predictions and dissemination of the news of ensuing disasters before hand and with sufficient time in hand. That is why a robust hydro-meteorological service for seamless real time forecasting is required for Sundarbans.

Present Scenario of Hydro-Meteorological Set Up in Sundarbans

Section A : Indian Sundarbans

Meteorological Observation & Dissemination in Indian Sundarbans by IMD

Indian Meteorological Department (IMD) is the authorised agency to make forecast regarding weather on different time range as also spatial range in India. IMD is having the mandate to measure different weather parameters through surface observatories being installed and maintained in different parts of India. IMD functions under the administrative control of Ministry of Earth Sciences (MoES), Government of India. IMD Headquarter is located in Mousam Bhawan in New Delhi.

Brief History of Meteorological Services in India

Meteorological observations and discussions in India have a long history. It started in the pre-historic period. Early philosophical writings of the 3000 B.C. era, such as the Upanishads, contain serious discussion about the processes of cloud formation and rain and seasonal cycles caused by the movement of earth round the sun. Varahamihira's classical work, the *Brihatsamhita*, written around 500 A.D., provides a clear evidence that a deep knowledge of atmospheric processes existed even in those times. It was understood that rains come from the Sun (*Adityat Jayate Vrishti* – in Sanskrit Language) and that good rainfall in the rainy season was the key to bountiful agriculture and food for the people. Kautilya's Arthashastra contains records of scientific measurements of rainfall and its application to the country's revenue and relief work. Kalidasa in his epic, 'Meghdoot', written around the seventh century, even mentions the date of onset of the monsoon over central India and traces the path of the monsoon clouds. (Source : IMD Website)

Modern Meteorology started in its present form from the 17th Century sometimes before the Industrial Revolution in Europe with the invention of barometer by Toricelli in 1643. Subsequently, Daniel Gabriel Fahrenheit invented the **alcohol** thermometer in 1709, and the mercury thermometer in 1714. During this period, different gas laws (like Boyle's Law, Charles's Law, Gay-Lussac's Law, Avogadro's Law etc.) governing the behaviour of atmospheric gasses were invented which helped for a strong foundation of Modern Meteorology.

It was in 1636 that Halley, a British Scientist, published his treatise on the India summer monsoon, which he attributed to a seasonal reversal of winds due to the differential heating of the Asian land mass and the Indian Ocean.

Some of the world's oldest meteorological observation stations are located in India. One of them, the Kolkata Centre was established in 1785 which is still catering the need of forecasting of weather in India. The Asiatic Society of Bengal (founded in 1784) at Kolkata also promoted scientific studies in Meteorology. In fact the term "Cyclone" (meaning the coil of a snake) was first coined by Captain Harry Piddington in his different papers dealing with tropical storms, which were published in the Journal of Asiatic Society.

A disastrous tropical cyclone struck Calcutta in 1864 and this was followed by failures of the monsoon rains in 1866 and 1871. In the year 1875, the Government of India established the India Meteorological Department, bringing all meteorological work in the country under a central authority in Calcutta (now Kolkata). Thereafter, the headquarter was shifted to Shimla, then Pune and now finally to New Delhi.

Organisation Structure in IMD

The Director General of Meteorology is the Head of the India Meteorological Department, with headquarters at New Delhi. There are 4 Additional Director General at New Delhi and 1 at Pune. There are 20 Deputy Directors General of whom 10 are at New Delhi.

For the convenience of administrative and technical control, there are 6 Regional Meteorological Centres (RMC), each under a Deputy Director General at Mumbai, Chennai, New Delhi, Kolkata, Nagpur and Guwahati. Under the administrative control of Deputy Director General, there are different types of operational units such as Meteorological Centres at State Capitals, Forecasting Offices, Agro-meteorological Advisory Service Centres, Flood Meteorological Offices, Area Cyclone Warning Centres and Cyclone Warning Centres.

Sundarbans in India is under the administrative and technical control of Kolkata RMC.

In addition, there are separate Divisions to deal with specialised subjects. These are:

- Agricultural Meteorology
- Civil Aviation
- Climatology
- Hydrometeorology
- Instrumentation
- Meteorological Telecommunication
- Regional Specialised Meteorological Centre
- Positional Astronomy
- Satellite Meteorology
- Seismology
- Training

Out of these eleven divisions, four divisions namely Agricultural Meteorology, Climatology, Hydrometeorology and Satellite Meteorology are of special importance to Sundarbans.

Surface Observatories around Sundarbans in India under IMD

IMD has the mandate to make measurements of different weather parameters through Surface Observatories. These weather parameters are being fed into different computer models for making weather forecasting for different meteorological subdivisions in India. However, all these measurements are supplemented by satellite observations as also ocean-based observations. INCOIS (Indian National Centre for Ocean Information Services), another autonomous organisation under the administrative control of MoES, Government of India has been mandated to carry out all infrastructures for ocean-based observations and to carry out all these measurements for weather forecasting.

There are altogether 32 number of Surface Observatories (Departmental) under RIMC, Kolkata out of which 6 (six) are around Sundarbans, as follows:

Table – 1.4 : Details of Surface Observatories (Departmental) around Indian Sundarban

Sl. No.	Station	Station Index	District	Lat	Long	MSL Height (M)
1.	Digha	42901	Purba Medinipur	21^0 50’	87^0 47’	6
2.	Haldia	42806	Purba Medinipur	22^0 4’	88^0 4’	NA
3.	Kolkata (Dum Dum)	42809	N-24 Pgs	22^0 39’	88^0 27’	6
4.	Canning	42812	S-24 Pgs	22^0 15’	88^0 40’	4
5.	Diamond Harbour	42811	S-24 Pgs	22^0 11’	88^0 12’	7
6.	Kolkata (Alipore)	42807	S-24 Pgs	22^0 32’	88^0 20’	6

Source : Website of IMD, Surface Instrumentation Division, Pune; http://imdpune.gov.in/surface_instruments/

Figure 1.1 : IMD Surface Observation Stations around Indian Sundarbans

The surface observatories normally measure different weather parameters on real-time basis at specific intervals of the day. Most of these stations are round the clock i.e. measuring data for 24 hours at 3-hours interval like those at Diamond Harbour, Haldia, Kolkata (Alipore), Kolkata (Dum Dum) and Digha. However the Surface Observatory of Canning, located within Central Rice Research Institute works from Dawn to Dusk (0 to 12 GMT) and records data at three hours interval.

In all these surface observation instruments, weather parameters, which are measured on a synoptic basis are: Temperature, Rainfall, Humidity, Wind Pressure, Wind speed and Direction at the height of 10 feet. Unfortunately, Digital High Speed Wind Recorders, which is essential for measuring the speed of wind during any cyclone in the coastal area, are not there in most of these IMD stations. Such an instrument is available only at Haldia and Digha. Such instruments are required for recording and verification of the forecasts, made through different models.

Table – 1.5 : Network of High Wind Speed Recorder (HWSR) around Indian Sundarbans

Station	Stn. Index	District	Wind Vane (Potentiometric)	GPRS Module	Anemometer (Optical)	Sensor Wind (Ultra sonic)	Data Logger	SMPS	Display (Slave)	Display (Round)

Haldia	42806	Purba Medinipur	–	✓	–	–	✓	–	–	–
Digha	42901	Purba Medinipur	–	✓	–	✓	✓	✓	–	✓
Sagar Island	42903	S-24 Pgs	–	✓	–	–	–	–	–	–

Surface Observatories (Non-Departmental)

There are altogether 40 number of Surface Observatories (Non-Departmental) under RIMC, Kolkata out of which 4 (Four) are around Sundarbans, although only one i.e. Basirhat can be termed as within the immediate vicinity, as follows:

Table – 1.6 : Details of Surface Observatories (Non-Departmental) around Indian Sundarban

Sl. No.	Station	Station Index	District	Lat	Long	MSL Height (M)
1.	Contai	42900	Purba Medinipur	21^{0} 47’	87^{0} 45’	11
2.	Uluberia	42805	Howrah	22^{0} 30’	87^{0} 57’	
3.	Basirhat	42810	N-24 Pgs	22^{0} 39’	88^{0} 52’	
4.	Midnapore	42803	Paschim Medinipur	22^{0} 25’	87^{0} 19’	45

Source : Website of IMD, Surface Instrumentation Division, Pune; (http://imdpune.gov.in/surface_instruments/)

Figure 1.2 : IMD Non-Departmental Surface Observation Stations around Indian Sundarbans

In case of Surface Observatories, which are non-departmental in nature, all the instruments etc. have been provided by IMD, but the readings are taken by personnel, who are not attached with the IMD on a full time basis and are not staffs of IMD *per se*. The readings are taken normally twice in a day and in some cases once in a day and the same are communicated to RIMC over phone or by Whats App messages which are then fed into the model on regular basis.

Table – 1.7 : Automatic Weather Stations (AWS) around Indian Sundarbans

Sl. No.	Station	Call sign	District	Lat	Long	MSL Height (M)
1.	Baruipur_Agro	BUI	S-24 Pgs	22.36^0	88.43^0	1
2.	Canning	CAN	S-24 Pgs	22.26^0	88.67^0	1
3.	Kakdwip	KKD	S-24 Pgs	21.87^0	88.18^0	1
4.	Nimpith	NTH	S-24 Pgs	22.17^0	88.45^0	1
5.	Raidighi	RDH	S-24 Pgs	21.50^0	88.35^0	1
6.	Sagar Island	SGL	S-24 Pgs	21.75^0	88.05^0	1
7.	Basirhat	BSH	N-24 Pgs	22.66^0	88.87^0	-
8.	Khejuri	KJR	Purba Medinipur	21.87^0	87.95^0	1
9.	Tamluk	TLK	Purba Medinipur	22.27^0	87.92^0	

10.	Uluberia	ULB	Howrah	22.47^0	88.09^0	
11.	Kalyani_Agro	KAL	Nadia	22.97^0	88.48^0	
12.	Chinsurah_Agro	CSR	Hooghly	22.90^0	88.37^0	

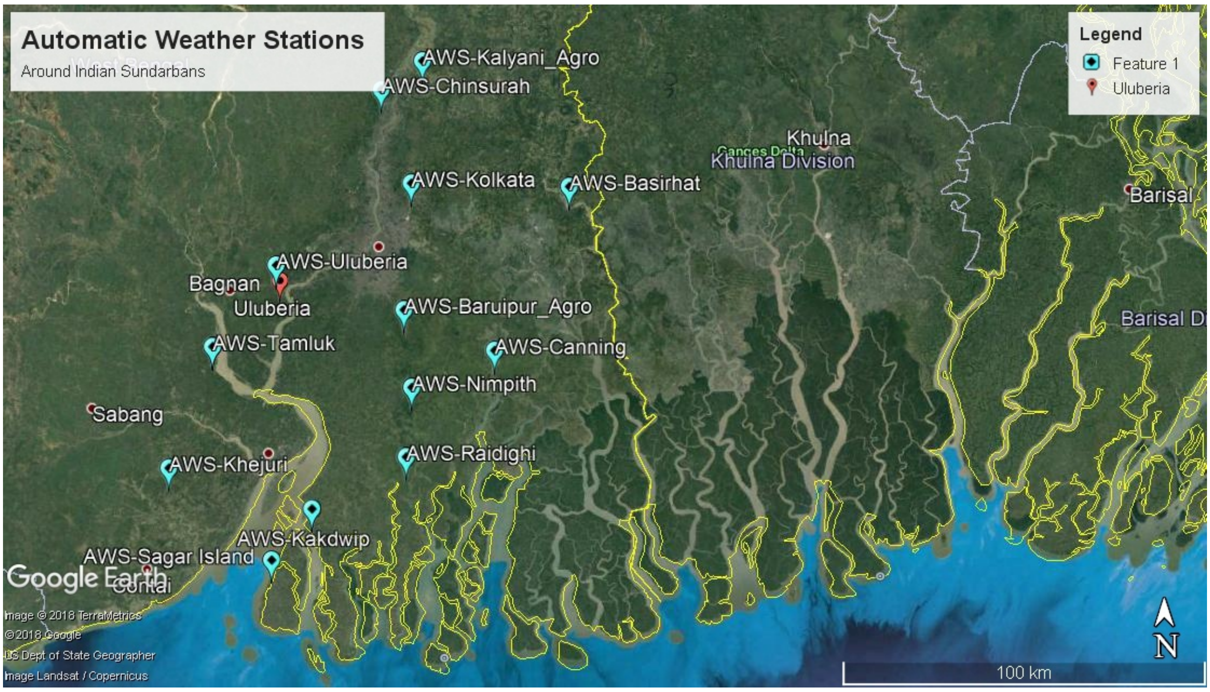


Figure 1.3 : Locations of the AWS in and around Indian Sundarbans

The AWS record all the parameters, as being recorded by the surface recorders, but with data loggers, the values are getting automatically recorded by the instruments. The major problems with these AWS instruments are repair and maintenance. Most of these instruments do not work throughout the year due to breakdown problem. Once, there is some problem, it is difficult to get repaired by sending technicians. As for example, the AWS at Sagar Island cannot be easily repaired due to accessibility problem.

The mode of communication of data as recorded in different AWS is mostly satellite communication. However, in some few cases both the communication modes namely satellite and GPRS are being used. In a few cases even dual sim communication of two different companies are also being used. But, real time communication of data to the head quarter is a challenge and not being possible for all the stations.

Automatic Rain Gauge (ARG) around Sundarban Area

There are altogether four Automatic Rain Gauge (ARG) Stations around Sundarban area, as stated below:

Table – 1.8 : Details of Rain Gauge Stations around Indian Sundarbans

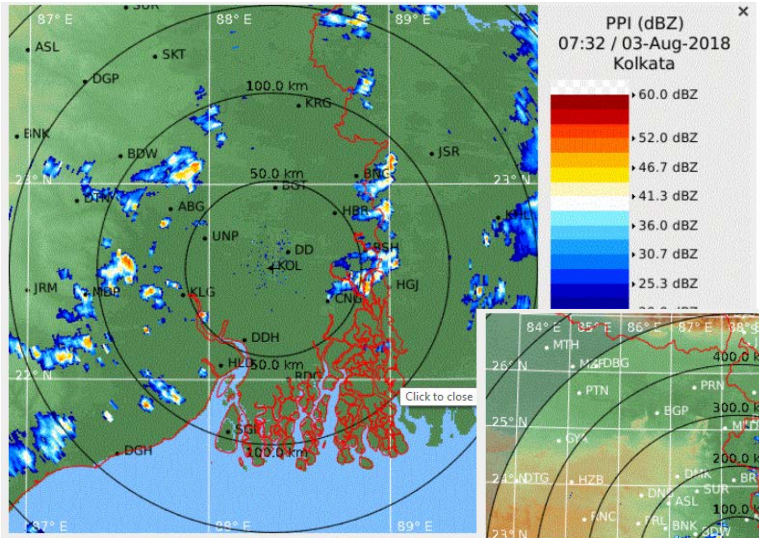
Serial No.	Name of Station	Name of District	Latitude	Longitude
1.	Kolkata (Alipore)	South 24-Pgs	22.54^0	88.33^0
2.	Deganga	North 24-Pgs	22.69^0	88.68^0
3.	Barrackpore	North 24-Pgs	22.76^0	88.36^0
4.	Jagatballavpur	Howrah	22.67^0	88.12^0
5.	Chakdah	Nadia	23.05^0	88.54^0
6.	Dhaniakhali	Nadia	22.96^0	88.09^0

Figure 1.4 : Locations of the ARG in and around Indian Sundarbans

The Automatic Rain Gauge (ARG) stations are similar to AWS and can be transformed to AWS at any point of time, provided additional sensors are added to it. The observations made at ARGs are communicated through satellite communication on daily basis.

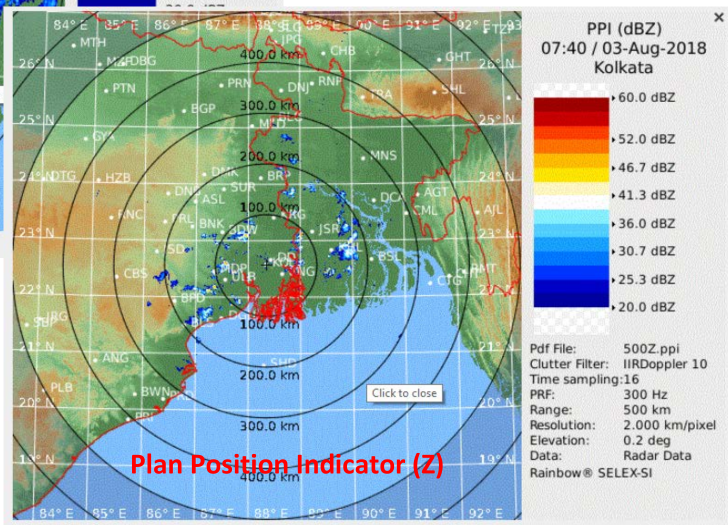
Doppler Weather Radar around Sundarban Area

Doppler Weather Radar (DWR) is an observational tool for monitoring and predicting severe weather events such as hailstorms, thunder storms, cyclones and tornadoes. It uses the Doppler effect by bouncing a microwave signal off a desired target to produce velocity data.



