Inventory of Freshwater Resources in the Sundarbans Landscape, Limited to the part of Landscape Located in India

1. Introduction

Water is a prime natural resource, a basic human need and a precious national asset. Water is fundamental to life, livelihood, food security and sustainable development. Planning, development and management of water resources are extremely important for the development of a fragile landscape like Sundarbans. Experts believe that the nexus between natural resources and water is key to sustainable and equitable economic development and growth in any State or Region. With the increasing population, the freshwater sources are getting exploited all over the world. Surface water is used more often than groundwater due to its easy accessibility. About 2.1 billion people in the world lacked safely managed drinking water services at home in the year 2015 (WHO and UNICEF, 2017).

At the same time 'freshwater is under stress due to its limited supply and increasing demand all over the world' (State of Environment Report, West Bengal, 2016). Fresh water is not available in plenty everywhere all the time. The demand of water will increase in accordance with the growth of population. The demand of water for a human being is not only restricted to his or her domestic demand. The water-footprint of a person is much larger than normally understood. It is estimated that 1,300 m^3 of water is required to produce food for a person at desired nutritional level (Falkenmark and Rockstorm, 2005). The ecological services demand more water. A human being needs 1,700 m^3 of water/year to satisfy all kinds of requirement. When the annual per capita availability of water is less than 1,000 m^3, the area is supposed to be suffering from "water-scarcity". When availability is between 1,000-1,700 m3, the area is considered as "water stressed". The per capita availability of water in West Bengal was 4,023 m^3 in 1951 and it declined to 1,159 m^3 in 2011 (SoE, West Bengal, 2016).

The Sundarbans region is one of the richest ecosystems in the world. The region contains arguably the world's largest remaining area of mangroves, and is known for its exceptional biodiversity, including numerous threatened species such as the emblematic Royal Bengal tiger and several species of river dolphin (The World Bank, 2014). In spite of the fact that Sundarbans is surrounded by rivers and sea on all sides except north and at the same time criss-crossed by innumerable creeks, there remains water crisis all over Sundarbans, since the water is saline in nature. Even the groundwater in shallow aquifers are quite saline and thereby beyond reach of the common men. In this backdrop, an attempt has been made to assess the freshwater availability in Indian part of Sundarbans.

2. Study Area

Sundarban landscape or the *Sundarban* Delta (also called the Ganges-Brahmaputra Delta) is the largest delta in the World (area nearly 105,000 km^2, house to 123 million people). The delta lies in Bangladesh and India (19% in India and 81% in Bangladesh), but rivers from Bhutan, China, India, and Nepal drain into it from the north. Most of the delta is composed of alluvial soils made up by small sediment particles. Red and red-yellow lateritic soils are found towards further east. The soil has large amounts of minerals and nutrients and is good for agriculture. It has the reputation as the highest (agriculture) productive delta in the World.

The Sundarban landscape is a labyrinth of rivers, channels, swamps, lakes, and flood plain sediments (called 'char's). Where the delta meets the Bay of Bengal, Sundarban mangroves form the world's largest mangrove eco-region, covering an area of 20,400 km^2 in a chain of more than 100 islands, of which about 10,200 km^2 is mangrove forests (60% in Bangladesh, 40% in India) (Das & Siddiqi, 1985). It is one of the richest ecosystems in the world, and is known for its exceptional biodiversity, including numerous threatened species such as the emblematic Bengal tiger, several species of river dolphins as well as numerous fauna including species of birds, spotted deer, crocodiles and snakes. It has been declared as a UNESCO World heritage site. The forest part attracts significant protection status 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".

Sundarbans is the single largest deltaic tidal halophytic mangrove forest in the world, (Blasco, 1977) with an area of 10,200 km^2 area, spreading over India (4,263 km^2 of Reserve forest) and Bangladesh (5,937 km^2 of Reserve forest). In both the countries, it has been declared as Reserve

Forest. In India, the Sundarban mangrove ecosystem covers an area of about 4,263 km^2 out of which about 2,530 km^2 is under forest canopy. Another 5,400 km^2 of non-forest, more precisely reclaimed forest, human inhabited region along the north and north-western fringe of mangrove forest is also known as Sundarban. Hence, the total area of Sundarban region in India is 9,630 km^2, which forms the Sundarban Biosphere Reserve (SBR). Thus, Indian Sundarbans is divided into two parts, reclaimed and non-reclaimed. Since this write up is related to the Indian part of Sundarbans only, so hereinafter Sundarbans referred in this document will only be related to Indian Sundarbans, excluding Bangladesh part.

Figure – 1 : Sundarbans Region in India and Bangladesh (Sanchez-Triana & et al, 2014)

It lies south-east of Kolkata in the South & North 24-Paraganas Districts of West Bengal and forms part of the Gangetic Delta, which borders on the Bay of Bengal. Indian Sunderbans lies between 21^0 30’ to 22^0 15’ North Latitude and 88^0 to 89^0 9’ East Longitude. Rudra, 2018, described that ‘According to official record, the Indian Sundarban covers 104 islands, of which 54 have been deforested. But counting from recent satellite image reveals that the total number of islands is 128, of which 29 islands are settled by mankind. Since the earlier counting was done after independence, many smaller islands have been coalesced together because of decay of intervening channels and new islands have emerged by the process of accretion.’ (Rudra, 2018). Much of the area of the Sundarban has been reclaimed for agriculture during the past 200 years but a significant seaward fringe of natural mangrove forest still exists.

This is also the only mangrove tigerland on the earth. A Tiger Reserve (2585 km^2), 3 sanctuaries and one National Park (1330 km^2) exist within Sunderbans. It is the nursery for nearly 90% of the aquatic species of east coast. The coastal fishery of east coast is dependent on Sunderbans. The mangrove forest is also providing shelter to the Kolkata metropolitan city from annual high gales. Total number of major elements of mangroves, minor elements of mangroves, back mangroves and the mangrove associates are estimated and reported as about 90% of the total mangrove species of the Indian sub-continent.

Mangroves Forest of Sunderbans

Formed at the estuarine phase of the Ganges-Bramhaputra river system, the Sunderban mangrove ecosystem covers an area of about 2,529 km^2 under forest canopy (Bhattacharyya, 2015). However, the landscape of the Indian Sunderbans have changed remarkably due to neo-tectonic movement and tilting along a hinge zone starting from Sagar to Malda (Morgan and McIntire, 1959). As a result, quantity of upland discharge particularly in Indian Sunderbans decreased over time. Compounded with it, large-scale human intervention has started from the beginning of the last century. As a result several species have become extinct or are in very much threatened or degraded state (Gopal & Chauhan, 2006; Sodhi et. al., 1987). The mangrove swamps are dynamic and differ horizontally and vertically due to the varying environmental conditions (Rudra, 2018). Mangroves show distinct type of assemblages based on salinity, landform, position of the trees so on and the assemblages of the mangroves into different zones have been studies in detailed using remote sensing technology (Bhattacharyya, 2015).

Administrative set up within Sundarban Forest

Entire Mangrove Forest in Sundarbans has been declared as Protected Forest. It consists of two major divisions namely 24-Parganas (South) Division and Project Tiger Division. The mangroves forest of Sundarbans has been divided into 22 forest blocks. 24-Parganas (South) Division consists of seven Forest Blocks namely, Muriganga, Saptamukhi, Thakuran, Chulkati, Dulibhasani, Ajmalmari and Herobhanga. On the other hand, Project Tiger Division consists of fifteen Forest Blocks namely Matla, Goashaba, Chhotahardi, Mayadwip, Chamta, Chandkhali, Gona, Netidhopani, Panchmukhani, Pirkhali, Harinbhanga, Jhilla, Khatuajhuri, Arbesi and Baghmara forest blocks, which are bounded by the Matla/Bidya and Haribhanga/Raimangal rivers to the western and eastern sides respectively.

Sundarban Biosphere Reserve was notified under the administrative control of Department of Forests, Government of West Bengal in March, 1989 and was ultimately constituted as

National Biosphere Reserve under Man and Biosphere Reserve Programme by UNESCO during November 2001. The eastern part of the mangrove forest (about 2,585 km^2) has been declared as Sundarban Tiger Project (STR) area. A major portion of STR has been further declared as a National Park, which is otherwise known as "Core Area" (1330 km^2), by Ministry of Environment & Forests (MOEF), Government of India. Other than this, three islands within the mangrove forests namely, Sajnekhali, Lothian and Halliday have also been declared as Wildlife sanctuaries by Ministry of Environment & Forests, Government of India. It has been declared as a World Heritage Site by IUCN in 1985.

Jurisdiction within Populated Areas

72nd amendment of the Constitution of India guarantees decentralized planning through democratically elected three-tier local bodies. As per this, lowest level body is Gram Panchayat (GP) consisting of 10-15 hamlets, then *Panchayat Samity* (coinciding with Comprehensive Development Block) consisting of several G.P.s and ultimately *Zilla Parishad* (District Council) at individual district level. There are altogether 19 blocks – six blocks of North 24-Parganas district and thirteen blocks of South 24-Parganas district under SBR. Six blocks under 24-Parganas North District are Haroa, Hasnabad, Minakhan, Sandeshkhali-I, Sandeshkhali-II and Hingalganj. Thirteen blocks under South 24 Parganas District are Canning-I, Canning-II, Gosaba, Basanti, Joynagar-I, Joynagar-II, Kultali, Mathurapur-I, Mathurapur-II, Kakdwip, Pathar Pratima, Namkhana and Sagar.