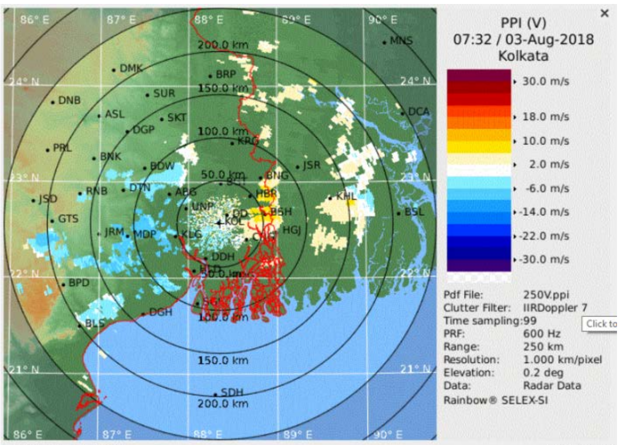
Plan Position Indicator (Z) - Close Range

This helps in analyzing objects motion by altered frequency of the returned signal. It mainly gives information about wind velocity and also about precipitation.



Plan Position Indicator (Z) press x to close

DWR can provide area specific rain and storm warnings which are important for disaster management and emergency response, aviation and related services. It can be used for wind speed measurements during cyclones and thunderstorms which are not possible in conventional weather radars. Thus, it helps in providing improved warning and better weather forecast.



Plan Position Indicator (V) press x to close

The S-band Doppler Weather Radar which is operating at Dum Dum (Latitude : 22.65^0, Longitude : 88.45^0) is having a range of 500 kilometres. So, it covers the entire Sundarbans of both India and Bangladesh, as claimed by concerned officials of IMD, Kolkata Office.

The above figures, as collected from IMD website on 3rd August, 2018 (http://www.imd.gov.in/pages/radar_main.php?adta=kol) clearly indicated that the Sundarbans as a unit has been covered even in the close range of the DWR. The Plan Position Indicator (Z) covers a large portion of Bay of Bengal and the entire part at the South of entire Bangladesh.

Forecasting

Time Scale

IMD generally make weather forecast for different time scale as stated below:

1) Nowcasting : Immediately for next 2 – 3 hours
2) Short Range – Normally for 24 hours to 72 hours
3) Medium Range : For 5-days
4) Extended Range : 4-weeks of a month at a time
5) Seasonal or Long Range : Normally for the entire monsoon season
6) Seasonal Outlook : This is not forecast, but a general indication regarding the season

All these forecasts are having different kinds of use in different fields and thereby having varied importance.

Spatial Scale

For the Forecasting purpose, IMD has subdivided the Indian sub-continent into 35 Meteorological subdivisions. Entire Gangetic West Bengal including Sundarbans is a subdivision. The forecasts are being made based on the entire subdivision on a regional scale. The time range is medium range for five days at a time, i.e. for a particular day and also for coming four days, altogether for five days. This forecast, being made on a Regional Scale, includes the entire Sundarbans. However, short range forecasts are also normally being made on regular basis for a particular day.

Then next level forecast is at “District Level”, which is normally the lowest unit. Here also, the forecasts are being made for a particular day and also for coming four days, altogether for five days. However, the forecasts for later days like day-4 or Day-5 gets changed with more and more information and inputs in the model with time. Indian part of Sundarbans extends over two districts of West Bengal, namely South 24-Parganas and North 24-Parganas. Thus, weather forecasts for these two districts are applicable for Sundarbans. Similarly, short range forecasts on regular basis for a particular day are also being made.

There is another forecast which is meant mostly for the large cities. This kind of forecast is made for a particular day and for next six days i.e. altogether for seven days. Incidentally, along with other parameters, the forecast also includes probable minimum temperature and maximum temperature. In case of West Bengal, forecasts are being made for 9 cities. Out of these, only Kolkata is near to Sundarbans, but that too at a quite long areal distance of more than 30 kilometres for the areas like Canning (nearest point of Sundarbans from Kolkata City). Forecast for Kolkata City has hardly any bearing on the weather of Sundarban.

There is another kind of forecast which is known as “Nowcasting”. This kind of forecast is being made based on Satellite / Radar input and is applicable for immediate two-three hours. Normally, Thunder squalls, high speed storms etc. are being forecasted through nowcasting. The Doppler Weather Radar at Alipore, which is having a range of 500 kilometres, is being utilised for making “Nowcasting”. This has been found to be extremely useful for different islands of Sundarbans especially during the period of Nor’westers.

Hydro-meteorological Services in IMD

IMD renders assistance and advice on the meteorological aspects of hydrology, water management and multipurpose river valley projects management. These services are utilised by the Central Water Commission, Ministry of Agriculture, Ministry of Water Resources, Railways, Damodar Valley Corporation Flood Control Authorities and the State Governments. Hydromet Division of IMD caters the information on various rainfall products through its 'Customised Rainfall Information System (CRIS)', in form of reports and maps on the CRIS portal.

Flood Meteorological Unit

Flood Meteorological Offices (FMO) have been set up by IMD at ten locations viz., Agra, Ahmedabad, Asansol, Bhubaneswar, Guwahati, Hyderabad, Jalpaiguri, Lucknow, New Delhi and Patna. During the flood season, FMOs provide valuable meteorological support to the Central Water Commission for issuing flood warnings in respect of Ajay, Mayurakshi and Kangsabati in Asansol (*For West Bengal & Odisha surrounding Sundarbans only).* However, there is no specific station for Sundarban area, although it is situated in the lower reaches of the rivers like Hooghly River.

Mode of Communication to Community

For public dissemination of weather forecasts and informing the policy makers as well as community regarding any warning, a number of communication channels are being used by IMD, as follows:

1. Website Communication: Daily weather forecasts and all weather related warnings for the Gangetic West Bengal (which includes Sundarbans and adjoining areas) are being published in the website of the RMC, Kolkata (http://www.imdkolkata.gov.in/) on regular basis. These information and bulletins are being utilised mostly by policy makers and Disaster Managers to get prepared for any ensuing weather problems. Since, these are in public domain and known to the interested quarters like media, forecasts published through media immediately get attention of media, web portals and newspaper house also.

2. All India Radio: All forecasts and warnings are routinely supplied to All India Radio, Kolkata Centre who in turn broadcast "Weather Bulletin" at fixed times of the day along with normal news bulletins. In case of any warning, AIR normally broadcast such warning message in between the standard news bulletin period also for communication to the general people. Radio bulletins are found to be extremely useful to the islanders of Sundarbans who are still depending on the radio for their source of entertainment as also news from outer world. Radio bulletins are perhaps the only source of communications to the fishermen who use to go to outer sea with country boat for fishing purpose.

3. Doordarshan: The Television Channels under Prasar Bharati are supplied with all weather forecasting on regular intervals by IMD so that the same can be broadcasted to the community during the scheduled news bulletins. In case of any warning situation, Doordarshan uses to make warning message as "Flash News" to communicate the same to the community. The private Television channels also regularly disseminate the information on weather in the weather bulletin section of their regular news bulletins. In case of any specific warning, they even make public announcements through scrolling of news at the bottom of the screen.

4. State Control Room at 'Nabanna' at Kolkata : RMC, Kolkata use to supply all weather related information and warnings to the State Control Room at Nabanna, Kolkata so that the highest level policy makers and State Administration can get all the information and get prepared for any situation.

5. Police Wireless System : All weather forecasting especially any kind of warnings are immediately communicated to the Police Head Quarters for dissemination to different police stations who are responsible to carry it forward to the general people. In many cases, depending on the emergency, police stations start announcements through microphones in public places also.

6. E-mail: A number of e-mail groups are being maintained by IMD, Kolkata centre. These e-mail groups have the e-mail addresses of District level officers, Sub-divisional Level Officers, Block Level Officers, some media groups, newspaper houses etc. Normally, e-mails are sent to the managers and executives of Government Agencies and institutions, but not public at large.

7. WhatsAPP Group: Now-a-days, with the introduction of Smart Phones, a number of WhatsAPP Groups have now been created by RMC, Kolkata. Any warning or important weather message is being passed over through WhatsAPP message. There are numbers of key persons of many such different groups like Directorate of Fisheries, different Fisheries Associations at different places. The idea is that these responsible persons will disseminate the message at the ground level. However, this kind of WhatsAPP messages are sent normally only in case of Nowcasting.

8. Specific WhatsAPP Groups: Other than those, which are mentioned above, there are separate WhatsAPP groups specifically for important officials of different Electricity Companies, Coast Guards, Indian Railways etc so that any warning, whatsoever, can be communicated on real time basis to different stakeholders.

9. Media Briefing: Everyday at 3-30 p.m., a scheduled media briefing is held at RMC, Kolkata Centre at Alipore where the forecasts and warning, if any, are informed to the media (both electronic as also print) for circulation amongst the people.

10. Social Media: All information regarding weather forecast, as also warnings are informed through the Facebook Page of RMC, Kolkata. These weather bulletins and information also includes those for Indian Sundarban.

Other than this, warnings to the fishermen are also informed through radio and whatsAPP group four times a day regarding latest satellite observation and requested (1) either not to venture in sea for fishing, or (2) return back near to mainland near the shore or coast and (3) sometimes to drift to other areas outside the impact zone of any disaster like situation.

Meteorological Observation from Sea Side along West Bengal Coast

Although numbers of Surface Meteorological stations are there in and around Indian Sundarbans, as has already been discussed, there is only a single sea based station being available along the entire West Bengal Coast for measurement of weather parameters as well as physical marine parameters. The role of meteorological observations from sea side is well known for proper forecasting of the weather. Unfortunately, this particular aspect has not received the desired attention so far.

This station has been set up by INCOIS in partnership with the scientists of Basanti Devi College, Kolkata. A wave rider buoy being placed in the Bay of Bengal off the Digha Coast and anchored firmly to the sea bed serves as this station. Augmentations of different sensors have been made on this wave rider buoy. The Station is located at 21.29 N Latitude and 87.65 E Longitude. It is part of Ocean Observation Network (OON) of INCOIS.

This station has been equipped with a number of sensors for measurements of significant wave height, wave direction and Sea Surface Temperature. In case of cyclonic weather, it can record the cyclone influenced wave heights also. The records are directly transferred through satellite communication to INCOIS with a HF link to a source station located at Old Digha, on premises arranged by the Digha Sankarpur Development Authority (DSDA). There is a limitation of distance that can be covered by the HF antenna, so this Shore Station has been set up at Old Digha to receive the HF data. The data from the Buoy is transmitted to INCOIS in real time by satellite and HF. This station was installed keeping in mind the entire West Bengal coast and thus it covers the portion of sea adjoining Indian Sundarbans also.

Along with the other instruments, an AWS has also been installed in this Shore Station during 2017 to measure different weather parameters to complement the Wave Rider Buoy data. This AWS has been specifically manufactured by National Institute of Oceanography (NIO), Goa and the measured data are directly sent to NIO for storage. NIO transfers the data regularly after an interval of about three months to INCOIS, Hyderabad. These data are so far, thus used for validation of the INCOIS Ocean State Forecast model. However, the range of AWS is quite small and thus the weather parameters of Sundarbans cannot be measured through this AWS.

The observation of different parameters for the West Bengal coast started from 21st January, 2016 and is still continuing with funding from INCOIS. The setting up of this station was carried out through a specific project, the maintenance of the station is still being looked after using the fund of the said project, which is getting renewal on regular basis.

Present set up for Hydrodynamic Study in Indian Sundarbans

At present there is no set up for carrying out hydrodynamic study in Indian Sundarbans. The basic reason behind this is manifold. As has already been discussed, a number of authorities and line departments are active in Sundarbans. But, none of these departments have the basic mandate to carry out these kinds of studies. Interestingly, even the departments like Irrigation and Waterways, Environment under State Government and Ministry of Environment, Forests and Climate Change, Government of India have never considered these studies to be important for the sustenance of Sundarbans and survival here. The primary reason being the fact the creeks and channels of Sundarban are not navigational channels for ships and commercial cargos. Local people, fishermen etc. are using these channels for different livelihood purposes like fishing, honey collection etc and also for commuting.

Further, there are number of restrictions in entering and carrying out any study in Indian Sundarban, since this is a reserve forest and also a World Heritage Site. A portion of this forest, which is more or less pristine in nature, is still almost in a pristine stage. It is difficult to get permission to enter this portion of Indian Sundarban, even for research purposes. The commercial cargos and barges, which earlier used an international channel passing through this portion of Indian Sundarban, are now-a-days not allowed to ply through this part of the forest. The only exception is the Hooghly River in which Sagar and Ghoramara Islands are located; both of them are considered within Sundarbans.

Hooghly River

The Hooghly River is the major navigational channel being used for ship and cargo navigation for both Kolkata and Haldia Ports. The Hooghly River is being looked after and navigational channels are kept alive by Kolkata Port Trust Authority. For this purpose limited hydraulic studies are being carried out by the KPT on regular basis. Haldia Port Trust, being a sister concern, normally depends on KPT for all these purposes.

River Hooghly is extremely important for the supply of freshwater (whatever small amount may be) to the Sundarbans through a small river knows as “Hatania – Doania” River near Namkhana joining River Hooghly with the western branch of Saptamukhi River just above Lothian Island. In fact, Sagar Island belongs to Sagar Block, one of the 19 (nineteen) blocks under Sundarban Biosphere Reserve. Thus, health of Hooghly River is also linked with the Indian part of Sundarbans.

KPT is an autonomous body under the Ministry of Shipping, Government of India. KPT is headed by the Chairman, normally from Indian Administrative Service. There are two departments in KPT, namely Marine Department and Hydraulic Study Department which are associated with hydraulic studies along Hooghly River. Marine Department is headed by the

Director, normally a Mariner, while Hydraulic Study Department is headed by Chief Hydraulic Engineer.

Marine Department is responsible for carrying out various hydrodynamic studies along Hooghly River from Nabadwip downwards upto the beginning of Eastern Channel in the South of Sagar Island. These data are being passed on to Hydraulic Study Department for carrying out different types of analysis using these data. For the stretch of Hooghly from Nabadwip upwards up to Farakka barrage, bathymetry studies are carried out by Hydraulic Study Department.

The condition of the navigational channel of the River Hooghly leading to Kolkata Dock System and Haldia Dock Complex is assessed under the following sections:

(i) For Kolkata Dock System (KDS), governing depths in the shipping channel downstream of Kolkata through the Maragolia area, Silver Tree Crossings and Hooghly Point area bars.

(ii) For Haldia Dock Complex (HDC), governing depths in the shipping channel downstream of Haldia through Auckland – Jelingham – Haldia Channel

Drafts at both KDS and HDC vary with the river bathymetry, in long and short terms. Hooghly River bathymetry is carried out using the standard sonar instruments from Farakka to beginning of Eastern Channel in Bay of Bengal, as already discussed. Bathymetry studies along the River Hooghly depend on the season. In case of Hooghly River, KPT normally follows three seasons, as stated below:

Pre-Freshet : Normally March to May when the inputs from Sea is maximum

Freshet : Normally June to September, when rainwater discharge along River Hooghly is maximum and thereby influence and input from Sea is minimum. This also coincides with 'Flood Season'.

Post-Freshet : Normally this is post-monsoon season, from October to February. This also coincides with the 'Dry Season'

Bathymetry studies along the portion of the river from Kolkata Port to South of Sagar Island are normally being carried out following plan lines. The Marine wing of Kopt normally carries out bathymetry survey from Nabadwip downwards. From Nabadwip to Bansberia and below up to Balagarh, such 'Bank to Bank' survey is being carried out once in a year in Post Freshet with a plan line of 500 meters distances apart.

From Balagarh to Diamond Harbour, such kinds of bathymetry studies are carried out twice in a year, Pre-freshet as well as Post-freshet time. Here also bank to bank surveys are carried out following plan lines of 500 meters distances apart.

From Diamond Harbour downwards to southern tip of Sagar Island, 'Bank to Bank' bathymetry survey is carried out only during Post-freshet period, i.e. 'Dry Season'. Normally, these surveys are restricted to the western part of Hooghly River (locally known as Rangafala Channel) since all the navigational channels are restricted to Rangafala Channel only. The surveys are carried out in small boats with a draft of about one metre to reach the nearest distance to bank. The plan lines are normally 500 metres apart, although in many cases, the plan lines are made more closely spaced, particularly near the submerged bars.

At many places, the perpendicular distance between two banks below Sagar Island is more than 30 kilometres or so. Beyond Sagar Island towards south, bigger survey vessels are generally employed to make bathymetry survey upto beginning of the 'Eastern Channel'. Such surveys are normally made once in a year with the plan lines drawn about 500 meters apart.

A number of navigational channels like, Middleton Channel, Eastern Channel, Auckland Channel, Gasper channel etc. along the Rangafala Channel (western branch of River Hooghly) are being maintained by KPT. Normally, these channels are having widths of 300 to 350 meters. Bathymetries along these channels are regularly being monitored by KPT, normally at the interval of each 15 days. At the beginning of any month, KPT releases the "Draft Forecast" on each day of the month along these channels to help vessel movements. Near the submerged shoals, normally the bathymetry surveys are carried out once in a week and for some of the shoals between Kolkata and Diamond Harbour, which are very critical in nature, bathymetry surveys are carried out on daily basis.

In the navigational channel leading to Kolkata Port en route Rangafalla channel (upstream of Sagar), there are thirteen bars and crossings, while in the shipping channel leading to Haldia Port, there are four estuarine bars. KPT carries out the bathymetry studies over these bars on regular basis and publishes the data. The following table gives the mean navigable depths over these bars during the freshet and dry season periods for the years 2013-2014 and 2014-2015.

Table – 1.9 : <u>Mean Navigable Depths over submerged bars in shipping channels</u>

(In Meters)

Name of the Bars/ Crossings	July, 2013 – October 2013	July 2014 – October 2014	November 2013 – March 2014	November 2014 – March 2015
1	**2**	**3**	**4**	**5**
Kolkata – Haldia Bars				
Panchpara	5.56	6.20	5.94	6.24
Sankrail	6.06	7.20	7.82	7.88
Munikhali	6.10	6.58	6.97	7.12
Pirserang	6.81	6.18	8.31	7.36
Poojali	6.51	5.83	5.61	4.98
Moyapur	3.83	3.63	3.72	3.88
Royapur	4.37	3.70	5.57	4.74
Phalta	2.79	2.80	2.36	3.28

Ninan	3.81	3.50	4.39	3.64
Eastern Gut	4.04	4.20	3.37	3.16
Silver Tree Crossing	4.01	4.18	4.10	4.50
Maragolia Crossing	5.76	5.40	5.28	5.30
Estuarine Bars				
Jellingham	3.64	3.68	3.50	3.78
Auckland	4.10	4.20	4.10	4.32
Middleton	6.82	6.68	7.60	6.60
Gasper	6.80	6.90	6.85	6.90

Thus, bathymetric studies along the Rangafala Channel are being carried out on regular basis, although such studies are restricted to navigational channels only. In general circumstances, other hydrodynamic studies like, current speed, current direction, flow pattern, suspended sediment load, bed sediment load etc. are not being carried out by KPT, unless there is specific requirement from any client for any kind of specific studies.

Eastern branch of Hooghly River (Locally known as Muri Ganga River) around Sagar Island is comparatively shallow in nature and thereby devoid of any navigational channel. So, bathymetric studies along this channel is being carried out once in a year by KPT. However, other hydrodynamic studies like current direction, velocity of current, bed load etc are also carried out by KPT in this channel as per specific requirements of any client only, but such occasions are extremely rare. Normally, each year before the Sagar Mela in the month of January, such studies are carried out by KPT in Muriganga River as per request of Government of West Bengal for the purpose of safe vessel movement.

Tidal Stations along Hooghly River

A number of tidal stations are there along the Hooghly River. As per the records available from Kolkata Port Trust, There are six permanent and major tidal measurement stations along Hooghly River, as follows:

Table – 1.10 : Tide Gauge Stations along Hooghly River

Sl. No.	Name of the Place	Latitude	Longitude	Set up in the year	Type of Tide Gauge
1.	Sagar	21^0 39’ 02.93” N	88^0 02’ 50.82” E	1944	Visual observation & thereby operated only during day time
2.	Gangra	21^0 57’ 02.84” N	88^0 00’ 50.82” E	1960	Visual observation & thereby operated only during day time
3.	Haldia	22^0 02’ 02.82” N	88^0 05’ 50.78” E	1970	Automatic, hence 24-hours observation
4.	Diamond Harbour	22^0 12’ 02.78” N	88^0 09’ 50.73” E	1947	Automatic, hence 24-hours observation

5.	Mayapur	22^0 26' 02.71" N	88^0 07' 50.73" E	1873	Visual observation & thereby operated only during day time
6.	Garden Reach (Kolkata)	22^0 33' 02.68" N	88^0 17' 50.65" E	1932	Automatic, hence 24-hours observation

Kolkata Port Trust publishes a 'Tide Table' at the beginning of each year mentioning probable diurnal High Tides and Low tides at each of these six stations for navigational purposes. But, the predictive tides are worked out based on a local datum called 'Khidirpur Old Dock Sill (KODS)', which is 0.14 meters below the Lowest Low Water ever recorded. The correlation between KODS and Mean Sea Level (MSL), however, has not been discussed analytically in the tide tables. Repeated attempts to get such correlation from KPT, also failed.

The predictions in this tide table are based on Harmonic Analysis of Observations at Sagar for 1974 & 1987 and corrected for Harmonic Shallow Water (H.S.W.) effects at station. Tidal observations are recorded by means of self-registering tide gauges kept in continuous operation at each of the stations except at Sagar, Gangra and Mayapur, where visual observations were carried out. The Harmonic Analysis, H.S.W. Analysis and tidal predictions (including H.S.W. corrections) were all done on PC H.S.W. Constants for each of the stations were obtained from the actual tides of 1975 to 79, 81 84 & 87 for Sagar, 1975 to 79, 81, 83 87 & 90 for Gangra, 1975 to 79, 81,83 89 & 90 for Haldia, 1975 to 79, 81 84-85, 90, 94 & 96 for Diamond Harbour, 1975-79, 81, 84-85, 90, 94 & 96 for Mayapur and 1975 to 77, 79, 81, 86-87, 88, 91 & 94 for Garden Reach (Tide Table for The Hugli River, 2018).

Temporary variations in the wind and barometric conditions as also abnormal droughts or freshets cannot be predicted and hence allowed for these predictions. However, these can exercise significant effect on the level of the water. Thus, the predictive tidal charts, as being provided by KPT for navigation, may be at best termed as indicative only. Further, the actual observations based on which these predictions have been made, are more than twenty years old, while the effects of climate change are more pronounced in the recent time. This is a major lacuna in the tidal data as provided to the mariners and the ships plying through River Hooghly.

It has been indicated in the Tide Table that between Kolkata and Pukuria Point (Near Budge Budge Oil Jetty, Location: Latitude – 22^0 29' 31.09" N; Longitude – 88^0 11' 03.50" E), all surroundings on the River Charts are reduced to the Level of KODS. However, below Pukuria Point, all surroundings are reduced to a datum 0.46 meters below the level of KODS.

In addition to the above-stated six tide gauges, a number of temporary tide gauges are also installed during equinox tides during the months of March and September of each year. In some of the occasions, temporary tide gauges are installed even at every 5 kilometres interval starting from "Hooghly Point" (Latitude – 22^0 12' 59.00" N; Longitude – 88^0 04' 13.58" E) i.e. near Noorpur in the eastern bank and opposite Geonkhali. Temporary tide gauges are installed in several locations like Panchpara, Howrah District (Latitude – 22^0 33' 33.91" N; Longitude – 88^0 16' 04.05" E), Geonkhali, Gadiara, Balari (North of Haldia Dock) etc. In all these places, manual tide gauges are installed for visual observations during day time only for a very limited period just for the sake of validation purpose.

It has also been indicated in the Tide Table, that Tidal Bores sometimes occur in the Hooghly River between Hugli Point and about 50 kilometres up-stream of Kolkata. Generally, bores are expected when the tidal range at Garden Reach is 4 metres and above. Tidal Bores are quite risky for the bathing people within the river at the time of those incidents. There is hardly any institutional mechanisms for announcement of warnings for 'Tidal Bores' either by KPT or by River Police leading to frequent accidents and mishaps.

Discharge Measurements along Hooghly River

For any river, the discharge needs to be measured beyond the estuarine portion, where tidal interplay is going on. In case of Hooghly River, discharge is measured at several points, but discharge measurements at only one point of River Hooghly are available in the public domain through administrative reports of different years, which are detailed below:

Table – 1.11 : Average Monsoon Discharge along Hooghly on Different Years

	2012		**2013**		**2014**		**2015**		**2016**	
	Average	Peak	Average	Peak	Average	Peak	Average	Peak	Average	Peak
At Swarupgunj about 120 km upstream of Kolkata	1583.25 cu mt per second	2151 cu mt per second on 21.08.12	1805.16 cu mt per second	2403 cu mt per second on 05.09.13	1826.58 cu mt per second	2638.48 cu mt per second on 21.08.14	2098.45 cu mt per second	3876.85 cu mt per second on 04.08.15	1717.62 cu mt per second	2755.68 cu mt per second on 22.08.16
	55912 Cusec	75963 cusec on 21.08.12	63749.5 Cusec	84854 cusec on 05.09.13	64505.75 Cusec	93178 cusec on 21.08.14	74106.75 Cusec	136911 cusec on 04.08.15	60657.8 Cusec	97317 cusec on 22.08.16

(Source : Administrative Reports of Kolkata Port Trust on different years)

Hydrodynamic measurements along Channels within Indian Sundarbans

Total lengths of channels and creeks in Indian Sundarbans are about 6,000 kilometres. But, these channels are not used for navigation on commercial basis. Although local people do ply their fishing boats and ferry boats using these waterways, but those are not being accepted by any departments and/or authorities for making investments towards carrying out any hydrodynamic studies along these channels, except for a single route being used as International Waterways following the 'Protocol on Inland Water Transit and Trade' as per the "Trade Agreement" between India and Bangladesh.

There are two such routes, although the Indian Parts of both the routes are same. The first route is (i) Kolkata – Haldia – Namkhana – Via Hatania Duania River – Pathar Protima (Lothian Island) – Choto Banashyamnagar – Satjalia – Atharabanki – Raimongal River (in India) – Chalna – Khulna – Mongla …. Shilghat (Bangladesh). There is another route which is same upto Mongla Port, Bangladesh but terminates at Karimganj in Assam, India. This route was earlier known as Assam Route.

The Indian Part of both the routes is being looked after by Inland Water Authority of India (IWAI). IWAI is supposed to maintain the depth along this channel as per the organisational mandate. As a result, IWAI carries out thalweg surveys along this route regularly in each month as per the specific instruction laid down in their Hydrographical Survey Instruction, 2012 and to take up intervention activities for improvement and maintenance of Least Available Depth (LAD).

The objective of the hydrodynamic surveys in the respective stretches is to ensure that navigable channel (deepest route) is maintained. So, normally the surveys are carried out along the length of the rivers and creeks and no cross-sectional bathymetry studies are carried out. However, only at the shoal locations where sedimentation rate within the river is comparatively higher, sufficient cross-sectional bathymetry studies are carried out so as to ensure corrections of LAD at the locations before issuing River Notices and LAD Report.

Channels are normally closely monitored when the depth reaches 0.5 meter above the targeted LAD. Normal targeted LAD is 2.5 meters. So, a depth of 2 meters during low tide condition is sufficient considering the tidal fluctuation in Sundarbans. The depths are measured with Echo Sounder, but when the depth is less, the depth is measured with calibrated sounding pole.

Based on the analysis of shoals through previous surveys and records, shoals are normally identified while doing thalweg survey. Identifications of shoals are normally made through reconnaissance surveys carried out along the cross-sections of the shallow areas and also in the secondary channels (meaning those channels which are not being used by the ships and barges) in the stretch. Normally, this kind of surveys are carried out once in a month.

After identification of the shoal limits, detailed surveys are conducted at shallow patches covering about 500 meters upper side and down side of the identified shoal. In such situations, plan lines for bathymetry surveys are normally drawn at an interval of 50 meters. However, no dredging work is carried out by IWAI in any channel within Indian Sundarbans, except at Muriganga River at Lot-8 during Sagar Mela. Since, Sundarban is a macro-tidal estuarine region having average tidal fluctuation of more than 4 meters, so the barges and ships depend on high tide condition for sailing when LAD is guaranteed.

Unfortunately, IWAI does not maintain any tide gauge along this route. There is no river training structure also in Sundarbans since it is an ecologically sensitive region. A number of buoys were initially fixed up by IWAI for guiding the ships and barges, but local fishermen use to cut the ropes of the buoys since these buoys create some hindrances in free movements of their nets.

Part B : Bangladesh Sundarban

Bangladesh part of Sundarbans is distributed over three districts, namely Satkhira (Shyamnagar Upazila), Khulna (Koyra and Dacope Upazilas) and Bagerhat (Mongla and Sarankhola Upazila).

<u>Meteorological Set Up around Bangladesh Sundarbans</u>

Bangladesh Meteorological Department (BMD) is the authorised agency for carrying out meteorological observation and weather forecasting in Bangladesh. It is considered as a Scientific & Technological organisation. Target of BMD is to ensure world class service to national and international level as the National Meteorological Organisation.

The weather and meteorological survey in Bangladesh dates back to 1867 when two meteorological observatories were set up in Jessore and Narayanganj in the then undivided colonial India, which subsequently became known as "Meteorological Service".

After the independence of Bangladesh in 1971, 'Meteorological Department' was set up which was subsequently renamed as "Bangladesh Meteorological Department" as a fully fledged department. BMD now acts as the national meteorological organisation and carries out 24 hours weather surveillance, meteorological observation, data collection and storage.

BMD is a member of World Meteorological Organisation (WMO) since August, 1973. As a member of WMO, BMD shares different weather and climate related data and observations with regional as also with global partners in specific period and time. It is also responsible for making daily weather forecasts for the purpose of agriculture and food security, aviation and navigation purposes, for general public, Government of Bangladesh and its different departments etc. It is also mandated to issue warning bulletins on weather conditions, if so required. BMD, as a member of WMO, tries to induct state of art technology and is associated with all regional and global level organisations so as to interact and to make appropriate forecasting on any natural calamity and issue warnings through application of modern science and technology and exchanging different data, information and knowledge with its partner organisations at both regional as well as global level.

At present, there are five weather radar stations at Dhaka, Cox's Bazar, Khepupara, Rangpur and Moulavibazar. Specific computer facilities have been installed and developed at the 'Storm Warning Centre' for receiving the data and image obtained from these Radar stations and thereafter analysing those data for making forecast on the cyclones developed over Bay of Bengal, cyclone trajectory, its location at different time, intensity, probable time of its crossing the land, heavy rainfall, nor'wester, Tornedo and other parameters related to weather forecasts. BMD plays a very important role for making forecasts on floods and flash floods. It is connected with Prime Minister's Office (PMO), Bangladesh Television, International Air Port, Flood Forecast and warning centre etc. by 'Wide Area Network' (WAN).

BMD can exchange within 15 minutes the data and information received from its different observation centres in each three hours interval with different countries of the world through Global Telecommunication Service (GTS) and uses to follow that on regular basis. Simultaneously, BMD is in possession of most modern technology like Klystron based Doppler Radar with composite windows facilities, Satellite Imageries, VSAT Telemetry etc for leading all out weather surveys.

BMD normally uses most modern WRF (Weather Research and Forecasting) Model, NHM (Non-Hydrostatic Model), ECMWF Model product Visualized by Diana (Digital Analysis) and

Tseries etc for making weather forecasting. It has the planning to augment most modern technological "PRECIS" model for making research and survey on Climate Change.

In addition, BMD is maintaining lively connection with 'Regional Tsunami Service Providers' (RTSP) like Indian National Centre for Ocean Information Service (INCOIS), Indonesian Tsunami Early Warning System and Australian Tsunami Warning System and communicate 'Tsunami Advisory' through GTS, Fax, SMS and E-mail to Storm Warning Centre. The information thus received are getting analysed for formulation of Tsunami advisory which then gets published and communicated by BMD.

BMD uses the most modern Storm Surge Model (IIT-D and MRI model) and Wave Model received from WMO for forecasting of storm surges during cyclones. In addition, BMD is implementing a WMO project entitled 'Coastal Inundation Forecasting Demonstration Project for Bangladesh (CIFDB-B), which will now be utilised in phases along the coastal zone of the entire world.

Basic Responsibilities of BMD

- To carry out weather related observations and collect information at Terrestrial surface and in different layers of upper atmosphere throughout day and night
- To exchange weather related information at national and international level
- To make all kinds of daily weather forecasting and warnings for cyclones, storm surge, heavy rain, Tornedo, Nor'wester after analysing different Bangladesh as well as regional weather related information for the benefit of people of Bangladesh, aviation, marine navigation, inland navigation, agricultural sector etc.
- To make forecasting through the weather centres located at different national and international airports so as to facilitate taking off, landing and navigation of the aircrafts in different national and international routes.
- To collect weather related information, monitoring, storage, analysis and to carry out regular survey and research on weather and climate and to provide processed information and data to different organisations and agencies.
- All kinds of data and information including forecasting and warnings to PMO, Flood Forecasting Centre of Water Development Board, Bangladesh Radio, different publicity media, national and international airports, listed government and private agencies and organisations etc.
- To run earthquake measurement laboratories, maintaining different instruments and equipment for recording and storing earthquake related data and information and communicating those information immediately to all concerned departments and agencies including Bangladesh Disaster Management Department.

- To issue forecasting and advisory on agricultural after recording different data and information agri-meteorological observation centres, storing and thereafter analysing those data and information

Meteorological Stations around Sundarbans

As per the records of WMO website, there are altogether 54 meteorological stations in Bangladesh. Out of these, only eight meteorological stations are located around Sundarbans. These stations are located at Barishal, Gopalganj Sadar, Jessore, Khepupara, Khulna, Mongla, Patuakhali and Satkhira. The details of these stations including locations, station types etc. are described at Annexure-I.