Total number of GPs under SBR is 190 – 50 in North 24-Parganas and 140 in South 24-Parganas district. A major part of the development works at these blocks and G.P.s is funded by Department of Panchayats & Rural development, Government of West Bengal. There are altogether 1297 hamlets, which constitute these G.P.s and blocks. In each village, there is a *Gram Sansad* (Village Panchayat), which is the forum for discussion of all the villagers. District Collectors of two districts and the Director SBR play important role in mitigating and coordinating different works being carried out by different agencies in Sundarbans. Thus, a number of agencies with different mandates and outlooks are operational in Sundarbans and a number of regulations are currently in vogue. Line departments of Government of West Bengal especially PHED are also currently implementing a number of drinking water supply projects in Sundarbans.

Climate

The climate is moist sub-humid and characterised by hot summers and mild winters and can be divided into three distinct seasons - Hot Dry, from March to early June, Hot Wet, from mid-June to September and Cold from October to February. The mean monthly temperature varies between 30^0 C and 40^0 C during the summer months. Winter is very pleasant with minimum temperature varying between 15^0 C to 20^0 C. Rain water is the major freshwater source in Sundarbans. Sundarbans receives rain mainly from South-West monsoon. Annual rainfall is about 1750-1800 mm of which 80% precipitation takes place between June and September. The average annual rainfall is 1625 mm but this may increase to 2000 mm in the high rainfall year and drop to 1300 mm in lowest rainfall year (Dasgupta, 2008). The mean annual rainfall covers 80 to 90% of the annual potential evapo-transpiration. Relative humidity is over 85% from June-September and over 70% from October-May.

Hydrology

Sundarbans, world's largest delta formed from sediments deposited by three great rivers, the Ganges, Brahmaputra and Meghna, which converges on the Bengal Basin. It has already been mentioned that the entire Sundarban area is intersected by an intricate network of interconnecting waterways, of which the larger channels like Matla are often more than 10 km in width and run in a north-south direction. There are altogether six major estuaries flowing through the Indian Sundarban – the Muriganga, the Saptamukhi, the Jamira, the Matla, the Gosaba and the Harinbhanga. Only two of these estuaries carry freshwater to Bay of Bengal during non-monsoon season - the Muriganga and the Harinbhanga (Rudra, 2018). Rest now carry little freshwater as they are mostly, if not all, are cut off from the Ganges, the outflow of which has shifted from the Hooghly-Bhagirathi channels progressively eastwards since the seventeenth century (Seidensticker and Hai, 1983) and can be termed as tidal creeks. The tidal creeks are funnel shaped being wide at the sea-face and narrow at their northern limits. This is due to subsidence of the Bengal Basin and a gradual eastward tilting of the overlying crust (Rudra, 2018).

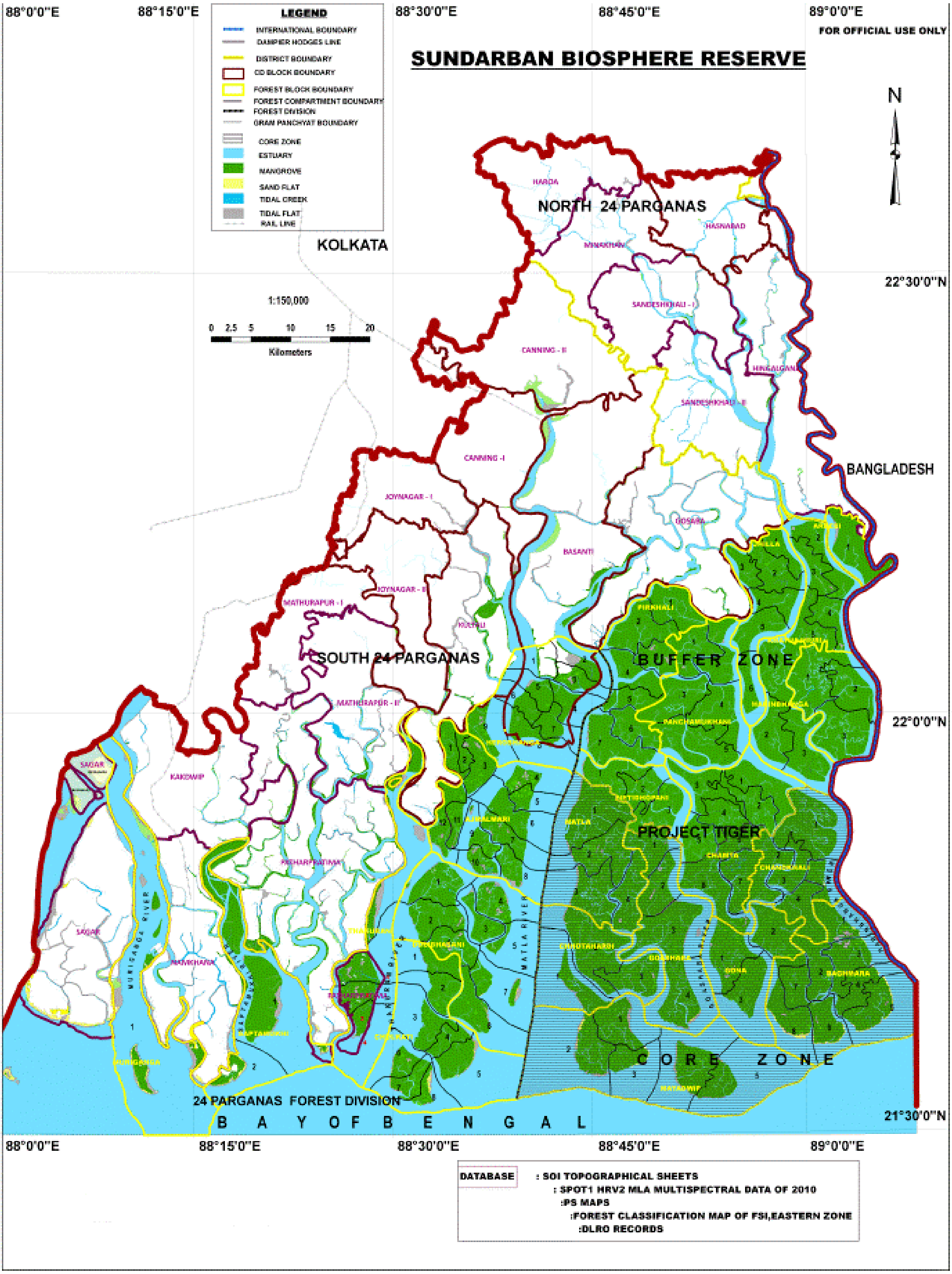
Entire Sundarbans is macrotidal (tidal range: >4 m) in nature and is characterized by embroidery of tidal creeks, encompassing the islands and offshore linear tidal shoals, aligned perpendicular to the shoreline and separated by swales. The hydrology here is mainly governed by the diurnal tide. In the Indian Sundarbans, the western portion receives some freshwater through the Bhagirathi-Hooghly river system but that portion designated as the tiger reserve is essentially land-locked, its rivers have almost completely cut off from the main freshwater sources over the last 600 years (Sanyal and Bal, 1986). Thus, waterways in the tiger reserve are maintained largely by the diurnal tidal flow, the average fluctuation being about 2.15 meters on the coast and up to 5.68 meters on Sagar Island (Lahiri, 1973). Tidal waves are a regular phenomenon and may be up to 6.5 meters high. Neap tidal range varies from 1.7 to 2.13 m. Tidal length in different inlets ranges from 60-80 km. In Hoogli river, the largest and widest channel of the region, it is more than 250 km. Wave height ranges from 0.1-0.6 m with a wave period of 5-7 seconds during the clam winter seasons whereas, these become 1.8-2.4 m and 12-

14 seconds during the rough summer season. During periods of cyclonic storms, wave height goes above 2.4 m and wave period above 14 seconds (Bhattacharyya, 2015).

Geomorphology

The present day configuration of Sundarbans is the outcome of the combined effects of deltaic deposits of the Ganga-Brahmaputra Rivers, the tidal deposits from the Bay of Bengal in a basement of the Bengal basin where there are events of Tertiary history of tectonic subsidence. These landmasses are very recent in origin, only 6000-7000 years old. The landscape of the Indian Sundarbans have changed remarkably due to the neo-tectonic movement and tilting along a hinge zone during 16th century. As a result, the course of the River Ganga has undergone a major tilt towards east and the quantity of upland discharge particularly in Indian Sundarbans decreased over time. This has a combined effect on the changes in salinity regime and consequent floral distribution along the Indian part of Sundarbans. This deltaic plain has a gentle seaward slope and major portion of it lies 5-7 meters above Mean Sea Level. The cumulative effect of the uplift operating for quite a long time progressively steepened the surfaces of older landforms all of which were initially much flatter. Deltaic plain of modern delta of comparable lithology slopes at 0.07 m/km while the Ganga delta slopes 0.1 m/km towards south.

There are 4 geomorphologic units as mapped by Geological Survey of India viz., i) Flood Plain of River Basin as occurring in the study area is very small lying NW of Diamond Harbour, ii) Lower Matured Deltaic Plain lying in Diamond Harbour and eastern part of it, iii) Lower Active Tide Dominated Deltaic Plain and shares a significantly larger area in an around Kakdwip and further east and southernmost part of Kakdwip and iv) Offshore Zone of Pro-delta occurring in Sagar Island and rest of the Islands of Sundarban region.



Figure–2 : Map of Sundarban Biosphere Reserve (Source : Sensarma & Bhattacharyya, 2013)

Soils

The soil under forest cover of mangroves is clayey loam down to a depth of 1.1 to 1.4 m and thereafter stiff black clay and sand. Soil of the area is affected by severe flooding with saline water resulting in very strong salinity of the soil. It is alkaline due to an excess of sodium chloride. These soils are known as Ardisols. The subsoil consists of alternate layers of clay and sand gradually changing into shale and sandstones. Soils of SBR are mainly river alluvium mixed with marine sediments and belong to clay, silty clay and silty clayey loam types. Drainage is governed by soil texture, landform situation and depth of ground water table. Textural analysis of the soil samples points to the fact that soil is poorly drained in nature. According to the modern system of soil taxonomy adopted by the United States Department of Agriculture (USDA), the soils of Sundarbans can broadly be classified as Inceptisols (comprising mainly younger alluvial soil) and Alfisols (comprising older alluvial soil and red soil).The Inceptisols are of five types namely (i) Deep fine clayey soils, (ii) Deep fine loamy soils with moderate salinity, (iii) Deep fine loamy soils with strong salinity, (iv) Deep fine clayey soils with moderate salinity and (v) Deep fine clayey soils with strong salinity. The Alfisols are present in a small area in the north-eastern part of SBR in North 24 Parganas district.

Population in Sundarbans

Vulnerability of the Sundarbans along with other reasons is primarily due to the fact that about 5 million people are dwelling within Indian Sundarbans. Without having no other source of livelihood, these people depend solely on agriculture and/or fisheries. Thus, life and livelihood of these 5 million people are directly dependent on the freshwater availability in Sundarbans which is a primary necessity for agriculture. Details of population dependent on Sundarbans are given below:

Table – 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**

3. Objectives

- To identify total freshwater demand of Indian Sundarbans
- To identify and look into the problems of availability of freshwater in Sundarbans
- To take a stock of different freshwater sources already available in Sundarbans
- To look into the future possibilities of harnessing freshwater supply in Sundarbans
- To look into the policy aspect of exploring the newer opportunities and to throw light on this specific issue in case of all the present and future sources
- To throw light on necessity of any further study, if required for achieving the mile stone of supplying freshwater to the residents as well as saving the ecosystem of Sundarbans

4. Finding out Requirements and predicaments

<u>Water Demand in Sundarbans</u>

Hazra et al, 2015 had made an attempt to understand the sectoral water demand of different blocks of Sundarbans. Block wise drinking and domestic water demand has been estimated based on Public Health Engineering Department (PHED), Government of West Bengal Vision 2020 Document (Govt. of W. B., 2015) as 70 litres per capita per day and the population census data (Govt. of India, 2011). These 70 litres include the water demand for drinking, cooking, bathing, washing, cleaning pots and household work. Block wise water demand for agriculture in different blocks of Sundarbans has been estimated by combining the area under different crops (Govt. of W.B. 2010) with the lifecycle water requirement of each crop (Rudra, 2009). Considering rainfall runoff analysis in an empirical method (CGWB, 2007) and block wise availability of water from available deep and shallow tube wells in different blocks of Sundarbans (Govt. of West Bengal, 2010), availability of freshwater in Sundarbans has been estimated (Hazra et al, 2015).

The consumptive water demand of Indian Sundarbans includes the water demand for drinking, domestic use and agriculture. The annual demand of drinking water in Sundarbans blocks is 8.08 mcm whereas the annual water demand for domestic use is 105.1 mcm. In 1951, the drinking water demand and the domestic water demand were 2.12 mcm and 27.52 mcm respectively. The water requirement for the Rabi and summer crop cultivation is 641.25 mcm, whereas for Kharif crop cultivation the demand is 2141.58 mcm. The study reveals that the water demand for agriculture is highest in July (902 mcm) followed by August (894 mcm) and lowest in April (1.22 mcm). The water demand in Rabi Season is 425 mcm (November to June) which is mainly used for Boro cultivation. The total annual water demand for drinking, domestic use and agriculture in the 19 blocks of Indian Sundarban has been estimated as 2895.92 mcm. (Hazra et al, 2015)

Table – 2 : Annual Sectoral Water Demand in Indian Sundarbans (2010-11)
(Source : Hazra et. al, 2015)

Blocks		Population 2011	Drinking (mcm)	Domestic (mcm)	Agriculture (mcm)		Total	Total (mcm)
					Rabi + Summer	Kharif		
Northern	Total	1369256	2.49	32.48	234.42	457.09	691.53	726.51
	Average	195608	0.36	4.64	33.49	65.30	98.79	103.79
Central	Total	2048350	3.74	48.59	304.45	1009.69	1314.15	1366.49
	Average	256044	0.47	6.07	38.06	126.21	164.27	170.81
Southern	Total	1008653	1.84	23.93	102.38	674.78	777.15	802.93
	Average	252163	0.46	5.98	25.60	168.70	194.29	200.73
	Total	4426259	8.08	105.01	641.25	2141.58	2782.83	2895.92

The block wise statistics reveal that drinking, domestic and agricultural water demands are the highest in the central blocks. The average water demand for rabi and summer crop cultivation is highest in central blocks whereas the average demand for kharif cultivation is the highest in the southern blocks. The average total water demand is also the highest in southern blocks (Table–2).

This water demand mentioned under Table-2 is just indicative and not exhaustive since it has not included water required for mangroves (as the major component of ecosystem in Sundarbans), fishing activity, aquaculture and also for navigability in river surrounded by different islands of Sundarbans. It has to be kept in mind that water has footprint in all spheres of life and freshwater as a component of water resource as a whole is extremely important for several of these uses like aquaculture, even fishing also since all living objects are having tolerance for salt to some extent, but under no circumstances these can withstand salt stress to any extent whatsoever. Extreme salinity is not tolerated by most of the species, which are being sold in the market. Freshwater has a major function of diluting and decreasing the salt stress in Sundarbans. This particular aspect has also been considered during preparation of this document.

Freshwater Related Problems in Sundarbans

Sundarbans is surrounded by rivers and creeks with plenty of surface water. The entire area of Sundarbans gets tidal subsidy of water twice in a day. In spite of these two facts there is immense stress in the entire Sundarbans regarding availability of potable water as also freshwater. This is due to fact that the rivers are saline in nature. The groundwater is also saline in shallow aquifers. Salinity of water limits its use in domestic as well as for agricultural practices. Even for aquaculture practices, use of high saline water does not always yield desirable results. The problem has been further complicated since Arsenic related problem has been found to crop up in several blocks of Sundarbans. Local people have to depend mostly on the groundwater for potable as also domestic use. But, safe fresh groundwater is only available at the deeper aquifer. In many places, the deeper aquifer is located at a depth of about 300 meters below ground level (bgl). As a matter of fact, for a common man, making arrangement for extraction of groundwater from such depth by Tube well / hand pump is not an easy job.

Interestingly, on an average rainfall over the entire area is more than 1600 mm. But without proper infrastructure and planning, the entire rainfall, which is again seasonal with high intensity only on few days, gets wasted by flowing into the adjoining Bay of Bengal. Lack of upland freshwater discharge into these rivers allows the saline sea water to move deep inland. Salinity intrusion in the agricultural field makes agriculture difficult. Though aquaculture in coastal zone needs saline water, but there should be a limit. Along with the increasing salinisazion, the depths of the rivers are also decreasing gradually at a fast rate. Navigation is also facing a lot of problems, particularly during low tide conditions in many areas. Due to erosion and embankment failure, people are also losing their land and livelihood and are becoming more vulnerable in the backdrop of climate change.

But it is difficult to discuss all these issues in this report and some of the issues are also beyond the scope of this report. However, a brief discussion on some of these issues has been made below so as to understand the dimension of the problems related with freshwater availability. The issues briefly discussed below are:

- Limited upstream freshwater discharge and Salinity Problem
- Salinity of the Groundwater
- Arsenic Contamination in Groundwater
- Problems in Agriculture & Irrigation
- Problems in Fishing and Aquaculture
- Problems of Siltation and Navigation
- Embankment Failure and Land Loss

Limited Upstream freshwater discharge & Salinity Problem

It has already been discussed that Indian Sundarbans is the western most part of the Ganga – Brahmaputra – Meghna (GBM) delta. The entire delta was formed due to sedimentation brought by numerous water channels from upland areas. Thus, rivers and streams and other natural flowing river channels which are part of the existing drainage network in Sundarbans are some way or other related with the Ganges – Brahmaputra – Meghna river system. Since Bhagirathi – Hooghly, a major distributary channel in this part of the country marking the western boundary of the Sundarbans, has a dominant presence, all the distributary channels passing through the Indian Sundarbans were someway linked with this river. Major present problem of Indian Sundarbans lies with the fact that the major rivers of Indian Sundarbans are either disconnected or have feeble connection with the Bhagirathi – Hooghly River System.

The Hooghly River, the southern end of River Bhagirathi does not have presently any major contribution of freshwater in Sundarbans ecosystem. The Saptamukhi System has lost all of its upstream connections and is connected with the Muriganga, the eastern branch of Hooghly River along Sagar Island through a narrow canal known as Hatania – Doania and receives very meagre amount of freshwater from the River Hooghly. The Thakuran System also became disconnected with upland discharge sources and only connected with Saptamukhi in the southern part to exchange saline water from Bay of Bengal. The Bidyadhari River, which was once a mighty river and a distributary channel of Bhagirathi during 15th – 16th century, now serves as a sewage and excess rainwater outlet from Kolkata city (Ghosh, 2012). Similarly, the upstream connections of the Matla River originating at the confluence of Bidyadhari, Karatiya and Rampur Khal have been lost in recent times. Ichhamati – Harinbhanga – Raimongal system, marking the border between India and Bangladesh used to receive freshwater supply from a distributary channel of the Ganga is now almost disconnected from its parent river. As a combined effect, mangrove ecosystems of Sundarbans are not getting freshwater supply from upland leading to deterioration of the entire habitat and endangering flora and fauna of Sundarbans.

A detail discussion on this aspect has been made subsequently in the subsection “River Network, its Discontinuities and Future Possibilities”.