All these eight meteorological stations are surface stations and measure different weather parameters, as detailed below:

Table – 1.12 : Details of Surface Meteorological Observatories around Bangladesh Sundarbans

Sl. No.	Name of Stations	Height (meter)	Observations / Measurements being carried out	
			Atmosphere	Terrestrial
	Barishal	3	(i) Clouds – cloud amount, position, cloud base, type of cloud (ii) Humidity – Humidity at specified distance from reference surface (iii) Past weather – [Geometry : Point] (iv) Present weather – [Geometry : Point] (v) Atmospheric Pressure (vi) Temperature – Air temperature (at specified distance from reference surface) (vii) Visibility (viii) Wind – Surface wind direction and speed, horizontal – deprecated	(i) Humidity & Evaporation – [Geometry: Point]
	Gopalganj Sadar	–	(i) Clouds – cloud amount, position, height of cloud base, type of cloud (ii) Humidity – Humidity at specified distance from reference surface (iii) Past weather – [Geometry : Point] (iv) Present weather – [Geometry : Point] (v) Atmospheric Pressure (vi) Temperature – Air temperature (at specified distance from reference surface) (vii) Visibility (viii) Wind – Surface wind direction and speed, horizontal – deprecated	(i) Humidity & Evaporation – [Geometry: Point] (ii) Soil Temperature
	Jessore	6	(i) Clouds – cloud amount, position, height of cloud base, type of cloud (ii) Humidity – Humidity at specified distance from reference surface (iii) Past weather – [Geometry : Point]	–

			(iv) Present weather – [Geometry : Point] (v) Atmospheric Pressure (vi) Temperature – Air temperature (at specified distance from reference surface) (vii) Visibility (viii) Wind – Surface wind direction and speed, horizontal – deprecated	
	Khepupara	2	(i) Clouds – cloud amount, position, height of cloud base, type of cloud (ii) Humidity – Humidity at specified distance from reference surface (iii) Past weather – [Geometry : Point] (iv) Precipitation – Amount of Precipitation (v) Present weather – [Geometry : Point] (vi) Atmospheric Pressure (vii) Temperature – Air temperature (at specified distance from reference surface) (viii) Visibility (ix) Wind – Surface wind direction and speed, horizontal – deprecated	–
	Khulna	3	(i) Clouds – cloud amount, position, height of cloud base, type of cloud (ii) Humidity – Humidity at specified distance from reference surface (iii) Past weather – [Geometry : Point] (iv) Present weather – [Geometry : Point] (v) Atmospheric Pressure (vi) Temperature – Air temperature (at specified distance from reference surface) (vii) Visibility (viii) Wind – Surface wind direction and speed, horizontal – deprecated	–
	Mongla	–	(i) Clouds – cloud amount, position, height of cloud base, type of cloud (ii) Humidity – Humidity at specified distance from reference surface (iii) Past weather – [Geometry : Point] (iv) Present weather – [Geometry : Point] (v) Atmospheric Pressure (vi) Temperature – Air temperature (at specified distance from reference surface) (vii) Visibility (viii) Wind – Surface wind direction and speed, horizontal – deprecated	–
	Patuakhali	2	(i) Clouds – cloud amount, position, height of cloud base, type of cloud (ii) Humidity – Humidity at specified distance from reference surface (iii) Past weather – [Geometry : Point] (iv) Present weather – [Geometry : Point] (v) Atmospheric Pressure	–

			(vi) Temperature – Air temperature (at specified distance from reference surface) (vii) Visibility (viii) Wind – Surface wind direction and speed, horizontal – deprecated	
	Satkhira	4	(i) Clouds – cloud amount, position, height of cloud base, type of cloud (ii) Humidity – Humidity at specified distance from reference surface (iii) Past weather – [Geometry : Point] (iv) Present weather – [Geometry : Point] (v) Atmospheric Pressure (vi) Temperature – Air temperature (at specified distance from reference surface) (vii) Visibility (viii) Wind – Surface wind direction and speed, horizontal – deprecated	–

Forecasting by Bangladesh Meteorological Department

In the website of BMD, there is a specific section where in each day around 11 a.m. (Local Time), announcements are made for daily forecast on 24 hours basis for each of the Upazilas under each district. Although there are options for making forecasting of daily weather for each individual Upazilas (sub-district), however, in most of the cases, it has been observed that the forecasts for all the Upazilas under any district are exactly the same.

In the same section under "Daily Forecasting" specific instructions for aquaculture on daily basis are available for the fish farmers. The instructions also include amount of feed to be put into the pond for aquaculture purpose, P_H to be maintained etc.

However, weekly forecasting and the forecasting for Monsoon are same for all the districts and sub-districts, as per the website. In other words, micro-level forecasting of weather is not being carried out at this moment.

In a specific webpage of this site, any government official or any person individually can register and put questions related to aquaculture including shrimp culture. BMD officials try to answer those questions in the website itself. Thus, the outreach section clearly clubs weather fluctuation with aquaculture and tries to address the day to day problems being faced by the fish farmers due to fluctuation in weather conditions.

Table – 1.13 : Details of Forecasting made by BMD on Regular Basis

Sl. No.	Name of the Services	Time of Communication	Different media where Communications are sent	Mode of sending the Information and receipt by stakeholders
1.	Forecasting on weather condition	Daily at 10-00 a.m. & 06-00 p.m.	Bangladesh Radio, Bangladesh Television,	Fax, Phone, Departmental website and phone call to phone number 10941 from

			Bangladesh State-owned News Agency (BSS)	any mobile phone belonging to any of the mobile service providers
2.	Forecasting on Agri-meteorology	Daily at 10-00 a.m. & 06-00 p.m.	Bangladesh Radio, Departmental website, Bangladesh State-owned News Agency (BSS)	Fax, Phone and Departmental website
3.	Weather forecasting for Inland River Ports	Daily at 05-00 a.m., 10-00 a.m., 04-00 p.m. & 10-00 p.m.	Bangladesh Radio, Departmental website, All Bangladesh Print media & Electronic Media	Fax, Phone, Departmental website and phone call to phone number 10941 from any mobile phone belonging to any of the mobile service providers
4.	Weather Forecast for fishing boats and trawlers located at Northern Bay of Bengal	Daily at 10-00 a.m., & 10-00 p.m.	Radio Stations of Coastal & Chittagong area and Departmental website	Phone, Fax and Departmental website
5.	Forecast for ships and trawlers going to sea	Daily at 10-00 a.m., & 10-00 p.m.	Bangladesh Radio, Departmental website, All Bangladesh Print media & Electronic Media	Fax, Phone, Departmental website and phone call to phone number 10941 from any mobile phone belonging to any of the mobile service providers
6.	Forecast for Dhaka and adjoining areas	Daily at 06-00 a.m., 12-00 noon, 06-00 p.m. & 12-00 night	Bangladesh Radio, Departmental website, Bangladesh State-owned News Agency (BSS)	Fax, Phone, Departmental website and phone call to phone number 10941 from any mobile phone belonging to any of the mobile service providers
7.	Forecast for sea-going vessels for the region between 21^0 N & 24^0 N Latitude	Daily at 05-00 p.m.	Radio Stations of Coastal region & Chittagong area	Fax, Phone and Departmental website
8.	Forecast for Chittagong, Hilly Chittagong, Noakhali and Cumilla region	Daily at 05-00 p.m.	Radio Stations of Coastal region & Chittagong area	Fax and Phone
9.	Monthly and quarterly Weather Forecast	First / Second working day of each month	Department of Disaster Management, Departmental website of BMD, Bangladesh State-owned News Agency (BSS), All Bangladesh Print media & Electronic Media, Government and Private agencies and organisations	Fax, Phone and Departmental website
10.	Warning for Depression in Bay of	Immediate	Department of Disaster Management, cyclone	Fax, Phone, BMD website

	Bengal, thick clouds in motion, storms		preparedness programme, BMD website, Bangladesh Radio and Television,	
11.	Special warning notification with warning symbols due to deep depression generated at Bay of Bengal and cyclone	Immediate	Ministry of Disaster Management, Department of Disaster Management, cyclone preparedness programme, BMD website, Bangladesh Radio and Television, Bangladesh State-owned News Agency (BSS), All Bangladesh Print media & Electronic Media, Government and Private agencies and organisations	Fax, Phone, BMD website and phone calls to phone number 10941 from any mobile phone belonging to any of the mobile service providers
12.	Warning for Nor'wester, stormy wind, heavy rain and land slide	Immediate	BMD website, Bangladesh Radio and Television, Bangladesh State-owned News Agency (BSS), All Bangladesh Print media & Electronic Media, Government and Private	Fax, Phone, BMD website and phone calls to phone number 10941 from any mobile phone belonging to any of the mobile service providers

Out of these above 12 forecasts/ warning messages, only two namely at serial no. 6 and 8 are not associated with Sundarbans and its impact zone. Interestingly, although there is weather forecast for specific region of Chittagong, Hilly Chittagong, Noakhali and Cumilla region, there is no specific forecasts for Sundarban and its impact zone.

Rainfall Measurement Stations

Apart from BMD, Bangladesh Water Development Board also maintains 318 number of rainfall stations all over Bangladesh. Rainfall data in these stations for about last 60 years are available to the registered users on payment basis. Details of the procedure for getting the data etc. are available in the website (http://www.hydrology.bwdb.gov.bd/index.php?pagetitle=request&_subid=131&id=224). Out of these stations, altogether 34 stations are located in and around Sundarbans, as detailed below:

Table – 1.14 : Rainfall Measurement Stations of BWDB in and around Sundarbans

Sl. No.	Stn. ID	Station Name	District Name	Upazila Name	Data Available	
					First Date	Last Date
1.	CL 255	Bauphal	Patuakhali	Bauphal	01.04.1961	30.04.2018
2.	CL266	Patuakhali	Patuakhali	Patuakhali Sadar	01.04.1961	30.04.2018
3.	CL 502	Benarpota	Satkhira	Satkhira Sadar	01.04.1961	30.04.2018
4.	CL503	Chalna	Khulna	Dacope	14.06.1962	30.04.2018
5.	CL505	Islamkati	Satkhira	Tala	18.05.1961	30.04.2018
6.	CL516	Rampal	Bagerhat	Rampal	01.06.1961	30.04.2018
7.	CL518	Satkhira	Satkhira	Satkhira Sadar	01.04.1961	30.04.2018
8.	CL261	Daulatkhan	Bhola	Daulatkhan	01.04.1961	30.04.2018

9.	CL268	Charfasson	Bhola	Char Fasson	01.04.1968	30.09.2012
10.	CL269	Khepupara	Patuakhali	Kala para	01.04.1968	30.04.2018
11.	CL272	Patharghata	Barguna	Patharghata	01.04.1968	30.04.2018
12.	CL504	Dumuria	Khulna	Dumuria	21.05.1961	30.04.2018
13.	CL506	Kaikhali	Satkhira	Shyamnagar	01.08.1962	30.04.2018
14.	CL511	Mollaghat	Bagerhat	Mollahat	21.05.1961	30.04.2018
15.	CL253	Bamna	Barguna	Bamna	01.04.1962	30.04.2018
16.	CL257	Borhanuddin	Bhola	Burhanuddin	01.04.1962	30.04.2018
17.	CL262	Galachipa	Patuakhali	Galachipa	11.09.1961	30.04.2018
18.	CL271	Nazirpur	Pirojpur	Nazirpur	01.04.1968	30.04.2018
19.	CL501	Bagerhat	Bagerhat	Bagerhat Sadar	01.05.1961	30.04.2018
20.	CL513	Nakipur	Satkhira	Shyamnagar	23.05.1961	31.03.1979
21.	CL256	Barguna	Barguna	Barguna Sadar	01.04.1968	30.04.2018
22.	CL508	Kaliganj (Khulna)	Satkhira	Kaliganj	19.05.1961	30.04.2018
23.	CL510	Khulna	Khulna	Khulna Sadar	01.04.1961	30.04.2018
24.	CL265	Mathbaria	Pirojpur	Mathbaria	01.07.1962	30.04.2018
25.	CL273	Rangabali	Patuakhali	Galachipa	01.04.1968	30.04.2018
26.	CL259	Bhandaria	Pirojpur	Bhandaria	01.04.1962	31.03.2018
27.	CL264	Jhalokati	Jhalokathi	Jhalokati Sadar	18.09.1961	30.04.2018
28.	CL509	Kapilmuni	Khulna	Paikganj	01.06.1962	30.04.2018
29.	CL512	Morrelganj	Bagerhat	Mollahat	01.06.1961	30.04.2018
30.	CL260	Bhola	Bhola	Bhola Sadar	01.04.1962	30.04.2018
31.	CL267	Pirojpur	Pirojpur	Pirojpur Sadar	01.04.1961	30.04.2018
32.	CL507	Kalaroa	Satkhira	Kalaroa	22.06.1961	30.04.2018
33.	CL515	Paikgacha	Khulna	Paikgacha	23.05.1961	30.04.2018
34.	CL517	Rupsa	Khulna	Rupsa	01.07.1962	31.10.2006

Rainfall data from these stations are having immense importance for carrying out climate change studies in Sundarbans. Unfortunately, some of the stations like CL268 (Serial No. 9), CL513 (Serial No. 20) etc. have stopped functioning for quite some time back which needs to be revived for increment of the coverage.

Evaporation Measurements at different Points around Sundarbans

Similarly, Evaporation measurements are also being carried out by BWDB in 47 stations all over Bangladesh. The list of these stations along with other details is provided at the website of BWDB.

Table – 1.15 : Evaporation Measurement Stations of BWDB in and around Sundarbans

Sl. No.	Stn Id	Station Name	District Name	Upazila Name	Data Available	
					First Date	Last Date
1.	CL256	Patuakhali	Patuakhali	Patuakhali Sadar	01.04.1972	30.04.2018
2.	CL502	Benarpota	Satkhira	Satkhira Sadar	01.04.1967	30.04.2018

3.	CL518	Satkhira	Satkhira	Satkhira Sadar	01.08.2015	30.04.2018
4.	CL269	Khepupara	Patuakhali	Kalapara	01.04.1972	31.03.1976
5.	CL510	Khulna	Khulna	Khulna Sadar	01.04.1967	30.04.2018
6.	CL260	Bhola	Bhola	Bhola Sadar	01.04.1972	30.04.2018
7.	CL267	Pirojpur	Pirojpur	Pirojpur Sadar	01.05.1972	30.04.2018

It has been observed that out of 47 stations of evaporation measurements, only 7 stations are located around Sundarbans, Bangladesh. The measured data are made available only to the registered users on payment basis.

Unfortunately, there are no sea meteorological stations in Bangladesh to supplement the observations as also validation of meteorological predictions from sea side. This is a great lacunae which needs to be addressed during designing of seamless hydro-meteorological system for Sundarbans.

Hydrodynamic Studies along Bangladesh Sundarbans

Bangladesh is one of the largest deltas in the world having a very flat topography. Three major rivers, the Ganges, the Brahmaputra and the Meghna having a total catchment area of about 1.7 million km^2, provides drainage to 1,660,000 km^2 of the combined catchment, pass through this country. 93% of the catchment area of these rivers lies outside the country in India, China, Nepal and Bhutan. The country has an average rainfall of about 2300 mm, ranging between 1500 and 5000 mm (Source : http://www.hydrology.bwdb.gov.bd/).

Bangladesh is a disaster prone country and almost in every year it experiences tropical cyclones, storm surges and associated floods, saline water incursions in the agricultural fields, loss of life and property of common men and so on. The gradient of the country towards the southern side is comparatively low and thereby faces utmost threat due to sea level rise under the current scenario of climate change. The problem has been further compound due to submergence along its western portion along Kolkata – Maimonsingh Hing Zone as a consequence of neo-tectonic movement. Thus, the water sector and the agricultural sector depending on river irrigation are facing a real challenge.

Bangladesh has a unique coastline of around 580 Kilometres, conical in shape, which causes a higher sea level during monsoon months. In some of the literatures, it has also been referred as 710 km (Emranul Ahsan, 2013). Sundarbans is located in the western part of Bangladesh Coastline and extends for a length of about 100 km. Bangladesh part of Sundarbans is bounded by Harinbhanga River in the west and mighty Baleswar River in the east. The Possur

River passes longitudinally through the Sunadarbans and almost divided Bangladesh Sundarbans into two halves.

Recorded total area of the Bangladesh Sundarban Mangrove Forest is about 6017 km^2 as determined from visual interpretation of multi-spectral SPOT satellite data. Of the total area, about 4038 km^2 is forestland and more than 115 km^2 is marshes within a network of 450 rivers. The rivers constitute about 12,000 km of waterways whose area ranges from 1757 km^2 to 1864 km^2, in addition to small rivers and creeks (Aziz A. and Paul A. R. 2015).

In Bangladesh, two different Ministries are involved in installations, maintenance for measurement of different hydrographic parameters. These two departments namely Ministry of Shipping and Ministry of Water Resources are regularly carrying out these activities and providing these data to public domain through different agencies/ authorities under their administrative controls. However, Ministry of Defence through one of the agencies under its administrative control, namely, Bangladesh Navy Hydrographic and Oceanographic Centre (BNHOC) also carries out some hydrographic studies and make available the predicted tide data in different points as a part of their responsibility to help in navigation.