Salinity of the Groundwater

Groundwater is perhaps the only option for the people of Sundarbans for getting safe potable water. That is why groundwater is extremely important for Sundarbans. There are three aquifer zones in the Indian Sundarbans – a shallow one, within 60 meters below ground level (bgl) which has fresh and brackish water interactions. A middle zone occurring between 70 – 160 m bgl is brackish to saline in nature. The third zone contains freshwater occurring in the depth zone of 160 – 400 m. The saline water aquifers above are separated from the underlying freshwater group of aquifers by a thick clay layer varying in thickness from 4 m in Gangasagar to 120 m in Kultali. However the average thickness of the intervening clay blanket is between 20 – 50 m or so (Sinha Ray, 2010). In some blocks of Sundarbans namely, Canning I & II, Kultali and Basanti blocks, saline water intrusion into the shallow aquifer from the adjoining creeks has been reported, which is really alarming.

A detail discussion on the groundwater scenario in Sundarbans and its prospect as a freshwater source in Sundarbans has been made subsequently in the subsection “Groundwater As a Source of Freshwater”

Arsenic Contamination in Groundwater

One of the major problems in using groundwater as a source of safe drinking water in Sundarbans is Arsenic. Arsenic values in groundwater above the maximum permissible limit of 0.01 mg/l have been reported from several areas of the lower delta region of the Ganga-Padma river system. It is confined to areas east of Hooghly River and to the shallow aquifer having depth of <150 m below ground level (Pal et al, 2002). It is estimated that about 6 (six) million people are affected in West Bengal alone (Guha Mazumder & Dasgupta, 2011). Altogether 104 number of blocks spreading over 13 districts of West Bengal are affected with presence of Arsenic in groundwater (Sinha Ray, 2018). Out of these blocks, eight numbers of blocks are located within Indian Sundarbans.

A detail discussion on Arsenic pollution in groundwater in Sundarbans has been included in the already mentioned subsection “Groundwater as a Source of Freshwater”.

Problems in Fishing and Irrigation

Saline river water and salinity in groundwater is perhaps the most important issue for agriculture in Sundarbans. To combat the menace of saline water, the farmers of Sundarbans have to depend mostly on the rainwater and also to some extent on the surface water being collected in impoundments and ponds. As a result, many areas of Sundarbans are single cropped where only *kharif* rice can be cultivated with rainwater since there is acute scarcity of water during *rabi* season. In these areas rainwater is the only source of irrigation water. However, during summer time, the stored water within ponds and impoundments are also being used for irrigation. Only in the areas near the few fresh-water rivers in the northern most part of Sundarbans, some irrigation facilities are available using freshwater canal system.

It is interesting to note, although Sundarbans is a saline water locked region, no special policy or technique has been adopted for sustainable agriculture here. The rice verities being used by the farmers in Sundarbans are almost similar to those being used in mainland of West Bengal. Some of the rice seed varieties are Talmugur, Dudheswar, Annanda, Nona-Bokhra etc. The Research Station of ICAR – Central Soil Salinity Research Institute (CSSRI) is located in Canning town within Sundarban itself. It is unfortunate to note that so far there was no remarkable intervention from this Research Centre to generate any technique and/or variety of salt tolerant rice seed for the farmers of Sundarbans in a mass scale. Nevertheless to mention that some salt tolerant varieties of rice seed has been produced in experimental stage, but for use of such variety in mass scale is yet to be achieved. There were attempts from several quarters, especially from several NGOs to supply such salt tolerant varieties of rice seed to the farmers of different islands of Sundarbans, especially in Mousuni Island, where flooding of agricultural land due to breaching of embankments is quite frequent. Unfortunately, those experiments could not yield impressive results since the paddy fields were simply washed away with the flood. But there is immense necessity and also potentiality to develop and practice this kind of farming in Sundarbans. Since the subject matter is not directly related with the freshwater availability in Sundarbans, this has not been elaborated any further.

For growing rice, the safe limit of soil salinity is 4 – 6 ppt (parts per thousand). The northern part, the low saline zone, records soil salinity up to 8 ppt; while the soil salinity in southern part ranges from 8 – 20 ppt (Ghosh, 2012). Generally a good rainfall during monsoon helps to dilute the soil salinity. However, due to erratic behaviour of rainfall during recent time as a consequence of climate change, this common option is getting diminished day by day. Lack of proper irrigation methods, non-availability of freshwater during post monsoon season, presence of salinity in surface/ ground water in soil had led to low crop yield in Sundarbans (Bhadra, 2013). Thus, irrigation with stored water is perhaps a major option left before the farmers here.

This particular option in Sundarbans has been included in the subsection “Reservoirs, Ponds and Impoundments as a Source of Freshwater”.

Problems in Fishing and Aquaculture

Sundarbans is the spawning and breeding grounds of many aquatic, marine, brackish and freshwater organisms like shrimps, muscles, fishes, turtles etc. Mangrove forest also supports a wide variety of fin and shell fish species. In fact, mangroves of Sundarbans have been considered as the major source of nutrients to the entire coastal fish population of the eastern India. Thus, Sundarbans act as a unique habitat for large number of organisms and plants. But, the health of this habitat is dependent on many physical parameters. Salinity and silt load in water are two important parameters. Since the health of the habitat as well as the migration of different fishes depends on the quality and quantity of water, the fishing activities are directly dependent on freshwater supply from the upstream. Best example in hand is perhaps the Hilsa (Tenualosa ilisha) fish, which is considered to be in heart of the Bengalis as delicious food. Hilsa needs comparatively less salinity for breeding and typically an estuarine fish. Although Matla – Bidya – Raimongal river system was once a favourite spawning ground of Hilsa, of late that has been changed. Even the availability of Hilsa along Hooghly River has come down in recent times.

Change in water quality due to increasing surface water temperature and increasing salinity of water makes fishing difficult and has a negative impact on fish health (Das & Sahu, 2012). Due to continuous erosion and loss of agricultural land more number of people in Sundarbans is shifting their livelihood from farming to fishing and aquaculture (Mandal & Mandal, 2012). As a result, competition on the available water resources is increasing. Due to lack of freshwater discharge, silts depositing on the river beds are forming shoals and finally islands leading to loss of fishing grounds. Development of an island in the near shore areas are pushing the fishing grounds far inside sea. All these are happening due to lack of freshwater discharge from upland areas along the rivers of Sundarbans.

The inland aquaculture practices in Sundarbans are either brackish in nature or purely freshwater. Both these two types need proper arrangements and places for storage of water. The survival of brackish water fisheries depends on maintenance of salinity in the ponds in a fine tuned manner. The freshwater fishes on the other hand are grown in ponds, reservoirs and impoundments and these are almost integrated with the freshwater supply through rainwater. Although instances of destruction of freshwater aquaculture due to saline water ingress are not rare in Sundarbans, still people consider this as a very good option for better earnings and livelihood generation.

Thus, availability and increment in number as well as coverage of areas under freshwater fisheries are directly related to freshwater reservoirs, ponds and impoundments in Sundarbans. This has been included in the subsection “Reservoirs, Ponds and Impoundments as a Source of Freshwater”.

Problems of Siltation and Navigation

In the water locked islands of Sundarbans, the only means of movement and transportation is navigation. Navigations along the channels and rivers of Sundarbans are very common. Common people use the navigational routes for movement within different islands and transport to main land. Sundarbans is a macro-tidal estuary and the tidal fluctuations along the estuaries of Sundarbans are more than 5 meters and sometimes even up to six meters. The tidal fluctuations in many times make the rivers and estuaries unsuitable for navigation during low time condition. This is particularly true on full moon day and new moon day and two days before and after of these two days in each month, especially during the month of September. The situation has further deteriorated due to continuous siltation and sedimentation on the river beds which has decreased the depth of water column to a great extent. Navigability along the creeks even in the southern most parts of Sundarbans near the sea has also become a problem now.

It has to be kept in mind that even in the near past, the then British Rulers of India constructed a port over Matla River at Canning and named after Lord Canning in 1853 as per suggestions of Bengal Chamber of Commerce. This port was considered to be a substitute of Kolkata Port, which was suffering due to siltation along the Hooghly River. Newly built port at Canning became moribund within a decade and was officially decaled as closed in the year 1871 (Bhadra, 2013). The British Rulers were left with no other option but to start dredging along Hooghly River to increase the navigability. The same process is still going on since the rate of siltation has further accentuated due to decrease in freshwater discharge along these rivers and channels with time.

This problem and possible solutions have been discussed in detail in subsection “River Network, its Discontinuities and Future Possibilities”.

Embankment Failure and Land Loss

Embankments are life line in Sundarbans. It has already been described that the inhabited part of Indian Sundarbans is actually reclaimed portion taken away from the mangrove forest. Embankments are crucial for the existence of human settlements in the islands of Sundarbans since it protects the people from ingress of saline water. 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).

The problem has been further accentuated due to decrease in upland freshwater discharge along the rivers and creeks of Sundarbans, which used to flush out a portion of the sediments getting deposited on the river beds. Absence of upland freshwater discharge along these rivers and creeks have also transformed these creeks into flood dominated estuaries where water from the Bay of Bengal with huge sediment load moves far inland through the channels within a comparatively short period of time; while the duration of low tide is more than high tide period. Tidal water gets sufficient time of stay within the channels when the sediments get flocculated and thereafter deposited on the riverbed itself. This has resulted in decreasing the carrying capacity of the individual channels which became unable to work as conduit for the passage of the tidal prism entering into the individual channels through their sea mouths. As a natural fall out, water column starts eroding the embankments to make space to accommodate the tidal water volume entering into the estuaries from the mouth. This goes on in a cyclic manner. With sea level rise, more amount of sea water is expected to be pushed into the estuaries during high tide. So, more and more erosions of the embankments are expected unless there is considerable upland discharge of freshwater along these estuaries. This problem is also related with the life and livelihood of about 4.5 million populations living in Sundarbans.

Possible solutions of this problem have been included under subsection "River Network, its Discontinuities and Future Possibilities".

5. Presence, Problems, Prospects & Potentiality of Freshwater Resources

Meaning of the word ‘Inventory’ in Oxford Dictionary points to take a ‘Stock’ of the current position and to list the available items related to it. In this section, an attempt has been made to discuss the ‘Freshwater Resources’ available in Sundarbans presently, to identify the possible issues and problems which created a scarcity of freshwater, possible solutions and also changes in policy matters, if necessary. In the following discussions four different sectors related with freshwater resources of Sundarbans have been discussed.

Reservoirs, Ponds and Impoundments as a Source of Freshwater

The Earth is called "the water planet" because it has approximately 14,108 cubic kilometres of water. However, 97.5% of this water exists in the seas, and nearly all of the remaining fresh water is locked up in the Antarctic or Arctic ice caps or as groundwater. Therefore, we can freely access only the water in lakes, ponds and reservoirs (0.007%) and in rivers (0.002%). Of these, lakes and ponds are the best "available freshwater source on the Earth's surface." Lakes and ponds are valued as water sources and for fishing, water transport, recreation, and tourism.

Reservoirs, ponds, lakes and impoundments are extremely important for storage of freshwater. Stored freshwater can be used for agricultural, domestic and industrial purposes. Such water can be used for drinking purposes also after making proper treatment since freshwater is the only option for potable water. Such filtered water can also be distributed to local residents and nearby business establishments through appropriate arrangements.

West Bengal is blessed with innumerable number of such ponds and impoundments. The state of West Bengal has 7.45% of total water resources of our country (Govt. of West Bengal, 2016). All kinds of water resources (like as fresh water, brackish water, marine water, reservoir water, river water, flood plain water, cold water & sewage water) are available in West Bengal. History reveals that even during Mughal Period, the earlier rulers took initiatives to excavate large ponds, locally known as ‘*Dighi*’ in Bengali. The cut-off meanders from different rivers within inland areas, locally known as ‘*beel*’ also serve the purpose of rainwater storage during monsoon period for future use during post-monsoon and summer seasons. These water bodies, now termed as ‘Wetlands’, were earlier considered as ‘Wastelands’ leading to mass scale reclamation and filling up for agricultural and real eastate business purposes. These water bodies were also considered as breeding places of mosquitoes. However, with better environmental awareness regarding the ecosystem functions being played by these freshwater bodies, people are now much conscious regarding the importance of these water bodies. Serious attempts on the part of citizens have also been noted to protect these water bodies apart from policy formulation and legislation by the Central and State Governments for protection of these wetlands.

In case of Sundarbans, these water bodies assume more importance, since these are the only source of surface water sources of freshwater over the entire inhabited areas. Unfortunately, due to typical physiographic set up of the Sundarbans, no natural lake is present here. Due to the salinity of the river water, not a single reservoir has also been constructed here. As per records of Fisheries Department, 2016, there is no reservoir in entire North 24 Parganas and South 24 Parganas Districts (Handbook of Fisheries Statistics 2015-16, 2016).

Freshwater Resource Concepts and Definitions

All the freshwater resources were initially considered important to the policy makers and in government circles in India only from the point of view of "Fisheries" and "Fish Production", although that notion is getting changed day be day. Indian Council of Agricultural Research (ICAR) defined the surface water bodies in simple language for universal understanding, which are till date accepted in the Government Departments (Gupta et al, 1991), as follows:

Ponds: Ponds are usually earthen, shallow, excavated water bodies, though masonry dykes are also not uncommon. Pond represents a restricted environment without a continual interaction with populations of neighbouring biotopes. The water level and biomass within ponds are highly influenced by the rate of evaporation and precipitation. Inundation is often the lone factor leading to exchange of biological communities with adjacent water bodies. For fisheries enumeration purposes, all such water bodies having an area of less than 5 ha at full water level are designated as ponds.

In reality, presently even small water bodies measuring 335 sq. meters or even less than that are being conserved as important water resources in West Bengal and specific legislation for conservation of these small water bodies have been enacted.

Tanks: Tanks are generally referred, in common parlance, to denote varying types of water bodies in different parts of the country. Tanks are larger than ponds, created on seasonal streams, mainly for irrigation purposes by constructing earthen or masonry barricades. These shallow water bodies generally get dried up during summer. Large excavated community ponds or temple tanks also fall under this category. Many authors consider tanks as an interchangeable expression for ponds and small reservoirs and these resources are often clubbed in resource assessment. Water bodies having an average area of 5–10 ha, irrespective of their water source, may be considered as tanks. These include small irrigation impoundments, temple tanks, community tanks and natural tanks fed by catchment from neighbouring areas.

In reality, tanks are considered as interchangeable expression for ponds. But, normally larger water bodies (normally called '*Dighi*' in Bengali) are called tanks, while smaller ones are known as ponds (In Bengali – '*Pukur*'). However, from the point of importance for freshwater storage, both are equally important.

Lakes: All lentil water bodies of natural origin exceeding 10 ha in area are included under the category of lakes. The process leading to the formation of these natural lakes may vary widely. Basins formed due to tectonic movements of earth crust, volcanic or glacial action; or wind action in the arid zones, depressions from landslides, or the basins formed due to stream action (flood plains) all constitute the natural lakes. The upland lakes spreading across the higher altitude regions of the country are mostly of volcanic, glacial or tectonic origin.

Reservoirs: Reservoirs are man-made impoundments of varying magnitude created by erecting bunds, dams, barrages or other hydraulic structures across streams or rivers, serving one or more purposes such as irrigation, power generation, flood control or other water resource development projects. All such water bodies, exceeding 10 ha in area at full level, are categorised as reservoirs. There are numerous lakes in the floodplains of peninsular rivers which draw from the catchment of the tributaries that no longer contribute to the main river. The states of Maharashtra and Madhya Pradesh have many such lakes which are traditionally recorded as reservoirs. For the sake of uniformity, these lakes, if above 10 ha, are also considered as reservoirs.

A large number of river valley projects taken up since independence has resulted in a chain of artificial impoundments across the country. By their sheer magnitude, they form one of the main freshwater fishery resources of the country. Each reservoir is a separate ecological entity and varies from another in its morphometry, area, geographical location and productivity status. For convenience of adopting a fisheries management strategy and to obtain a reliable estimate of fish production from them, these are further classified into three groups based on their area at FRL:

1. Small reservoir (10-500 ha)
2. Medium reservoirs (500-1000 ha)
3. Large reservoirs (above 1000 ha)

Brackish water impoundments: These are estuarine man-made impoundments where freshwater is mixed with sea water. Due to the tidal action, the beds of many rivers and creeks in the estuarine areas of Bengal gets silted up and in due course they are reclaimed for agricultural purposes by constructing bunds to safeguard against floods and tidal water. Some portions of these reclaimed areas are too low for agricultural crop cultivation and are utilised for fish culture. They support both finfish and shellfish fisheries. The brackish water tidal wetlands namely mud flats, swamps, marshes, paddy fields, etc. are locally known as "bheries" in West Bengal. They are large shallow water bodies embanked by low earthen dykes all around and are located in the north, north-east and south of the Sundarbans in the district of 24-Parganas of West Bengal. An inventory survey during 1982-84 has estimated the total number of bheries as 1334 covering a brackish water area of about 0.033 lakh ha spread over three spread zones *viz.*, high, medium and low. The shape of bheries is irregular and the Size varies from a small (2 ha) to big water area (267 ha). Swamps may be defined as derelict marshy water bodies mostly infested with grasses and weeds. They are seasonal in character and vary widely in water depth and area.

In case of Sundarbans, although brackish water fisheries are very common in such impoundments and also in paddy fields, but there are several freshwater impoundments also which are being used by local people for different purposes including drinking water source for the live stocks.

Inventorying Reservoirs, Ponds and Impoundments

There were hardly any attempt from any quarter for carrying out survey and mapping exclusively for the freshwater resources following any scientific technique in any part of the country. As already indicated, the surface water bodies with freshwater were always considered to have only one function i.e. fisheries. Thus, the quantification of acreage of these water bodies was first attempted for the purpose of estimation of Fishery Resources. Incidentally, Fisheries Department in West Bengal is a very old department and started its functioning way back to 1911, more than one hundred years ago (Source : https://www.wbfisheries.in/fisheries_department.php accessed on 27.11.18).

The Departments of fisheries in the States and Union territories have their statistical cells which used to collect and compile data through their field staff in accordance with the concepts and definitions provided by the FAO and other organizations. The data thus collected were compiled, though not on systematic basis, by these organizations. Such data normally covered most of the categories of water resources. These estimates were based on certain factors like lease amount, issue of licences, departmental exploitation, market arrivals of catch, transactions of cooperatives etc (Gupta et al, 1991). It is therefore obvious that those data were only indicative of freshwater resources, but cannot be considered as any inventory *per se*.

However, there was acute need for developing a uniform and standardised methodology for estimation of different types of inland fisheries resources (Gupta et al, 1991). Realising the need, a pilot investigation was launched in 1955-56 by ICAR in two districts of erstwhile Hyderabad state far developing suitable sampling techniques for inland fisheries. Later on, the Government decided to transfer the work from ICAR to the Directorate of National Sample Survey (NSSO) in April 1956. In September 1958, the Directorate of the National Sample Survey took up the survey work in Orissa to evolve suitable sampling techniques for estimation of fish production and not for fisheries acreage estimation.