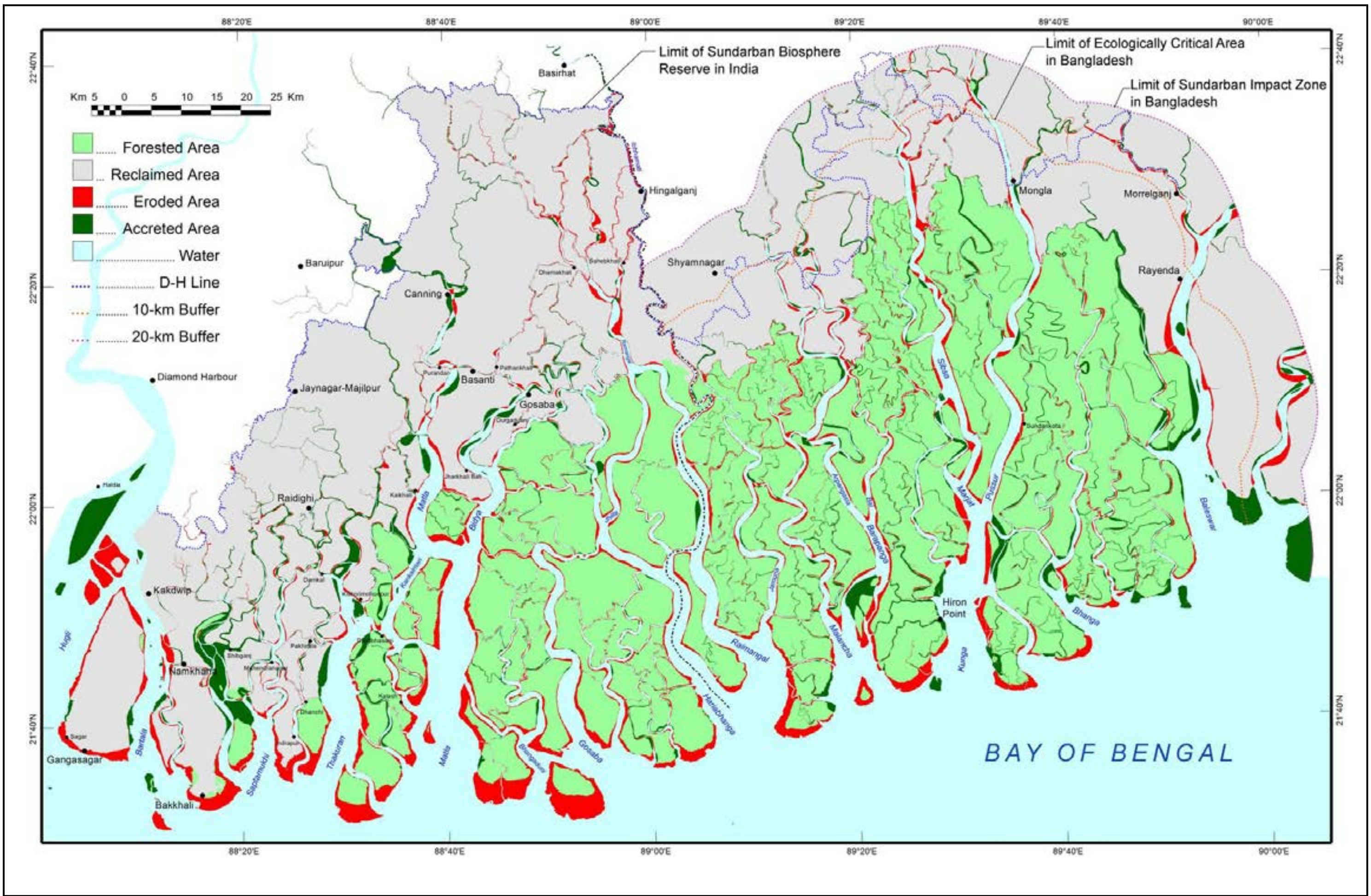


Figure – 1.6 : Composite map of the Sundarban. 1829-30 extent of the mangrove wetlands is indicated by the Dampier–Hodges (D–H) Line that is still regarded as the northern limit of the Sundarban region in India and includes both reclaimed and non-reclaimed parts. In Bangladesh, Sundarban represents only the forests. A 10-km and a 20-km buffer from the forest boundary designate the Ecologically Critical Area and the Sundarban Impact Zone (SIZ), respectively. (Bandyopadhyay S., 2017)

Bangladesh Inland Water Transport Agency (BIWTA)

Out of these three ministries albeit three agencies/ authorities to carry out the hydrogrpahic measurements, Ministry of Shipping plays the most vital role. The tide gauge stations in Bangladesh are mainly installed and maintained by Bangladesh Inland Water Transport Authority (BIWTA), an autonomous body under the administrative control of Ministry of Shipping. It is a massive organisation headed by Chairman and three members namely Member, Engineering; Member, Planning & Management and Member, Finance.

Bangladesh has about 24,000 km. of rivers, streams and canals that together cover about 7% of the country's surface. Most part of the country is linked by a complex network of waterways which reaches its extensive size in the monsoon period. Out of 24,000 km length of rivers, streams and canals, only about 5,968 km length is navigable by mechanized vessels during monsoon period which shrinks to about 3,865 km during dry period. The Inland Water Transport sector carries over 50% of all arterial freight traffic and about 25% of all passenger traffic. Thus, this sector is of significant importance for the development of the nation.

BIWTA has the following functions, as per their website (http://www.biwta.gov.bd/ observed on 11.06.18):

1. To carry out river conservancy works including river training works for navigational purposes and for provision of aids to navigation including marks, buoys, lights and semaphore signals ;
2. To disseminate navigational and meteorological information including publishing river charts;
3. To maintain pilotage and hydrographic survey services;
4. To draw up programmers of dredging requirements and priorities for efficient maintenance of existing navigable waterways and for resuscitation of dead or dying rivers, channels, or canals, including development of new channels and canals for navigation;
5. To develop, maintain and operate inland river ports, landing ghats (meaning small jetties) and terminal facilities in such ports or Ghats;

6. To carry out removal of wrecks and obstruction in inland navigable waterways;
7. To conduct traffic surveys to establish passenger and cargo requirements on the main rivers, feeders and creek routes;
8. To develop the most economical facilities for passenger traffic to ensure comfort, safety and speed;
9. To fix maximum and minimum fares and freight rates for Inland Water Transport on behalf of the Government (as provided in Section 544 of the Inland Mechanically propelled Vessels Act, 1917);
10. To approve time tables for passenger launch services;
11. To develop rural water transport by progressing of schemes for modernising and mechanizing country craft;
12. To ensure co-ordination of Inland Water Transport with other forms of transport, with major sea ports, and with trade and agricultural interests for the optimum utilisation of the available transport capacity;
13. To conduct research in matters relating to Inland Water Transport including development of a. Craft design, b. Technique of towage, c. Landing and terminal facilities, d. Port installations;
14. To arrange programmers of technical training for Inland Water Transport personnel within and outside Bangladesh;
15. To maintain liaison with the shipyard and ship repair industry to meet the requirements of the Inland Water Transport fleet repairs and new constructions;
16. To maintain liaison with the Government and facilitate import of repair materials for Inland Water Transport Industry;
17. To prepare plans or schemes for carrying out any of the above mentioned functions;
18. Any other function or functions which the Government may, from time to time, prescribe.

BIWTA is perhaps one of the largest civil government agencies in Bangladesh with a total staff strength of 4359. It functions through 16 (sixteen) separate departments. Out of these departments, the Hydrographic Department of BIWTA carries out all the hydrographic surveys.

Hydrographic Department of BIWTA

Hydrographic Department of BIWTA is the designated authority in Bangladesh to authenticate the tidal gauge data being collected along the coast line as also in the estuaries. It may thereby be considered as the counterpart organisation of 'Survey of India' in Bangladesh. It is a considerably large department with total staff strength of about 254. It is headed by one Director. One Additional Director helps the Director in management of the department. There are seven different sections, each with separate mandate for carrying out different functions of the Hydrographic Department. These sections are (i) Survey, (ii) Tidal section, (iii)

Instrumentation section, (iv) DGPS section, (v) Cartography section, (vi) Administrative section and (vii) Planning and Integration section. There are five different DGPS stations, presumably to understand the subsidence of the land mass due to neo-tectonic movement, although the functions of these DGPS stations have not been discussed in detail in public domain. These DGPS Stations are : (i) DGPS Regulation Station at Dhaka, (ii) DGPS RM Station at Narayanganj and three DGPS Beacon Stations at (i) Maymonsingh, (iv) Jessore and (v) Chittagong (Source: http://biwta.portal.gov.bd/sites/default/files/files/biwta.portal.gov.bd/page/1db55178_5552_4f72_9da3_fbdc319d2e2e/Organogram-of-Hydrography-Department.pdf). Each of these DGPS stations are managed by one Executive Engineer assisted by three Assistant Engineers and other support staffs. Thus, so far as manpower is concerned, these centres may be considered as well equipped. Interestingly, all three DGPS Beacon stations located along Bangladesh coast to help in coastal navigation are located far away from Sundarbans and are not in a position to assist the mariners travelling through Sundarbans, although Passur River upon which numbers of important ports are located, passes through Sundarbans.

BITWA altogether maintain 54 (Fifty Four) gauge stations in Bangladesh through the Hydrographic Section, as per the information provided by BITWA in their website. Different functions of the Hydrographic Section of BITWA are as follows:

1) To carry out hydrographic Survey and to prepare charts along the inland and coastal navigational routes
2) To carry out hydrographic survey for setting Buoy, Beacon and Light along the navigational routes for safe movement of the vessels
3) To carry out hydrographic survey for Pre-Bandalling survey and pre & post-dredging survey for maintenance of the required navigability
4) To collect and store gauge data from 54 (Fifty Four) inland and coastal gauge stations
5) To use the gauge data for preparation of hydrographic survey charts
6) To prepare and publish the predicted tide table based on collection and analysis of water level data collected from Gauge Stations and to sell / supply the tide tables as per demand.
7) To measure and calculate navigational distances along different rivers in between different places and to publish it in book forms and to supply that to different government and non-government organizations as per demand
8) To supply / sell the gauge data to different research and educational organizations as per demand
9) To collect gauge data for providing technical assistance to Ministry of External Affairs for preparation of Co-tidal charts, determining Base line, EEZ (Exclusive Economic Zone), Continental Shelf towards determination of Maritime Boundary of the Country

10) To prepare, publish and proper preservation of comprehensible hydrographic charts and to sell and supply printed copies as per demand

11) To transmit the signals in an uninterrupted manner using Differential Global Positioning System (DGPS) methodology for determination of satellite based locations

12) To maintain, repair and preserve Differential Global Positioning System (DGPS) and related instruments (like transmitter, receiver, Diesel Generator etc.) at offices and at field level

13) To install, maintain and repair all instruments and equipment (Echo-sounder, Water Level Recorder, Total Stations etc.) required for Hydrographic Survey at different offices and in field

14) To install, maintain and repair all HFSSB, VHF sets/ instruments being used by the authority

15) To provide technical help and support for installation, maintenance and repair of different types of electronic gadgets and instruments being used by the authority

16) To install, maintain and repair all air-conditioner instruments and refrigerators being used by the authority

17) To formulate different development oriented projects and their implementation

18) To provide technical support to the Ministry of Shipping for setting up of Deep Sea Port.

Bangladesh Water Development Board (BWDB)

BWDB is an autonomous authority under the Ministry of Water Resources, Government of Bangladesh governed by a Governing Council (GC) consisting of 13 (thirteen) members under the chairmanship of Minister-in-Charge of Water Resources Department. It is guided by the National Water Policy (NWPo) – 1999 and National Water Management Plan (NWMP) – 2004 and is responsible for looking after the entire waterways of Bangladesh including the estuaries.

BWDB started its operation in erstwhile East Pakistan in 1959 as per recommendations of Krug Mission, an UN Mission formed in 1956 which submitted its report in 1957 for enhancing the food productivity and for proper management and development of Water Resources (Kamal, 2006). As the principal agency of the government for managing water resources of the country, it was given the responsibility of accomplishing the tasks of executing flood control, drainage and irrigation projects to increase productivity in agriculture and fisheries. After the independence of Bangladesh, BWDB was restructured and transformation of the organisation took place through the enactment of BWDB Act, 2000.

<u>Activities of BWDB</u>

- Providing inputs and technical reviews for the preparation of National Level Perspective and the Five Year Development Plans.

- Micro planning for water resources development consistent with the NWP and within context of the National Water Management Plan (NWMP).
- Hydrological studies, data collection, management and research.
- Undertaking activities for formulation and preparation of planning documentation for BWDB projects.
- Maintaining updated management information related to planning of water sector development.
- Supporting Water Resources Planning Organisation (WARPO) and other water sector agencies in the development of efficient water resources management and utilisation of plans and updating various Guidelines on water management.
- Design, construction and implementation of plans for new large and medium-scale water development projects.

Thus, BWDB plays an extremely important role for water resources conservation and management in Bangladesh. It has a separate Hydrology Department which has been carrying out different kinds of hydrological observations and studies all over the nation. Hydrology Department started working as the Directorate Planning and Investigation under Chief Engineer Planning. By the mid 1960's, Hydrology was placed under Chief Engineer Hydrology and projects were undertaken to establish monitoring network for hydrological, hydrogeological, morphological data collection and processing (Source : http://www.hydrology.bwdb.gov.bd/index.php?pagetitle=home&id=75).

The declared mission of Hydrology Department includes:

- Analyze the hydrological, hydrogeological, morphological and hydro-meteorological data collected by field offices quality control and processing.
- Manage real time data collection for flood forecasting purpose and timely dissemination of flood warning to different Ministries/ Organizations/ News media and NGO's.
- Publish Monthly Flood Report during the monsoon and Annual Flood Report after the monsoon. Publish monthly groundwater forecasting report.
- Co-ordinate with different agencies on hydrological and hydro-meteorological studies, research and data management. .
- Develop and disseminate appropriate technologies for conjunctive use of rainwater, groundwater and surface water.
- Prepare district and country wide hydro-geological maps.
- Maintain and update water models and programs for monitoring and forecasting the hydrological conditions.
- Maintain equipment, survey vessels, telemetering and wireless system, calibrating tank and field installations.

- Collect real time hydrometric and telemetric data for running flood forecasting and inundation models under Flood Forecasting and Warning Center (FFWC).
- Prepare warning bulletin on the basis of the model output and flood inundation maps integrating GIS and real time data.
- Arrange acquisition of NOAA/GMS Satellite and Radar data and process, interpret and prepare necessary graphs.
- Maintain Webpage on flood situation.
- Maintain different equipment used for flood forecasting.

A specific circle known as "Processing and Flood Forecasting Circle" (PFFC) has been created under Hydrology department to assess the current trend of hydrologic conditions for overall water resources development and management and to predict future changes due to human activities and climate change impacts. Generation of adequate data and information by setting up appropriate monitoring network of hydrographic observations is one of the objectives of PFFC.

Activities of Hydrology Department

Activities under Hydrology Department are broadly classified under three different categories. Interestingly, all the activities under different categories are directly linked with the hydro-meteorological issues in and around Sundarbans. These activities are (i) River Morphology and Research, (ii) Processing and Flood Forecasting and (iii) Surface Water Hydrology. Out of these, activities under 'Processing and Flood Forecasting' are similar to those of Hydrology Department itself. The major activities under other two heads, related with the objective of this study, are as follows:

Major Activities of River Morphology and Research

- Organize and manage the collection and preservation of raw data
- Supervise the cross sections and the Bathymetric survey of major rivers in Bangladesh.
- Monitor morphological changes in the river system of the country
- Supervise morphological data compilation process in the field
- Co-ordinate with other BWDB offices and agencies on morphological studies, research, data management and other related job
- Supervise the activity of the Mapping Cell and maintenance of instruments therein
- Preparation of survey reports of unserviceable/ condemned materials, equipment etc. and their disposal
- Take necessary steps for implementation of projects included in the ADP including their monitoring.

- Preparation of Maps using PHOCUS software by Planicomp P33 and undertake activities including field verification of BM.

Major Activities of Surface Water Hydrology

- Supervision and technical guidance to the quality control of hydrological and climatological data collection, including preliminary processing of data
- Collect, standardization and improvement of surface water hydrological data (river stage, discharge, rainfall, sediment load, salinity, evaporation, temperature, sunshine hour etc).
- Supervision and technical guidance to all field surface water hydrologic data collection network and ensure quality control
- Supervise surface water hydrology benchmark survey, evaluation and other studies required by the country.
- Supervise timely transmission of flood related data to the Flood Forecasting and Warning Centre.
- Co-ordinate with other offices and agencies on hydrological and climatological study, research, data management etc.
- Supervise capacity building in surface water hydrology
- Data collection network includes about 215 and 128 nos Non-tidal and Tidal water level stations respectively, 110 and 7 nos. of Non-tidal and Tidal discharge measurement stations respectively, about 100 surface water salinity and 26 sediment load measurement points all over the country. Network also includes 269, 3 and 39 nos. of rainfall, climatology and evaporation recording stations.

Thus, BWDB measures the water level at 128 stations, which are affected by tidal activities. These measurements, in other ways, represent the tidal fluctuations in these stations.

Real Time Measurements of tide

One of the major activities being carried out by Hydrology Department is water level measurement along selected stations using floats and disseminates that data on real time basis in the website. The registered users (restricted to Bangladesh Nationals only) can have access to these data on real time basis. In case of tidal rivers, the water levels in the rivers indicate the tidal condition as well and water level records at different times can be deciphered from these records, even without formal tide gauges. The water level is recorded as per PWD Datum, which is 0.46 meter below MSL (Maswood M., 2015).

Bangladesh Navy Hydrographic and Oceanographic Centre (BNHOC)

BNHOC is an offshoot of Bangladesh National Hydrographic Department, which was created in 1983 and is responsible for renewing and maintaining hydrography in maritime waters of Bangladesh (Dupuy, Pierre-Yves, et. al. 1998). Since the country's independence in 1971, the Bangladesh Inland Water Transport Authority (BIWTA) under the Ministry of Shipping was only responsible for carrying out of hydrographic studies in rivers and streams of Bangladesh. At that time, the hydrographic surveys were carried out very close to inshore, as required from time to time. However, since the bathymetric surveys were carried out from boats, it was not possible to carry out hydrographic studies in maritime waters away from shore. Hence, Hydrographic Department was created under the authority of the Director of Hydrography (DoH) and facilities were created at Chittagong.

After modernization of hydrography department the responsibility and sector of hydrographic survey increased in manifold. But BN Hydrographic Department was not a full-fledged organization to monitor the survey works, data processing, cartographic works, storing of data, circulation and in general to act as a research institute. Necessity was felt to establish a centre as the hub of all hydrographic activities of Bangladesh. In order to perform all those tasks BN Hydrographic and Oceanographic Centre (BNHOC) was established in the year of 2001 at the end of Hydro Bangla Project-2 and BN Chart Depot was merged with that centre.

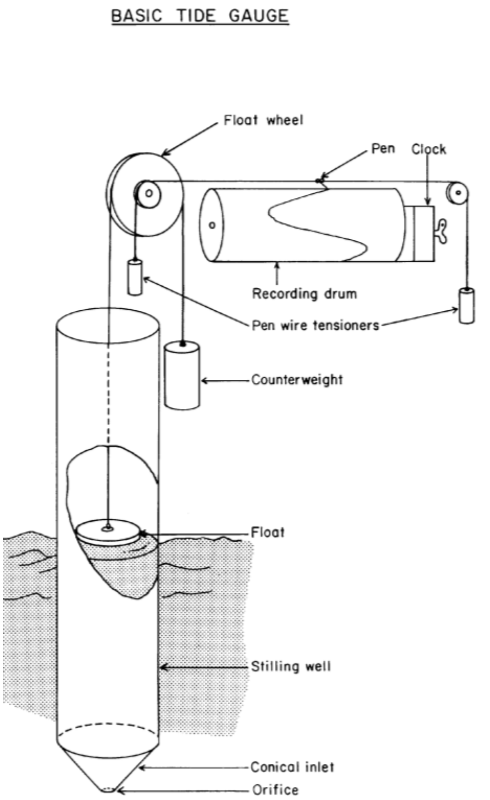
Mission of BNHOC is to ensure availability of reliable and updated information of the marine environment in order to derive maximum benefits from Bay of Bengal.

Tide Gauge Stations around Bangladesh Sundarbans

A number of tide gauge stations / water level measuring stations are being maintained and operated by these three organisations/ agencies around Sundarbans, which are discussed below:

Tide Gauge Stations as maintained by BIWTA

As indicated in the description of the functions of BIWTA, 54 gauge stations under the control of BIWTA are not all “Tide Gauge” Stations. Almost all these stations are “Float Gauge” stations indicating the level of water in the rivers, particularly in inland rivers. These stations essentially use "Float Gauges" which indicate the level of water in the river with a pen recorder. A schematic diagram of a float gauge in a stilling well is shown in the adjacent figure.



The float wheel is shown driving a pen recorder, but the same pulley could equally drive a digital shaft encoder or a potentiometer, which can then be recorded by a local data logger or interfaced to a telemetry system (IOC Manuals and Guides No.14, Vol. IV, 2006). The well is shown with a conical inlet at its base, since this is the most common configuration and is to some extent self-cleaning. There are many other configurations of the inlet system available in the market. The conical orifice does restrict the inflow relative to the outflow, but this does not appear to have a significant effect on the records even in the presence of waves. However, the exact inlet system being used by BITWA is also not readily available. Further, whether the float gauges have been upgraded to digital shaft encoder and connected to data logger or interfaced to telemetry system cannot be confirmed from the concerned authority of BITWA.

These float gauges are maintained by Bangladesh Inland Water Transportation Authority (BIWTA) (Chiu & Small, 2016). Because many of the gauges are located in remote areas of the coastal zone, it is difficult to assume that regular benchmarking and datum checks have been done, although this is one of the essential requirements for float gauges, as per the recommendation of IOC. Normally, the datum used is a Chart Datum modified from the Indian Spring Low Water (ISLW) Chart Datum (Mondal, 2001), but it was not possible to confirm this from BIWTA. The ISLW was intended for semi-diurnal dominated tides with small shallow water constituents. The additional term in the Chart Datum presumably takes into account these shallow water constituents, which can play a large role in tidal propagation in the Bangladesh coastal zone. It is also not clear whether ISLW datum is the same as PWD Datum, being used by BWDB, described subsequently.

There are three major ports in Bangladesh – Chittagonj, Mongla and Dhaka Sadar Ghat. Most of the tide stations are concentrated around these three major ports, of which Chittagonj is the largest seaport compared to other two ports.

The tide gauge stations are normally installed with the purpose of getting information regarding the navigability in the coast, estuaries and rivers near coast rather than for any other academic and long-term research purposes. In case of Bangladesh also, there is no exception. Most of the tide gauge stations are concentrated around Chittagong, which is the busiest seaport on the coastline of the entire Bay of Bengal, and the second busiest in the overall region of countries dependent on Bay of Bengal. As per the records of PSMSL, there are as many as six tide gauge stations located in and around Chittagong as follows:

Table – 1.16 : Locations of six tide gauge stations in and around Chittagonj

Sl. No.	Name of the Station	Station ID as per PSMSL	Latitude	Longitude	GLOSS ID
1.	Chittagong (Sadar)	416	22.33333	91.83333	36
2.	Chittagong A	2196	22.246667	91.825	36
3.	Chittagong (T. M. Compound)	975	22.316667	91.816667	36
4.	Chittagong (Khal # 10)	1573	22.266667	91.816667	36
5.	Chittagong (Juldia Point)	991	22.25	91.833333	36
6.	Chittagong (Patenga Point)	750	22.243889	91.805556	36

Source: Website of Permanent Service for Mean Sea Level (PSMSL): http://www.psmsl.org/data/obtaining/ as observed on 06.06.2018

Thus, it is apparent that many tide gauges are there in and around Chittagong. Chittagong Port Authority maintains the Chittagong tide gauge stations (Rose & Bhaskaran, 2015), although the Chittagong is a recent water level observing station. However, the data for all the stations are being provided to the Joint Archive for Sea Level (JASL) and University of Hawaii Sea Level Centre (UHSLC) by BIWTA, since the Hydrography Department of BIWTA is the designated data authority at PSMSL.

However, since the longitudinal distances of these stations from eastern most boundary of Sundarban are more than 200 kilometres along the coast, these tide gauge stations are not of much importance for Sundarban.

One of the major advantages of Bangladesh part of Sundarban is the location of Mongla Port on the Possur River, which divides the Sundarban in almost two separate halves. Mongla Port is the second largest port in Bangladesh, next to Chittagong Port, so far as cargo handling is concerned. The aerial distance of Mongla Port from the northernmost tip of Sundarban is about 12 km and thus it is well within the impact zone of Sundarban.

The Hiron Point where a tide gauge in operation since 1977 is located almost at the meeting point of Possur River with the Bay of Bengal. Here the instrument type is float and well type gauge (Munro) (Source : http://www.psmsl.org/data/obtaining/stations/1451.php). As far as Datum Information is concerned, here the data is collected based on a Local Reference, which was further revised in 1983. The Revised Local Reference (RLR) is 9.00 m below Primary Benchmark (BM). For data values 1983 onwards, as recorded at PSMSL site, 5.216 m is to be added to refer to RLR.

Another tide gauge station which was in operation near the Hiron Point from 1951 onwards is at Dublakhal. Unfortunately, this station seems to be not in operation at this moment since 1980 and PSMSL site has no update after that.

Another important tide gauge station located in the east of Hiron Point is Khepupara. It is also a float and well type gauge (Munro). As per the PSMSL information, this station is in operation since 1977, although the last data was obtained from this station is 17th October, 2002. It is located at the point of meeting of Baleswar River with the Bay of Bengal, which marks the eastern boundary of Sundarbans. Similar to Hiron Point, the data authority agency here is BIWTA.

There are three more tide stations along Possure River namely tide gauges at Sundarikota, Mongla and Khulna, which are about 40 km, 95 km, and 160 km upstream of Hiron Point, respectively. The symmetric tidal wave gradually becomes asymmetric as it travels upstream, tidal range increases and the mean water level becomes higher.

There are 10 tide gauge stations in and around Sundarbans being maintained by BITWA, as understood from different literatures and websites of BITWA, as follows:

Table – 1.17 : Locations of Tide Gauge Stations around Bangladesh Sundarbans being maintained by BITWA

Sl. No.	Name of the Station	Station ID as per PSMSL	Station Code	Latitude	Longitude	On which River
1.	Hiron Point	1451	3	21.783333	89.466667	Possur
2.	Dublakhal	1966	1	21.85	89.533333	Possur
3.	Khepupara	1454	37	21.833333	89.833333	Baleswar
4.	Sundarikota	–	–	22.12917222	89.569722	Possur
5.	Mongla Port	–	–	22.467222	89.5825	Possur
6.	Chalna Port Reach	–	–	22.60037222	89.5166083	Possur
7.	Khulna Port	–	–	22.82309167	89.5593917	Possur
8.	Betbunia	–	–	22.4939861	89.7922083	Pangunchi
9.	Ghashiakhali	–	–	22.5272722	89.7631222	Pangunchi

10.	Charduani	–	–	22.1205	89.9273111	Baleswar

Chiu & Small (2016) referred the 'water level records from a network of 15 tide gauge stations on the lower GBD to quantify systematics of 54 cyclones occurring in the BoB between 1977 and 2010.' Although, the exact coordinates of these 15 tide gauge stations have not been provided, however, the locations of these 15 tide gauge stations on a MODIS False Colour Composite (FCC) had been provided. It appears that apart from the Hiron Point and Khepupara, three more tide gauge stations have been mentioned which are either within Sundarban or within its impact zone. These three tide gauge stations are Betbunia, Ghashiakhali and Chandrani. They have specifically mentioned that all the data have been received from BIWTA. Hence, the locations of these three tide gauge stations and the authorised agency for looking after these stations have been considered as BIWTA.

Betbunia is located on the side of Pangunchi River and is at a distance of about 11 km from the northern side of the Sundarban Forest. Pangunchi River is a tributary of Baleswar River. Ghashiakhali is located on the side of the Pangunchi River at a distance of about 4.5 km north of Betbunia. Since, no exact location of tide gauge station has been provided, so it has been assumed that the tide gauge station is located near the 'Ferry Ghat' and location of 'Ferry Ghat' has been assumed as the location of the tide station here. Ghashiakhali is located at a distance of about 14 km from Sundarbans and is thereby well within the impact zone of Sundarbans. Charduani is located on Baleswar River just on the opposite bank of Sundarbans. It is located at a distance of about 4 kms from Sundarbans and thus within the Ecologically Critical Area of Sundarbans.

Tide Gauge Stations as maintained by BWDB

It has already been mentioned that Hydrology Department of BWDB maintains the water level at 128 points along the tidal rivers. These water levels are measured with "Float Gauges". Since continuous recording of the water levels are being carried out in some of these stations, so data from these stations can very well be used as tidal fluctuation at that point.

BWDB and other government departments refer water levels to the Public Works Datum (PWD). PWD is a horizontal datum believed originally to have zero at a determined Mean Sea Level (MSL) at Kolkata. PWD is located approximately 1.5 feet below the MSL established in India under the British Rule and brought to Bangladesh during the Great Trigonometric Survey (Source : http://www.ffwc.gov.bd/). However, its relationship with respect to Indian Spring Low Water (ISLW) Chart Datum, being used by BITWA is not clearly mentioned in any document.

A number of tide gauge stations around Sundarbans have been referred in literature, although other details like exact locations, type of instruments etc have not been referred. Sarwar, 2013 has mentioned about long time tidal data from 15 tide gauge stations of Bangladesh for his analysis. Out of these, two tide stations namely Amtali (Data available from

1958 to 2002), Rayenda (Data available from 1969 to 2001) seem to be located within Sundarban, as per the map provided by him. Sarwar, 2013 mentioned that *"Data collected from BWDB have been provided in the form of mean daily high water level and mean daily low water level"* confirming that BWDB also maintains and collect tidal data along different tidal stations of Bangladesh. He has mentioned that out of 15 tide gauge stations, he collected long term tide data of 11 (Eleven) tide gauge stations from BWDB, although it is not understood that whether BWDB actually maintains tide gauge stations or these are also "Float Gauge" Stations, data from which are being alternatively used for tidal analysis along Bangladesh Coast. Thus, the water level data of BWDB plays an important data source as tide data.

Rayenda Sharankhola is located on the Baleswar River, the eastern boundary of Sundarban at a distance of around 6 km and thereby well within the vicinity of Sunadarban. However, Amtali is a sub-district of Barguna District in Barisal Division. It is located on the side of Payra River, which is a tributary of Baleswar River. The longitudinal distance of Amtali from the eastern part of Sundarban is about 35 km and the tidal data at Amtali may not be of so much importance for Sundarbans because of the distance only.

There is a list of total 366 stations spreading over entire Bangladesh where the water levels are being monitored by BWDB. These 366 stations also include the 128 centres where the tidal fluctuations are being measured by Hydrology Department on regular basis.

Out of these stations, about 31 stations are in around Sundarbans and its impact zone in Bangladesh. Sundarban in Bangladesh spreads over three districts namely, Shatkhira, Khulna and Bagerhat. The other two districts, namely Pirojpur and Barguna are adjacent to Sundarbans. So, the water level measurement stations within these five districts have been considered as tide stations in and around Sundarbans.

Figure 1.7 : Southern Districts of Bangladesh Surrounding Sundarbans

(Source : Edited Map of Bangladesh received through Google Image)

Details of these tide stations located in the five districts are given below:

Table – 1.18 : Water Level Measurement Points in and around Sundarbans by BWDB

Sl. No.	Stn Id	Station Name	River Name	District Name	Upazila Name	Data Available	
						First Date	Last Date
1.	SW1	Bagerhat	Alaipur Khal Daratona	Bagerhat	Bagerhat Sadar	01.04.1959	30.04.2018
2.	SW23	Kalaroa	Betna-Kholpetua	Satkhira	Kalaroa	01.04.1968	30.04.2018
3.	SW24	Benarpota	Betna-Kholpetua	Satkhira	Satkhira Sadar	01.04.1968	30.04.2017
4.	SW107A	Nazipur	Gorai-Madhumati – Haringhata – Baleswar	Pirojpur	Nazipur	01.04.1991	29.12.2001
5.	SW241	Khulna	Rupsa-Pasur	Khulna	Khulna Sadar	01.10.1937	30.04.2018
6.	SW243	Chalna	Rupsa-Pasur	Khulna	Dacope	01.04.1931	30.04.2018
7.	SW128	Shakra	Ichamati (Western Border)	Satkhira	Debhata	01.04.1968	30.04.2018
8.	SW39	Patharghata	Biskhali	Barguna	Patharghata	01.04.1958	30.04.2018
9.	SW105	Off take at Atharobanka	Gorai-Madhumati – Haringhata – Baleswar	Bagerhat	Mollahat	01.04.1929	30.04.2018
10.	SW108	Chardoani	Gorai-Madhumati – Haringhata – Baleswar	Barguna	Patharghata	01.04.1996	31.03.1997
11.	SW37.5	Betagi	Biskhali	Barguna	Betagi	01.04.1993	30.04.2018
12.	SW165	Kobadak Forest House	Kobadak	Khulna	Koyra	01.04.1968	30.06.2016
13.	SW28	Dumuria	Bhadra	Khulna	Dumuria	01.04.1969	30.04.2018
14.	SW107.2	Rayenda	Gorai-Madhumati – Haringhata – Baleswar	Bagerhat	Sarankhola	01.04.1968	30.06.2016
15.	SW129	Basantapur	Ichamati (Western Border)	Satkhira	Kaliganj	01.04.1952	30.04.2018
16.	SW38	Bamna	Bishkhali	Barguna	Bamna	18.11.1958	30.04.2018
17.	SW163	Tala Magura	Kobadak	Satkhira	Tala	01.04.1968	30.04.2018
18.	SW184	Patuakhali	Lohalia	Patuakhali	Patuakhali Sadar	24.10.2015	24.10.2015
19.	SW244	Mongla	Rupsa-Pasur	Bagerhat	Mongla	01.10.1960	30.04.2018
20.	SW20	Amtali	Barisal – Buriswar	Barguna	Amtali	01.04.1957	30.04.2018
21.	SW26	Protapnagar	Betna – Kholpetua	Satkhira	Assasuni	01.04.1968	30.04.2018
22.	SW38.1	Barguna	Bishkhali	Barguna	Barguna Sadar	01.04.1990	30.04.2018
23.	SW107	Pirojpur	Gorai-Madhumati – Haringhata – Baleswar	Pirojpur	Pirojpur Sadar	01.05.1952	30.04.2018
24.	SW164	Chandkhali	Kobadak	Khulna	Paikgachha	01.12.1955	28.02.2001

25.	SW259	Nalianala_Hadda Sibsa	Sibsa	Khulna	Dacope	01.04.1961	31.12.2016
26.	SW25	Chapra	Betna – Kholpetua	Satkhira	Assasuni	01.04.1968	30.04.2018
27.	SW29	Sutarkhali Forest Office	Bhadra	Khulna	Dacope	01.04.1968	30.04.2018
28.	SW130	Kaikhali	Ichamati (Western Border)	Satkhira	Shyamnagar	01.04.1968	30.04.2018
29.	SW136.1	Umedpur	Kocha	Pirojpur	Pirojpur Sadar	01.04.1977	30.04.2018
30.	SW253	Swarupkati	Swarupkati	Pirojpur	Nesarabad (Swarupk)	01.01.1959	30.11.2015
31.	SW258	Paikgacha	Sibsa	Khulna	Paikgachha	01.04.1961	30.04.2018

The data in the website are loaded up to 30.04.2018 and thereby any station having data up to 30.04.2018 may be considered as in operation. However, out of 31 stations, tide stations at serial numbers 4, 10 and 24 are not in operation for a long time and may thus be considered as defunct. Tide stations at serial number 3, 12, 14, 18, 25 and 30 were in operation till recent time and thus can be made operative with proper intervention. Maintenance of these float gauges is a real problem, as communicated by senior officials of BWDB during discussions.

Further, there are three stations in the above list of 31 stations of BWDB which also appear in the list of tide stations, being maintained by BITWA. These stations are at serial no. 5 – Khulna (referred as Khulna Port in BITWA list); serial no. 6 – Chalna (referred as Chalna Port Reach in BITWA list) and Serial no. 19 – Mongla (Referred as Mongla Port in BITWA list). In this connection, it is to be noted that the tide stations at Mongla, Chalna and Mongla are being maintained by Mongla Port Authority. There is a possibility that both BITWA and BWDB get water level data from Mongal Port Authority and depend on these data. But, at the same time possibility of two authorities maintaining separate tide gauges at these three stations cannot be ruled out also.