By the end of 1958, certain basic information such as various resources of inland fisheries and their relative importance, availability of sampling frame, fishing practices and availability of suitable agency for field work were collected, which later on farmed the basis of the pilot survey in Orissa during 1962-63. The NSSO undertook pilot survey of inland fisheries in 1962-63 in Orissa in 3 districts viz. Cuttack, Sambalpur and Mayurbhanj, based on the technical programme given by Indian Agricultural Statistical Research Institute (IASRI), New Delhi. The primary objective of the survey was to develop suitable methodology for the estimation of (i) number and area of ponds, tanks and swamps and (ii) total catch of fish there from. The information was collected mainly through enquiry and in some cases by physical verification.

An attempt was made by Indian Statistical Institute (ISI), Kolkata, West Bengal for evolving sampling methodology for inland fisheries during 1960-61. The study created some awareness and experiences regarding the field problems in understanding the fishery resources. The sampling work was seriously disturbed and no estimation could be made out of it.

The Central Inland Capture Fisheries Research Institute (CICFRI), Barrackpore made an attempt to estimate the area and catch from ponds in the district of Hooghly, West Bengal during 1962-63. But the survey could not be continued due to some administrative difficulties. In 1973-75, the NSS0 conducted a survey covering 3 districts one each in West Bengal, Tamil Nadu and Andhra Pradesh with the aim at obtaining estimate of catch both from impounded water as well as riverine resources by enquiry method only. The estimates worked out were not satisfactory, particularly from the riverine resources.

Another pilot survey was conducted jointly by lASRI, New Delhi and CICFRI, Barrackpore in one district of West Bengal during 1978-81. The data were collected both through enquiry and by physical observations. The main objectives of the survey were (1) to evolve suitable sampling methodology for estimation of (a) inland water resources and (b) total catch of inland fisheries and (2) to study the prevailing practices of pisciculture. The study covered only ponds in the district of 24-Parganas in West Bengal. The catch estimate of other important resources viz. estuaries, rivers, brackish water impoundments, beels etc. could not be attempted due to limited manpower. In spite of all these attempts, there was no scientifically designed method for collection and estimation of all types of inland fishery resources, especially the spatial extent of the inland fisheries or in other words the freshwater bodies which actually produce the inland fishes.

<u>Estimation of spatial extent of freshwater resources using latest technology</u>

The first ever attempt for Mapping and inventorization of the water bodies/ wetlands of the entire State of West Bengal including Sundarbans was attempted using IRS 1B LISS II satellite data of the years 1992-93 on 1:50,000 scale by Institute of Wetland Management & Ecological Design (IWMED) in collaboration with Space Applications Centre, ISRO, Ahmedabad. Visual interpretation technique was employed using PROCOM II for preparation of the wetland maps following a classification system accepted at the national level. Both pre-monsoon and post-monsoon remote sensing data were utilized to understand the spatial coverage of the wetlands during monsoon season so as to delineate their boundaries in an accurate manner. The project was completed in December, 1998. Minimum mapping unit was 2.25 hectares due to scale factor, although the water bodies/ wetlands having areas more than one hectares and were readily identifiable in remote sensing images of post monsoon season were identified and their locations were marked on the maps with dot marks without spatial extension. All wetland maps were numbered following the Survey of India topographic sheets. A topographical map-wise database showing distribution of wetlands, their central co-ordinates, wetland area, their water spread during pre-monsoon and post-monsoon seasons, aquatic weed infestation and qualitative turbidity (as understood from remote sensing images) was created in DBF. The study showed that there were 7248 wetlands of size greater than 2.25 hectares in the State of West Bengal during 1992-93. In addition, 34,679 wetlands smaller than 2.25 hectares were also identified (Bhattacharyya et al, 2000). These smaller wetland bodies actually represent "Tanks" and larger Ponds". During this study, Sundarbans did not get any priority and District of 24 Parganas was undivided. So, the data representing the 24 – Parganas actually includes that of Sundarban also.

The hard copy maps thus prepared were digitised and put in the GIS environment to create a GIS database which was termed as Wetland Information System (WINSYS) for the State of West Bengal. (Patel et al, 2003). During that time, since individual blocks were not considered, so the wetlands for the entire district were included. From that database, data representing freshwater resources are produced below.

Table – 3: Freshwater Wetlands as Identified in Undivided 24-Parganas District during 1992-93 during 'Wetland Mapping' (Source : Patel et al, 2003)

Sl. No.	Wetland Type	Total		Pre-monsoon		Post-monsoon	
		Number	Area (ha)	Number	Area (ha)	Number	Area (ha)
1.	Inland Man Made Tanks	189	1074.13	160	717.74	188	990.84
2.	Inland Natura Lake/ Pond	52	3034.77	49	325.62	51	5137.00
3.	Inland Natural Ox-bow lakes / cut-off meander	232	8646.34	183	1686.11	230	3881.90
4.	Inland Natural Swamp/ marsh	23	1501.22	23	64.41	23	975.98
5.	Inland Natural Waterlogged	295	3590.63	217	739.71	295	3574.91
6.	Total	791	17847.09	632	3533.59	787	14560.63

7.	Wetlands (< 2.25 ha)	2494					

These data immediately reveal that some of the wetlands/ water bodies in the district of 24-parganas district (now North and South 24 Parganas) get dried up during summer season indicating the scarcity of water during summer season, It needs to be understood that these wetlands/ water bodies are considerably larger in extent and the size of these wetlands are > 2.25 ha i.e. more than 22,500 square meter. If such big wetlands can get dried up during summer, the status of the other wetlands/ water bodies during summer season as regards presence of water is doubtful.

Inventorisation of Freshwater Resources by SDB and BAE & S

Sundarbans Development Board (SDB) was constituted by Government of West Bengal through a Gazette Notification on 7th March, 1973 for 'Integrated and accelerated development of Sundarbans area' wherein Functions and Powers of SDB were clearly mentioned. Subsequently, a completely new department known as Department of Sundarban Affairs was created by Government of West Bengal on 24th January, 1994. SDB was placed under Sundarban Affairs Department for implementation of different development projects. Most of the development projects of Sundarban Affairs Department are being implemented through SDB. SDB thus functions as the Directorate of Sundarban Affairs Department.

One of the major tasks by SDB is to take stock of the natural resources in different gram panchayats on each year. Unfortunately, SDB and Sundarban Affairs Department are concerned only with the development projects being implemented by the Board or Department. Since SDB has regular contacts with the Panchayati Raj institutions up to the tier of Gram Panchayats on day to day basis, for conservation of the freshwater resources in Sundarbans, intervention from SDB will be more effective, particularly in the backdrop of different awareness programmes being implemented by SDB in different times on environmental issues.

Bureau of Applied Economics and Statistics (BAE & S), under the Department of Statistics & Programme Implementation, Government of West Bengal collects the data from the base level and compiles those in each year for different sectors for production of reliable and dependable data. One of the mandates of BAE & S is to produce District Handbooks to provide statistical information on various socio-economic aspects of the districts in a compact form. Attempts are normally made to incorporate up-to-date information so that continuity of the time series of the data published in earlier issues of district handbooks of any particular district is maintained. Data at the Block level are also incorporated as far as available, so that those could be effectively used by planners, policymakers and researchers (Govt. of West Bengal, 2012 – District Handbook, South 24 Parganas District) (Source :

http://www.wbpspm.gov.in/Home/Statistics accessed on 20.11.18). Unfortunately, BAE & S are not concerned with the natural resources *per se*, rather collect information on only those natural resources which are being used for generation of livelihood. BAE & S is interested in surface water resources only from the Fisheries point of view.

The last handbooks released by BAE & S for North and South 24 Parganas Districts are up to the year 2011. Block level statistics on Fisheries Resources in Sundarbans are produced from these two handbooks below in tabular form:

Table – 4 : Details of Fisheries in North 24 Parganas District & Related Information
(Source : BAE & S Handbook, for 2010 & 2011 for N 24 Pgs.)

Particulars of Fisheries in Six Blocks under Sundarbans in North 24-Parganas for the year 2010-11

Sl. No.	Name of Block	No. of Govt. Scheme operated	Expendi-ture ('000Rs.)	Assistance to needy fishermen ('000Rs.)	Net area available for piscicul-ture (ha)	Net area under effective piscicul-ture (ha)	No. of person engaged in the profession	Approx. annual production (qtl)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	Haroa	1	252	252	9125	8668.61	18468	260058.3
2	Minakhan	2	1114	1114	6790	6450.46	17638	193513.8
3	Hasnabad	3	990	990	2376	2257	20439	67710
4	Hingalganj	1	324	324	1186	1126.73	12243	33801.9
5	Sandeshkhali-I	1	288	288	6032	5730.18	11413	171905.4
6	Sandeshkhali-II	2	1800	1800	2868	2725.04	12346	81751.2
7	Total	**10**	**4768**	**4768**	**28377**	**26958.02**	**92547**	**808740.6**

Source : Asstt.Director of Fisheries, North 24 Parganas

Table – 5 : Details of Fisheries in South 24 Parganas District & Related Information
(Source : BAE & S Handbook, for 2010 & 2011 for S 24 Pgs.)