Real Time Tide Data

There are 28 stations for which real time water level data is available in the website of BWDB for the registered users. (Source : http://www.hydrology.bwdb.gov.bd/index.php?pagetitle=real_time_automated_data&sub2=129&_subid=131&id=125). It appears that only Bangladesh National can access these data on real time basis. Out of these 28 stations, six stations are in and around Sundarban, as already mentioned in the above table. These stations are Benarpota (Upazila – Satkhira Sadar) and Shakra (Upazilla – Debhata) of Satkhira District (Serial Nos. 3 and 7); Rayenda (Upazilla – Sarankhola) and Mongla (Upazilla – Mongla) of Bagerhat District (Serial Nos. 14 and 19); Kobadak Forest Office (Upazilla – Koyra) and Nalianala_Hadda (Upazilla – Dacope) of Khulna District (Serial Nos. 12 and 25).

Flood Forecasting and Warning Centre (FFWC)

It is to be noted that a specific organisation under hydrology Department of BWDB works as "Flood Forecasting and Warning Centre" (FFWC). It is being assisted by the International Centre for Integrated Mountain Development (ICIMOD), which is a regional intergovernmental learning and knowledge sharing centre serving the eight regional member countries of the Hindu Kush Himalaya – Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan.

FFWC generates and provides flood forecast and warning information to enhance the disaster management capacity of national agencies and communities using the best scientific principles, real time data, weather forecast information and mathematical models. This center works with partners for continuous updating and improvement of FFWS and capacity of professionals for better services.

Flood Forecasting and Warning Center (FFWC) aims to recognize as a center of emergency response through Flood Forecasting and Warning Services (FFWS) to minimize or mitigate loss of life and damage of properties in more effective manner through enhanced capacity of agency and community for disaster management and to meet national needs of disaster risk reduction.

There are only four stations under the ambit of this centre for making Real Time Forecasting. Out of these four centres, flood forecasting is carried out only at three points namely Sirajganj, Lalon Shah Bridge and Bhairab Bazar, while at Kurigram other weather parameters like Temperature, Relative Humidity, Rainfall, Pressure, Wind Speed, Wind Direction are being reported on real time basis. All these stations are in Northern Bangladesh and far away from the Northern fringe of Sundarbans. Thus, the real time data of these four stations do not really help in understanding the hydrographic as well as weather situation of Sundarban and its impact area.

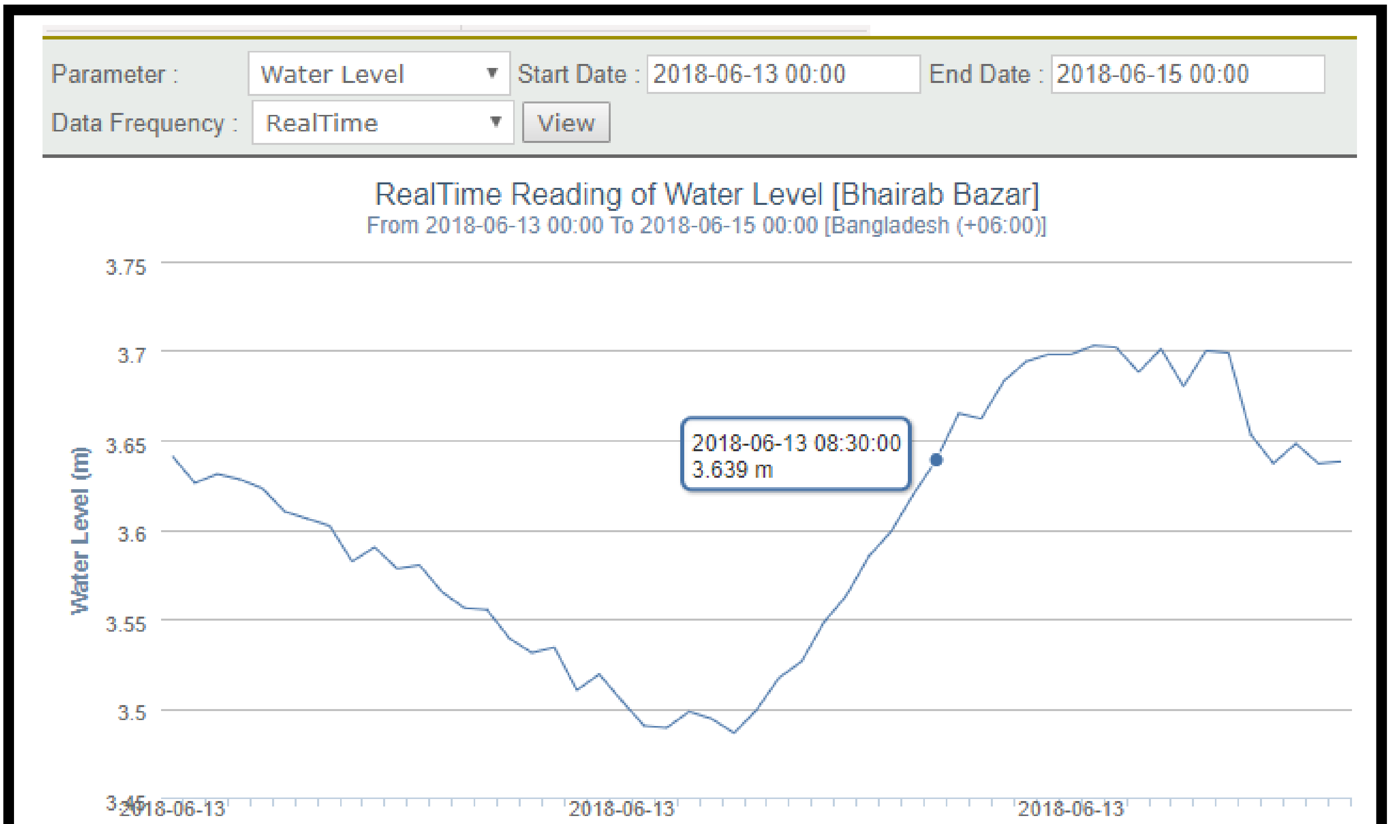


Figure 1.8 : Water Level Fluctuation in Meghna River at Bhairab Bazar
(Source : Website of FFWC http://www.ffwc.gov.bd/)

Incidentally, Bhairab Bazar is located about 240 km (aerial distance) away from northern part of Sundarban.

Tide Gauge Stations as maintained by BNHOC

BNHOC make tidal prediction for 13 (thirteen) ports on daily basis (Source : http://bnhoc.navy.mil.bd/?page_id=79). Out of these only four stations are in and around Sundarbans, namely Hiran Point, Mongla Port, Sundarikota and Chalna Reach. However, it is not clear from any source, whether these predictions are based on the independent observations made by BNHOC or dependent on observations of other organisations like BIWTA. Incidentally, BITWA maintains water level observation stations at all these four stations, as indicated in the Table – 1.17.

Other Hydrological Studies and monitoring

It has already been discussed that the Hydrology Department under BWDB carries out different hydrological studies also, which are important for the Hydro-meteorological set up of Sundarbans. These observations are measurement of Discharge of different rivers at different points, measurement of sedimentation at different points along various rivers, measurement of Evaporation at different stations, measurement of salinity at different points along different rivers, water quality testing at different stations in fixed intervals, River Morphology Studies, Rainfall observation etc.

Some information about these observations / studies has been reported, as stated below:

Discharge Measurements at different Points around Sundarbans

Table – 1.19 : Details of Single Station of discharge measurement located within Bangladesh Sundarban

Sl. No.	Stn Id	Station Name	River Name	District Name	Upazila Name	Data Available	
						First Date	Last Date

1.	SW28	Dumuria	Bhadra	Khulna	Dumuria	09.03.1994	30.09.1998

Interestingly, out of 154 points, where the discharge is being measured along different rivers of Bangladesh, there is only one point in and around Sundarbans, wherein the discharge measurement is being carried out. This may be due to fact that discharge measurements are carried out only at a point which is beyond tidal fluctuation. However, the two major rivers are important for supply of freshwater to Sundarbans are Passur River (a distributary channel of the Ganges and which meet Sibsa River within Sundarbans) which almost bifurcates the Bangladesh part of Sundarbans and Baleswar River(which is also a distributary channel of the Ganges and gets the name at the lower reaches after Gorai-Madhumati – Haringhata rivers) which marks the eastern boundary of Sundarbans. A number of discharge measurements stations are there on the Ganges River as also Gorai–Madhumati– Haringhata – Baleswar Rivers, as described below.

Table – 1.20 : Details of discharge measurement stations located around Bangladesh Sundarban

Sl. No.	Stn Id	Station Name	River Name	District Name	Upazila Name	Data Available	
						First Date	Last Date
1.	SW102	Bhatiapara	Gorai – Madhumati– Haringhata – Baleswar	Gopalganj	Kashiani	02.01.1999	30.08.2001
2.	SW101.5	Kamarkhali (Gondhakhali)	Gorai – Madhumati– Haringhata – Baleswar	Faridpur	Madhukhali	06.09.2001	23.02.2005
3.	SW99	Gorai Railway Bridge	Gorai – Madhumati– Haringhata – Baleswar	Kushtia	Kusthia Sadar	08.09.1980	23.05.2005
4.	SW103	Bardia	Gorai – Madhumati– Haringhata – Baleswar	Narail	Kalia	08.12.1998	22.12.1998
5.	SW101	Kamarkhali Transit	Gorai – Madhumati– Haringhata – Baleswar	Faridpur	Madhukhali	23.03.1983	24.03.2018
6.	SW93.5L	Mawa	Ganges – Padma	Munshiganj	Lohajang	01.06.1994	25.10.2017
7.	SW91.9L	Baruria Transit	Ganges – Padma	Manikganj	Harirampur	11.04.1968	19.04.2018
8.	SW 90	Hardinge Bridge	Ganges – Padma	Kusthia	Bheramara	05.04.1958	31.05.2018

From the data availability time of the discharge data, it is obvious that some of these stations are for temporary period and in those cases the measurement of discharge amount has stopped long back. However, even after such discharge data, it is difficult to estimate the amount of freshwater discharge along Bangladesh part of Sundarbans since it is not expected that total discharge along Ganga Padma is flowing through Sundarbans only. Further, a number of other distributary channels are also there which flow through Sundarbans and discharge measurement along these channels have not been available also.

Measurement of Sedimentation at different Points around Sundarbans

BWDB measures rate of sedimentation along different rivers of Bangladesh at altogether 21 points, list of which is provided at the website. Out of these 21 stations, not a single one falls in and adjoining Sundarbans (Satkhira, Khulna and Bagerhat distriucts), not even in the adjoining districts like Pirojpur, Jhalokati, Borguna, Patuakhali and Bhola. Thus, although BWDB has the infrastructure and capability of measurement of sedimentation along rivers, somehow they have not currently considered to carry out the measurements in any station in and around Sundarbans.

River Water Quality Measurement at different Points around Sundarbans

As per the information provided by BWDB in public domain, the hydrology department normally carries out water quality measurements at 35 stations and make those data available to registered users. Unfortunately, not a single one of these stations falls in and adjoining Sundarbans (Satkhira, Khulna and Bagerhat districts), not even in the adjoining districts like Pirojpur, Jhalokati, Borguna, Patuakhali and Bhola. Thus, the present scenario points to the fact that so far as water quality measurements along the rivers of Bangladesh is considered, Sundarban is being ignored currently, although it is a fragile ecosystem and is being considered as a world heritage site.

Salinity Measurements at different Points around Sundarbans

Increment of salinity along rivers especially in the coastal zone has been going on due to sea level rise as a consequence of climate change. Thus, measurement of salinity along different rivers on regular basis is extremely important for climate studies and research. There are 138 stations at which BWDB carries out salinity measurement on regular intervals. Out of these, about 68 stations are either in Sundarbans or in the adjoining three districts. Thus, altogether approximately 50% of the salinity measurement stations are located in this region. It may be due to the fact that Sundarban is a fragile ecosystem and its sustainability is under threat due to climate change. So, it needs regular monitoring.

Table – 1.21 : Details of Salinity measurement stations along rivers located around Bangladesh Sundarban

Sl. No.	Stn Id	Station Name	River Name	District Name	Upazila Name	Data Available	
						First Date	Last Date
1.	SW1	Bagerhat	Alaipur Khal Daratona	Bagerhat	Bagerhat Sadar	23.04.2000	24.06.2017
2.	SW24	Benarpota	Betna-Kholpetua	Satkhira	Satkhira Sadar	30.12.1999	24.06.2017
3.	SW23	Kalaroa	Betna – Kholpetua	Satkhira	Kalaroa	30.12.1999	24.06.2017
4.	SW244.18	Pashur_26	Rupsa-Pasur	Bagerhat	Mongla	13.01.2017	17.02.2018
5.	SW244.16	Pashur_24	Rupsa-Pasur	Bagerhat	Mongla	13.01.2017	17.02.2018
6.	SW244.3	Badra	Rupsa-Pasur	Bagerhat	Mongla	13.01.2017	16.02.2018
7.	SW244.2	Bajua	Rupsa-Pasur	Bagerhat	Mongla	13.01.2017	16.02.2018
8.	SW241.3	Luban Chora	Rupsa-Pasur	Khulna	Khulna Sadar	13.01.2017	18.02.2018
9.	SW243	Chalna	Rupsa-Pasur	Khulna	Dacope	11.11.2000	18.02.2018
10.	SW241	Khulna	Rupsa-Pasur	Khulna	Khulna Sadar	30.12.1999	18.02.2018
11.	SW243.3	Dacob	Sibsa	Satkhira	Satkhira Sadar	15.01.2017	18.02.2018
12.	SW244R	Mongla Right	Rupsa-Pasur	Khulna	Khulna Sadar	13.01.2017	16.02.2018
13.	SW244.9	Pashur_17	Rupsa-Pasur	Bagerhat	Mongla	13.01.2017	17.02.2018
14.	SW244.7	Pashur_15	Rupsa-Pasur	Bagerhat	Mongla	13.01.2017	16.02.2018
15.	SW243.5	Kalibari Launch Ghat	Sibsa	Satkhira	Satkhira Sadar	15.01.2017	17.02.2018
16.	SW259.9	Shibsa_9	Sibsa	Bagerhat	Mongla	14.01.2017	17.02.2018
17.	SW278	Daulatkhan	Surma-Meghna	Bhola	Daulatkhan	15.11.1993	24.06.2017
18.	SW39	Patharghata	Bishkhali	Barguna	Patharghata	28.02.1994	24.06.2017
19.	SW108	Chardoani	Gorai-Madhumati – Haringhata – Baleswar	Barguna	Patharghata	13.03.1994	24.06.2017
20.	SW105	Off take at Atharobanka	Gorai-Madhumati – Haringhata – Baleswar	Bagerhat	Mollahat	30.12.1999	24.06.2017
21.	SW259.3	Shibsa_3	Rupsa-Pasur	Bagerhat	Mongla	14.01.2017	17.02.2018
22.	SW244.19	Hiron Point Jetty	Rupsa-Pasur	Bagerhat	Mongla	13.01.2017	17.02.2018
23.	SW244.5	Pashur_13	Rupsa-Pasur	Bagerhat	Mongla	13.01.2017	16.02.2018
24.	SW259.7	Shibsa_7	Sibsa	Bagerhat	Mongla	14.01.2017	17.02.2018
25.	SW37.5	Betagi	Bishkhali	Barguna	Betagi	28.02.1994	24.06.2017
26.	SW136	Kawkhali	Kocha	Pirojpur	Kawkhali	27.04.1994	24.06.2017
27.	SW259.4	Shibsa_4	Rupsa-Pasur	Bagerhat	Mongla	14.01.2017	17.02.2018
28.	SW244.11	Pashur_19	Rupsa-Pasur	Bagerhat	Mongla	13.01.2017	17.02.2018
29.	SW244.6	Pashur_14	Rupsa-Pasur	Bagerhat	Mongla	13.01.2017	16.02.2018
30.	SW259.11	Shiba_11	Sibsa	Bagerhat	Mongla	14.01.2017	17.02.2018
31.	SW28	Dumuria	Bhadra	Khulna	Dumuria	07.11.1980	24.06.2017