Particulars of Fisheries in Thirteen Blocks under Sundarbans in South 24-Parganas for the year 2010-11

Sl. No.	Name of Block	No. of Govt. Schemes operated	Expendi-ture ('000 Rs.)	Assistance to needy fishermen ('000 Rs.)	Net area available for pisciculture (ha)	Net area under effective pisciculture (ha)	No. of persons engaged in the profession	Approx. annual production (qtl.)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	Jaynagar-I	5	679	679	1500	1185	10280	28070
2	Jaynagar-II	9	2896	2896	200	1819	14907	36660
3	Kultali	7	4895	4895	3743	3445	43020	68500
4	Canning-I	6	733	733	6740	6209	44090	105760
5	Canning-II	6	3259	3259	7150	7091	50148	110260
6	Basanti	10	12485	12485	2350	2052	22637	40300
7	Gosaba	7	8254	8254	3637	3098	35249	66780
8	Mathurapur-I	6	561	561	898	828	7245	15048
9	Mathurapur-II	6	408	408	2690	2147	30265	45940
10	Kakdwip	7	1197	1197	3113	2744	46877	52500
11	Namkhana	9	2864	2864	3285	3077	47284	55940
12	Sagar	7	703	703	3600	2980	29169	61750
13	Patharpratima	7	1364	1364	5600	5301	73242	100930
14	**Total**	**92**	**40298**	**40298**	**44506**	**41977**	**454413**	**788438**

Sources : 1) Assistant Director of Fisheries; 2) Fisher Farmer's Development Agencies (F.F.D.A.); 3) Brackish-Water Fisher Farmer's Development Agencies (B.F.D.A.), if any for 24-Parganas (South) 4) Marine-Water Fish Farmer's Development Agency (M.F.D.A.), if any for 24-Parganas (South)

From the above two tables, it may be considered that the 'Net area available for Fisheries' at column no. 6 seems to refer to the area of the available water resources in individual blocks and in a combined manner for six blocks of Sundarbans in North 24-Parganas District and thirteen blocks of Sundarbans in South 24-Parganas District. However, these areas do include the 'brackish water bodies' also, which are quite common in all these blocks. Hence, it would be difficult to comment on the freshwater bodies from these statistics. It would be better, if BAE & S be requested in future to separate two kinds of fisheries, namely inland freshwater fisheries and brackish water fisheries and collect those data from the block level. However, policy level intervention is required to change the mode of data collection by BAE & S, since ever since its inception in 1940, BAE & S has been collecting and compiling the Fisheries data in such a combined format only.

Inventorisation of Freshwater Resources by Fisheries Department

As per the latest document of Fishery Department, Government of West Bengal, fishery resource area of the State of West Bengal is yet to be surveyed completely (Govt. of West Bengal, 2016). In the year 1976, 50% Mouzas of West Bengal had been surveyed by the

Fisheries Department and from that survey data the current ponds & tanks area had been estimated by the Fishery Department (Govt. of West Bengal, 2016). Different freshwater bodies as also brackish water statistics as recorded in this document are reproduced below:

Table – 6 : District wise Impounded Fresh Water Area for North & South 24 Parganas District (Including Beel & Baor), (Source : Handbook of Fisheries Statics, 2016)

Sl. No.	Name of the District	Area (in ha)
1.	North 24 Parganas	26,008
2.	South 24 Parganas	49,237
3.	**Total**	**75,245**

Table – 7 : District wise Impounded Water Area for North & South 24 Parganas District (as per 1976 Survey of Fisheries Dept.)

(Source : Handbook of Fisheries Statics, 2016)

(in ha)

Sl. No.	Name of the District	Culturable Area	Semi-Derelict Area	Derelict Area	Total Area
1.	North 24 Parganas	8641.45	1068.76	277.80	9988.01
2.	South 24 Parganas	11237.79	1389.87	361.28	12988.94
3.	**Total**	**19879.24**	**2458.63**	**639.08**	**22976.95**

There are only three districts where brackish water reserves are available. These three districts are North 24 Parganas, South 24 Parganas and Purba Medinipur. Since, Sundarbans is spreading over North and South 24 Parganas districts, data for these two districts only are reproduced here. Although, this document has been prepared primarily for exploring the freshwater resources, but brackish water bodies assign importance, It can give a rough estimate regarding percentage of brackish water bodies within the total acreage of water bodies in Sundarbans also. This is particularly important since in many cases total coverage of surface water bodies are mentioned only, which also brackish water bodies in case of Sundarbans.

Table – 8 : District wise Brackish Water Area Resources North & South 24 Parganas District (as per 1976 Survey of Fisheries Dept.)

(Source : Handbook of Fisheries Statics, 2016)

Sl. No.	Districts	Area (in ha)
1.	North 24 Parganas	35371

2.	South 24 Parganas	17759
3.	**Total**	**53,130**

This document has also included some data for freshwater resources in a block wise manner. From this Handbook of the year 2015-16, the data for individual 19 blocks of Sundarbans has been extracted, compiled and produced below:

Table – 9 : Impounded Water Area in six blocks of Sundarbans in North 24 Parganas District
(Source : Handbook of Fisheries Statics, 2016)

Sl. No.	Name of the Block	Freshwater area (in ha)	Brackish Water Area (in ha)	Total Water Body (in ha)
1	Haroa	780.7	8344.15	9124.85
2	Minakhan	495.46	6294	6789.46
3	Sandeshkhali - I	490.66	5541.11	6031.77
4	Sandeshkhali - II	456.66	2411.8	2868.46
5	Hasnabad	1073.29	1302.49	2375.78
6	Hingalganj	823.88	362.15	1186.03
Total		**4120.65**	**24255.7**	**28376.35**

Table – 10: Impounded Water Area in thirteen blocks of Sundarbans in South 24 Pgs. District
(Source : Handbook of Fisheries Statics, 2016)

Sl. No.	Name of the Block	Freshwater area (in ha)	Brackish Water Area (in ha)	Total Water Body (in ha)
1	Canning - I	3920	2820	6740
2	Canning - II	3650	3500	7150
3	Mathurapur - I	651	250	901
4	Mathurapur - II	1595	1095	2690
5	Jaynagar - I	1500	-	1500
6	Jaynagar - II	1500	500	2000
7	Kultali	2816	927	3743
8	Basanti	2000	350	2350
9	Gosaba	3000	637	3637

10	Kakdwip	1998	1115	3113
11	Sagar	2800	800	3600
12	Namkhana	2060	1225	3285
13	Patharpratima	3200	2400	5600
Total		**30,690**	**15,619**	**46,309**

Above tables indicate that the total freshwater impoundments, meaning freshwater bodies, in Sundarbans is 34,810.65 hectares while brackish water bodies occupy an area of 39,874.7 hectares. Thus, altogether 74,685.35 hectares of inland water bodies are there in Sundarbans, out of which 46.61% is freshwater in nature while 53.39% water bodies are brackish in nature. This only points to the fact that brackish water bodies are dominant in Sundabans even within the inland water bodies. This is particularly true for the part of Sundarbans under North 24 Parganas where the brackish water bodies occupy a total area covering sex times of that of freshwater areas. It is therefore evident that freshwater bodies are comparatively scarce and for the purpose of daily needs like potable water, irrigation, domestic chores, livestock feeding etc more freshwater bodies are required.

Looking at the ownership patterns, very few of these water bodies are either government owned or under the administrative controls of different departments of Government of West Bengal. These water bodies are not exclusively freshwater water bodies, the brackish water bodies are also there. But, these data seem to be important to understand how much of the total water bodies within these impounded areas are being looked after or used by the Government. Compared to the total areas under water bodies, unfortunately these figures are meagre. This only points to the fact that whatever may be the policy decisions regarding water bodies in Sundarbans, that need to be undertaken in consultation with the people of Sundarbans, since they legally own most of the water bodies in Sundarbans.

Table–11: Government Water Bodies (5.00 acres and above) in North & South 24 - Parganas (Source : Handbook of Fisheries Statics, 2016)

District	L & L.R. Department	Fisheries Department	Other Department	Not Specified	Total

	No.	Area in acre	No.	Area in acre	No.	Area in acre	No.	Area in acre	No.	Area in acre
North 24 Parganas	20	1851	7	1362.63	7	561.14	34	789.52	68	4564.29
South 24 Parganas	19	945.92	1	38.23	1	226.5	7	249.14	28	1459.79
Total	39	2796.92	8	1400.86	8	787.64	41	1038.66	96	6024.08

Fisheries Handbook, 2016 has revealed the number of rivers and the cumulative lengths of the rivers passing through individual districts, number of canals/ streams and the cumulative lengths of these canals/ streams passing through each districts of West Bengal. These figures have been worked out from the recent satellite imageries. Since Indian Sundarbans is spreading over two districts, namely North and South 24 Parganas Districts, hence data for these two districts are only mentioned below. In the same table total numbers of reservoirs and their cumulative area coverage in individual districts have been shown. Since North and South 24 Parganas districts are devoid of any reservoirs whatsoever, in both the cases the figures are zero and hence not mentioned here.

Table – 12 : Number of Rivers, Canal/ stream and their areas in North & South 24 Parganas (as per satellite imagery)

(Source : Hand Book of Fisheries Statistics 2016)

Sl. No.	**District**	**River (No.)**	**Length (in Km)**	**No. of Canals / Streams**	**Length (in Km)**
1	North 24-Parganas	28	859	69	395
2	South 24-Parganas	64	1468	399	2271
Total			**2327**		**2666**

Fisheries Handbook, 2016 has also indicated the area covered in hectares by River, Canal/ Khal, Beel and Baor following the 1976 Survey data, carried out by Fisheries Department. These data have been released for all the districts except Kolkata. Since Sundarbans is spreading over two districts, namely North 24 Parganas and South 24 Pargans, data for these two districts are only given below:

Table – 13 : Area under River, Canal/ Khal, Beel & Baor in North & South 24 Parganas (as per 1976 Survey of Fisheries Department, West Bengal)

Source : Hand Book of Fisheries Statistics 2015 - 16

Sl. No.	District	River (in ha)	Canal / Khal (in ha)	Beel/ Baor (in ha)	Total area (in ha)
1.	North 24 Parganas	14299	8712	8861.19	31872.19
2.	South 24-Parganas	17704.98	13492.47	5749.47	36946.92
Total		**32,003.98**	**22,204.47**	**14,610.66**	**68,819.11**

Obviously, these areas include brackish to saline water rivers and canals also. In case of Sundarbans, all the rivers are saline in nature since in all these rivers, diurnal tides play an important role in making these rivers saline. Moreover, there is hardly any upland discharge of freshwater in these rivers also. Unfortunately, separate data exclusively for the Sundarbans have not been provided in the handbook.