32.	SW107.2	Rayenda	Gorai – Madhumati – Haringhata – Baleswar	Bagerhat	Sarankhol a	30.12.1999	24.06.2017
33.	SW259.5	Shibsa_5	Rupsa – Pasur	Bagerhat	Mongla	14.01.2017	17.02.2018
34.	SW244.8	Pashur_16	Rupsa – Pasur	Bagerhat	Mongla	13.01.2017	16.02.2018
35.	SW242.2	Pashur_2	Rupsa – Pashur	Khulna	Khulna Sadar	13.01.2017	18.02.2018
36.	SW259.10	Shibsa_10	Sibsa	Bagerhat	Mongla	14.01.2017	17.02.2018
37.	SW38	Bamna	Bishkhali	Barguna	Bamna	28.02.1994	24.06.2017
38.	SW244.17	Pashur_25	Rupsa – Pasur	Bagerhat	Mongla	13.01.2017	17.02.2018
39.	SW244.15	Pashur_23	Rupsa – Pasur	Bagerhat	Mongla	13.01.2017	17.02.2018
40.	SW244.12	Pashur_20	Rupsa – Pasur	Bagerhat	Mongla	13.01.2017	17.02.2018
41.	SW244.10	Pashur_18	Rupsa – Pasur	Bagerhat	Mongla	13.01.2017	17.02.2018
42.	SW244L	Mongla Left	Rupsa – Pasur	Khulna	Dacope	13.01.2017	16.02.2018
43.	SW244	Mongla	Rupsa – Pasur	Bagerhat	Mongla	11.11.2000	24.06.2017
44.	SW243.4	Badbuir Bazar	Sibsa	Satkhira	Satkhira Sadar	15.01.2017	18.02.2018
45.	SW259.6	Shibsa_6	Sibsa	Bagerhat	Mongla	14.01.2017	17.02.2018
46.	SW259.12	Shibsa_12	Sibsa	Bagerhat	Mongla	14.01.2017	17.02.2018
47.	SW20	Amtali	Barisal – Buriswar	Barguna	Amtali	02.12.1994	24.06.2017
48.	SW38.1	Barguna	Bishkhali	Barguna	Barguna Sadar	28.02.1994	24.06.2017
49.	SW107	Pirojpur	Gorai – Madhumati – Haringhata – Baleswar	Pirojpur	Pirojpur Sadar	28.02.1994	24.06.2017
50.	SW164	Chandkhali	Kobadak	Khulna	Paikgachh a	22.11.1976	27.03.1980
51.	SW244.13	Pashur_21	Rupsa – Pashur	Bagerhat	Mongla	13.01.2017	17.02.2018
52.	SW244.4	Chal Bogi	Rupsa – Pashur	Bagerhat	Mongla	13.01.2017	16.02.2018
53.	SW244.1	Dhang Mari	Rupsa – Pashur	Bagerhat	Mongla	13.01.2017	16.02.2018
54.	SW242.1	Pashur_1	Rupsa – Pashur	Khulna	Khulna Sadar	13.01.2017	18.02.2018
55.	SW254.5	Elachar	Satkhira Khal	Satkhira	Satkhira Sadar	15.11.2001	24.06.2017
56.	SW259.2	Kala Bogi	Sibsa	Satkhira	Satkhira Sadar	14.01.2017	17.02.2018

57.	SW259	Nilianala_Hadda	Sibsa	Khulna	Dacope	23.04.2000	17.02.2018
58.	SW136.1	Umedpur	Kocha	Pirojpur	Pirojpur Sadar	25.11.1996	24.06.2017
59.	SW244.14	Confluence of Shibsa	Rupsa _ Pasur	Bagerhat	Mongla	13.01.2017	17.02.2018
60.	SW243.1	Pashur_5	Rupsa _ Pasur	Khulna	Khulna Sadar	13.01.2017	16.02.2018
61.	SW242.3	Jhop Jhopia	Rupsa – Pasur	Khulna	Khulna Sadar	13.01.2017	18.02.2018
62.	SW241.2	Rupsa Bridge	Rupsa – Pasur	Khulna	Khulna Sadar	13.01.2017	18.02.2018
63.	SW244.2	Chaud Pai	Rupsa – Pasur	Bagerhat	Mongla	13.01.2017	18.02.2018
64.	SW242	Jalma	Rupsa – Pasur	Khulna	Batiaghata	13.01.2017	18.02.2018
65.	SW259.1	Hadda Khal	Sibsa	Satkhira	Satkhira Sadar	14.01.2017	17.02.2018
66.	SW259.8	Shibsa_8	Sibsa	Bagerhat	Mongla	14.01.2017	17.02.2018
67.	SW258	Paikgacha	Sibsa	Khulna	Paikgachha	23.04.2000	24.06.2017
68.	SW253	Swarupkati	Swarupkati	Pirojpur	Nesarabad (Swarupkati)	28.02.1994	24.06.2017

In case of some of the stations, like at Chandkhali (Serial no. 50), the observation has been stopped a long time back, but the database already available for the previous time may be used as control data for comparison with present day measurements. Although, nothing has been mentioned regarding the type of tide gauges used in the individual stations, but looking at the time of installations and the temporary nature of these stations, the float gauge type of installations are most likely. Even use of tide pole gauges or tide staffs gauges in some stations is also possible.

Real Time/ Automated Data Measurements at different Points around Sundarbans

It has already been discussed that BWDB carries out water level measurements along different rivers of Bangladesh at 366 stations covering entire Bangladesh. Out of these, diurnal tidal fluctuations occur at 128 stations. However, water level measurements at 28 stations only have been disseminated to public domain by BWDB on real time basis.

Out of these 28 stations, 10 (ten) stations are located around Sundarbans. Since the water levels are also measured here on real time basis, so the constant measurements of water levels ultimately provide the tidal fluctuations at these stations. Tidal data, as measured, is provided only to the registered users on real time basis. However, Graphical views of the data are also available at the website of the BWDB on delayed basis, which also covers all the above mentioned stations. It has been observed that the water levels in all these stations are also measured with respect to PWD datum, already described.

Table – 1.22 : Table enlisting the water measurement stations in and around Sundarbans where the data are provided on real time basis

Sl. No.	Stn Id	Station Name	District Name	Upazila Name	Data Available	
					First Date	Last Date
1.	SW24	Benarpota	Satkhira	Satkhira Sadar	01.04.1968	30.09.2017
2.	SW128	Shakra	Satkhira	Debhata	01.04.1968	30.04.2018
3.	SW165	Kodak Forest Office	Khulna	Koyra	01.041968	30.06.2016
4.	SW107.2	Rayenda	Bagerhat	Sarankhola	01.04.1968	30.06.2016
5.	SW184	Patuakhali	Patuakhali	Patuakhali Sadar	24.10.2015	24.10.2015
6.	SW244	Mongla	Bagerhat	Mongla	01.10.1960	30.04.2018
7.	SW259	Nalianala_Hadda	Khulna	Dacope	01.04.1961	31.12.2016
8.	SW38.1	Barguna	Barguna	Barguna Sadar	01.04.90	30.04.2018
9.	SW253	Swarupkati	Pirojpur	Nesarabad (Swarupkati)	01.01.1959	30.11.2015
10.	SW37	Jhalokati	Jhalokati	Jhalokati Sadar	01.05.1952	30.04.2018

Studies on River Morphology

Studies on River Morphology are being carried out by BWDB on regular basis at different points and on different rivers. The cross-sectional areas as also the bathymetry of the rivers at the specific points are measured over the years to make a comprehensive idea about siltation along the rivers and/or erosion of the banks and so on. During bathymetry studies, normally the depth is measured with respect to PWD datum. However, in many cases, the depths are measured with respect to a local datum. Graphical data from the website indicates that in some cases rather than measuring the cross-sectional depth, the thalweg depth is measured and recorded as the depth of the river. River morphology studies are carried out altogether at 1464 stations covering almost all the rivers and tributaries. Detail list of these 1464 stations are available at website of BWDB. A number of stations are located in and around Sundarban. However, in many of these stations, river morphology study has so far been carried out only once as clearly mentioned in that list. Unfortunately detail bathymetry studies along the estuaries and in tributaries and creeks of Sundarban has so far not being carried out, although sufficient infrastructure and logistic arrangements seem to be available with BWDB.

Summary of the existing Hydro-meteorological system in and around Sundarbans

From the above discussions, it is obvious that the existing hydro-meteorological system in Sundarbans is far from satisfactory. This is true the entire Sundarbans covering both the countries, as summarised below:

- There is not a single tidal observation centres in Indian part of Sundarbans. All the tidal gauges in Indian part of Sundarbans are located along Hooghly River and far from the Sundarbans. Thus, the actual SLR along Indian Sundarbans is still a guess work.
- Some of these stations along Hooghly River are still manual in nature and thereby allow day time observations only. Possibility of manual errors in successive measurements cannot be ruled out.
- In case of Bangladesh part of Sundarbans, although about 10 (ten) tidal stations (maintained by BITWA) are there, but systematic covering (Latitude – Longitude wise distribution) of the entire Sundarban area is completely lacking. Some of these stations like Dublakhal have also stopped functioning a long time back
- BWDB on the other hand maintains about 31 number of 'Water Level Measurement Stations' in and around Sundarbans. Since all the rivers at the measurement points are tidal in nature, thereby continuous measurements of water levels at these points actually serve the purpose of tide level measurements. Incidentally, some of these stations has stopped functioning long back; at the same time, some of these stations like Khulna and/or Chalna etc have been functioning for quite long time and thereby having the records for about last 100 years.
- At least six stations of BWDB located within Sundarbans disseminate tide data on real time basis in the website of BWDB, which is definitely commendable in nature.
- All these tide gauge stations in Bangladesh are conventional "Float Gauges". How many of these stations are automatic and fitted with data recording "Drum and Pen" and/or Data Logger cannot be ascertained at this moment.
- There is no standard datum for observation of the water level of the entire Sundarbans leading to confusion. Thus, the tidal level being mentioned at Indian part of Sundarbans is difficult to match with those in Bangladesh part, although belonging to same physiographic unit.
- Even within the same country, the datum for different tidal stations is different and basically local in nature. As for example, the tide station at Garden Reach in India use KODS as the datum, while that at Sagar has a different datum. Similarly, BWDB and BITWA, being agencies under the same National Government use different datum. Such differences in datum ultimately lead to confusion and it is difficult to make any correlation between different tide gauge levels.
- Although, the tidal stations have been measuring the eustatic level of waters at the measurement stations, but the quantum of subsidence which is conclusively adding to the Relative Sea Level Rise (RSLR) has not been measured even at a single point.

Thus, it is not possible and unfortunately has not been attempted so far to understand the actual component of SLR within this RSLR due to climate change at any of these tide gauge stations in both the countries.

- The datum correction, which needs to be carried out after specific interval of time is not being carried out in case of float gauges which may lead to erroneous measurements. Further, in case of the "Float Gauges", the water level measurement is dependent on the density of the tidal water. In case of Bangladesh, since the discharges of the freshwater along all the rivers vary widely during summer and monsoon, it is difficult to consider the water level measurements as absolute and due to SLR only due to wide variation in density of the estuarine water. However, this is a universal problem with "Float Gauges" and hence is being phased out with modern equipment in recent time in other parts of the world.
- The hydrodynamic parameters like bathymetry, current speed and direction measurements in different tidal phases and at different layers of estuarine water over the years, freshwater discharge measurements, wave heights measurements etc are not being carried out at all in Indian Sundarbans. Systematic water quality measurements over the years for identification of salinization are also not being carried out, although measurements of water quality parameters are being reported in scientific literature on sporadic basis for a temporary project period.
- There is no practice of water quality measurements of the estuarine water along Bangladesh Sundarbans except salinity measurements at several different points. However, records point to the fact that in many cases such measurements are being carried out for a very short duration along the rivers at specific points and thereby it will be difficult to make any comprehensive idea regarding salinization over the years due to climate change in absence of long term data.
- BWDB claims to make River Morphology studies on regular basis along the rivers of Bangladesh including those in Sundarbans. However, data available in website points to the fact that there is total absence of systematic bathymetry surveys along pre-determined plan lines across the cross sections of the rivers. In many cases thalweg depth is measured. There is also no fixed datum. In absence of these precisions, it is difficult to make any comparison regarding the changes in bathymetry, as also sedimentation and bed level rise of the estuaries.
- Measurement of other hydrodynamic parameters like current speed, directions during different tidal phases and at different water depths, wave heights etc are not at all measured along Bangladesh part of Sundarbans.
- Indian part of Sundarbans is almost totally landlocked except the River Hooghly which marks the western boundary of Indian Sundarbans and the Harinbhanga River (also known as the Icchamati River marking the eastern boundary of Indian Sundarbans). However, the upland discharge along Harinbhanga River has almost stopped due to

unauthorised reclamation of the river bed as is evident from the remote sensing image. Thus, freshwater discharge for Indian Sundarbans seems to be not so relevant with the present physiographic condition.

- However, for the Bangladesh part of Sundarbans it is quite relevant and discharge measurements at Ganges-Padma cannot reflect the actual amount of freshwater discharge along the Sundarbans since Ganga-Padma has a number of distributary channels and only a few of these pass through Sundarbans. It is also interesting to note that the discharge of water is measured at least 8 (eight) points in and around Sundarbans, but it is difficult to comprehend whether such discharge measurements actually denotes freshwater discharges or not since it is hardly possible to understand whether these stations are beyond tidal actions.
- There is no measurement regarding the rate of sedimentation within Sundarbans, in both Indian and Bangladesh, although it has been predicted that abundant sediment supply from sea side may allow the estuary to 'warp up' for keeping pace with sea level changes – the "Rollover Model" (Pethick & Lowe, 2000a & 2000b; Pethick, 2001).
- No flood monitoring station or flood recording station does exist in Indian Sundarbans. Thus, during a natural calamity like 'Cyclone Aila' (which occurred on 23rd May, 2009), there is hardly any authentic report on scale of inundation and flooding of different inhabited islands of Indian Sundarbans due to breaching of embankments. Researchers have to depend on the versions of the local population, which are many times contradictory in nature.
- Even there is no record available in the worst affected villages whether water enters into the villages by 'over topping' the embankments after which the breaching of embankments took place due to pore pressure or water entered the village due to breaching of embankments first as a result of wave action and mass slumping of the earthen embankments as a consequence of wet condition. In absence of this crucial information, the wave heights due to cyclone cannot be confirmed also.
- Although Bangladesh maintains four stations as part of FFWC for real time forecasting of flood situation, unfortunately none of these stations are located in and around Sundarbans.
- There are only six Surface Observatories under IMD around Indian Sundarbans, out of which only one, namely at Canning is only located in Sundarbans. Unfortunately, this is not automatic and observations are made from Dawn to Dusk only. There is no Digital High Wind Speed Recorders (HWSR) in Sundarbans to record the wind speed during cyclones. Both Haldia and Digha are located far away from Sundarbans. Thus, it is difficult to make validation of the forecasting regarding wind speed during cyclones in and around Indian Sundarbans.

- Amongst the Non-departmental Surface Observatories in and around Sundarbans, Basirhat is the nearest one from where the northern most point of mangrove forests of Sundarbans is more than 52 km, while from Hasnabad, nearest town within Sundarbans, is about 10 km. Being Non-departmental in nature, seamless measurements and its transmission to IMD server for weather modelling of the weather parameters are not being done here. As has already been described, readings are taken normally twice in a day and in some cases once in a day and the same are communicated to RIMC over phone or by WhatsAPP which are then fed into the model.
- Although altogether five AWS are there within Sundarbans, namely at Canning, Kakdwip, Nimpith, Raidighi and Sagar Island, but the communication of data from these AWS is to some extent irregular due to maintenance problems.
- There is not a single Automatic Rain Gauge (ARG) Station in Sundarbans. The nearest one is at Deganga in North 24-Parganas, which is at a distance of about 30 kms from Hasnabad, nearest township within Sundarbans and the northernmost edge of Sundarban mangrove forest is about 60 kms away. Thus, the five AWS stations only record the rainfall over an area of about 4,200 sq. km of Indian Sundarbans.
- In contrast to Indian Sundarbans, there are altogether eight surface observatories for recording of meteorological around Bangladesh part of Sundarbans, out of which at least four surface observatories namely at Khepupara, Khulna, Mongla and Satkhira are either within Sundarbans itself or within the ECA or SIZ.
- So far as sea surface meteorological observation station is concerned, there is only a single such station at Digha installed recently under OON, but the observations made at this station are neither used for weather forecasting, nor even used for validation. It also does not cover Sundarbans due to distant location. Interestingly, there is not a single sea surface meteorological station along Bangladesh coast, even under OON (Ocean Observation Network).
- There are altogether 32 Rain fall measurement stations in and around Bangladesh part of Sundarbans. In most the cases, the data available is for a period of about 60 years or so. But, evaporation measurement stations are very few in number, only 7 (seven), although definitely exceeds such facility available in Indian part.
- There is no DWR in Bangladesh although the DWR at Kolkata covers the entire Sundarbans even in close range. However, Bangladesh gets the cyclone warnings from Regional Specialized Meteorological Centre (RSMC) for Tropical Cyclones over North Indian Ocean, New Delhi (Source : http://www.rsmcnewdelhi.imd.gov.in/index.php?lang=en) as per international arrangement under Severe Weather Forecasting Demonstration Project of World Meteorological Organization (Source : http://www.wmo.int/pages/prog/www/swfdp/SWFDP-SeA.html).

- Collection of different weather parameters and using those on real time basis for operational forecasting are the two most important issues required for saving the life and property of the common people as also for the natural resources. At the same time area specific forecasting with considerable time in hand before any natural calamity is also required to safeguard the interest of the citizens.

- Although, numbers of weather forecasting are being carried out in both the countries in frequent intervals, those are always targeted towards coastal part on a generic mode. There is not a single weather forecasting targeting towards people and natural resources of Sundarbans covering more than 10,000 km^2 and having a population size more than Sweden, Switzerland or Portugal etc.

- IMD, Kolkata Office maintains several social media like WhatsAPP Groups etc. for timely passing the area specific information especially nowcasting, but that is quite inadequate to get disseminated amongst the larger section of population. Further, there is hardly any location specific forecasting for Sundarbans at all, although it has been predicted to be one of the most vulnerable areas in the backdrop of climate change.

- Regional cooperation on sharing of weather/ climate data of Sundarbans between two countries is completely absent. Though some of the weather data are displayed in the website of BWDB for placing in the public domain, it is meant only for the registered users and only Bangladesh Nationals can be registered users in this website for accessing the data.

- It can thus be summarised that the present hydro-meteorological set up in Sundarbans covering both the countries have practically no infrastructure as also logistic and institutional arrangements for measurements and transmission of micro-climatic parameters required for area-specific weather modelling on real time basis and operational forecasting in short intervals with proper local level arrangements for timely dissemination among the community.

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