Mapping of Small Water Bodies by Fisheries Department

The State of West Bengal is enriched with a vast resource of small and large water bodies and a small coast line (about 220 Km). These water bodies are large in number in the Gangetic planes of South Bengal. Though most of these water bodies hold fresh water, there are a good number of brackish water ponds also, commonly known as 'Bhery' in the three coastal districts of Purba Medinipur, South 24-Parganas and North 24- Parganas. There is also a large open water resource in the form of streams, rivers and canals. Unlike other parts of the country, this State has innumerable number of smaller water bodies of the sizes of 0.08 acre (0.032 ha) and above which is the vast resource for culture and production of fries/fingerlings/small table fishes (Government of West Bengal, 2015). These water bodies are not only the main source of water for agriculture and domestic use in rural areas but are also potential source of fish production in the rural sector. A proper policy for development of these resources for fish production will play a major role in food supply and maintaining ecological balance between flora and fauna. Hence, it is crucial to develop a scientific plan to make an inventory of these water bodies and to develop a comprehensive plan for sustainable management of these water resources.

A paradigm Shift in inventorying water bodies under Fisheries Department

Under the aegis of Department of Fisheries, Government of West Bengal a project was initiated in the year 2008 with the funding from the State's Plan budget to prepare a digital map of the water bodies of the State of West Bengal with an attribute data base attached with respective water bodies. Thereafter, in the year 2009 the project was included as one of the components under the Central Sector Scheme "Strengthening of database and development of GIS for the fisheries sector" by the Government of India in the Ministry of Agriculture, Department of

Animal Husbandry, Dairying and Fisheries with 100% central assistance. The project started in the year 2008 with setting up of a satellite image interpretation lab and a server system to store the spatial data with associated attribute database. Identification of all water bodies measuring 5 Cottah (335 sq. mtr.) and above in the rural areas and all water bodies measuring one Cottah (67 sq. mtr.) and above in the municipal areas in the entire State of West Bengal was the main objective of the project.

Generation of water body maps for Mouza, Gram Panchayat, Block and District on the scale of 1:4000, 1:10000, 1:25000-40000 and 1:150000- 250000 respectively were also the target. In fact, once the digital database is ready, creation of layout and printing of hard copy maps on different scales should not be a problem. Major task was to create the digital database. Depending on the mapping scale at the time of interpretation of remote sensing imagery as also the sptial resolution of the imagery, the database can reveal the data for the smaller water bodies. For municipal areas mapping scale is 1:4,000 or 1:5,000 depending upon the circumstances (Government of West Bengal, 2015). Thus, a detail inventories of Block-wise / Municipality-wise all types of surface water resources have been created under 'Fisheries Mapping Project'. The features including water bodies initially identified and mapped from Quickbird image of the years 2004 to 2008 were again updated from multispectral satellite image of 0.5 meter spatial resolution taken by World View II satellite in the year 2010. This database and maps prepared out of the database are extremely helpful to planners and administrators to make development plans on Agriculture, Pisciculture, Irrigation, Drainage, Flood Control etc. Under this project, development of GIS application by linking spatial database and non-spatial or attribute data to these water bodies is also going on.

This database is not available in public domain and also to the non-government persons. Initially there was a target to webhost the entire database, but it is yet to be done. However, some data in tabular format have been indicated in some reports. The total impounded district wise water areas of entire West Bengal, as measured through this exercise, have been mentioned in the Handbook of Fisheries Statics, 2016. Data for North and South 24 Parganas districts are mentioned below:

Table – 14 : District wise Total Impounded Water Area for North & South 24 Parganas District (By satellite imagery analysis)

(Source : Handbook of Fisheries Statics, 2016)

Sl. No.	Name of the District	No. of Water Area	Total Area (in ha)
1.	North 24 Parganas	198951	60,994
2.	South 24 Parganas	432298	47,922

3.	**Total**	**6,31,249**	**1,08,916**

(Source: Hand Book on GIS Based Mapping of Smaller Water Bodies and Creation of Fisheries Database in West Bengal, under the Dept. of Fisheries, Government of West Bengal, 2015)

This data is extremely important since it indicates that number of water bodies in two districts mapped cumulatively is more than 6.31 lakhs and the total area is 1.09 lakh hectares. Obviously, these jump in figures (Compared to Table No.–6 and Table–8) are due to the smaller water bodies, which could not be mapped earlier and were not brought under survey and inventory. Conservation and maintenance of these water bodies can definitely help in solving the scarcity of freshwater in Sundarbans. So, at the policy end one has to think for this particular intervention for protecting these already existing small water bodies and to encourage creating more such water bodies.

Table – 15: Size and Class wise Distribution of Water Bodies in North & South 24 Parganas

Name of the District	No.	Area	No.	Area	No.	Area	No.	Area	No.	Area	
		Acre		Acre		Acre		Acre		Acre	Hectare
	≥ 0.08 < 1.00		≥ 1.00 < 2.50		≥ 2.50 < 5.00		≥ 5.00		Total		
North 24-Parganas	177810	46479.409	13889	21122.28	3872	13204.09	3380	69848.60	198951	150654.38	60993.68
South 24-Parganas	420525	79617.052	8493	12613.251	1894	6465.31	1386	19672.39	432298	118368.00	47922.27
Total	598335	126096.461	22382	33735.531	5766	19669.4	4766	89520.99	631249	269022.38	108915.95

(Source: Hand Book on GIS Based Mapping of Smaller Water Bodies and Creation of Fisheries Database in West Bengal, under the Dept. of Fisheries, Government of West Bengal, 2015)

This data clearly indicated the importance of small water bodies. It has been observed that smaller water bodies having area ≥ 0.08 <1.00 occupy an area of 126096.461 acres out of 269022.38 acres, which is about 46.87% acreage. Thus, appropriate policy for conservation of these water bodies is required. Incidentally most of these water bodies, if not all, are freshwater bodies, since these are essentially ponds and tanks without any connection with larger water bodies or running water sources, which are tidal and saline in case of Sundarbans.

Realising the importance of these smaller water bodies, Fisheries Department carried out updation of the old database by further mapping from high spatial resolution World View II imageries of the year 2010 for the entire state. Relevant data for North and South 24 Paragans district are narrated below:

Table – 16: Size and Class wise Distribution of Smaller Water Bodies in North & South 24 Parganas after Updation

	No.	Area	No.	Area	No.	Area	No.	Area	No.	Area	No	Area

Name of the District	≥ 0.032 < 0.20	Ha	≥ 0.20 < 0.40	Ha	≥ 0.40 < 1.00	Ha	≥ 1.00 < 2.00	Ha	≥ 2.00	Ha	Total	Ha
North 24-Parganas	156074	12682	21736	6136	13889	8552	3872	5346	3380	28279	198951	60994
South 24-Parganas	401765	27067	18760	5166	8493	5107	1894	2618	1386	7965	432298	47922
Total	557839	39749	40496	11302	22382	13659	5766	7964	4766	36244	631249	108916

(Source: Hand Book on GIS Based Mapping of Smaller Water Bodies and Creation of Fisheries Database in West Bengal, under the Dept. of Fisheries, Government of West Bengal, 2015)

The above table confirms the area coverage by small water bodies and the importance of smaller water bodies as sources for surface water storage, already mentioned.

Jal Dharo Jal Bharo Programme

A programme named "Jal Dharo-Jal Bharo" (*Catch water – Harvest water*) was launched during 2011-12 with the aim on preserving precious water resources by large scale harvesting of rainwater as well as arresting runoff of surface water to improve and availability of precious water resources through the construction and management of Minor Irrigation structures. Water Resources Investigation & Development Department, Government of West Bengal has taken a lead role under the programme to re-excavate all kinds of water bodies viz, tanks, ponds, reservoirs, canals where water holding capacities have lower down at present in convergence with Panchayat & Rural Development (P&RD) Department, Government of West Bengal and other different programmes and also emphasised on underground artificial recharge of aquifers through rooftop rainwater harvesting. Check Dams, Water harvesting Tanks and Surface Flow Minor Irrigation Schemes which are being constructed by Water Resources Investigation & Development Department (WRI & DD) would help in arresting surface runoff water and at the same time irrigation potential of the state are being increased by utilisation of the same. Increased holding capacities in the water bodies will immensely support protective irrigation during the dry spell. Apart from agriculture, pisciculture activities would develop in such water bodies which in turn open a further avenue of income to the poor farmers. Availability of water throughout the year will also help the local villagers in their domestic activities and animal husbandry activities. JAL DHARO-JAL BHARO PROGRAMME' also aims towards building citizen's awareness for rain water conservation and efficient water-use in irrigation.

As of December 2014, 1,18,557 numbers of water bodies/ retention structures have been created out of which 32,851 pond equivalent has been created by WRI&DD, 85,423 nos have been created in convergence with P&RD Deptt. and 283 nos tanks have been created by WRI&DD under Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA)

(Source: https://wb.gov.in/portal/web/guest/jal-dharo-jal-bharo). However, no district-wise or block wise detail break up of these water bodies are available in the website. But, undoubtedly, this programme has created large number of water bodies which will get recorded in any future mapping programme. Incidentally, all these water bodies are freshwater bodies and created for rainwater harvesting. Surely, number of freshwater bodies in different blocks of Sundarbans has increased by this time.

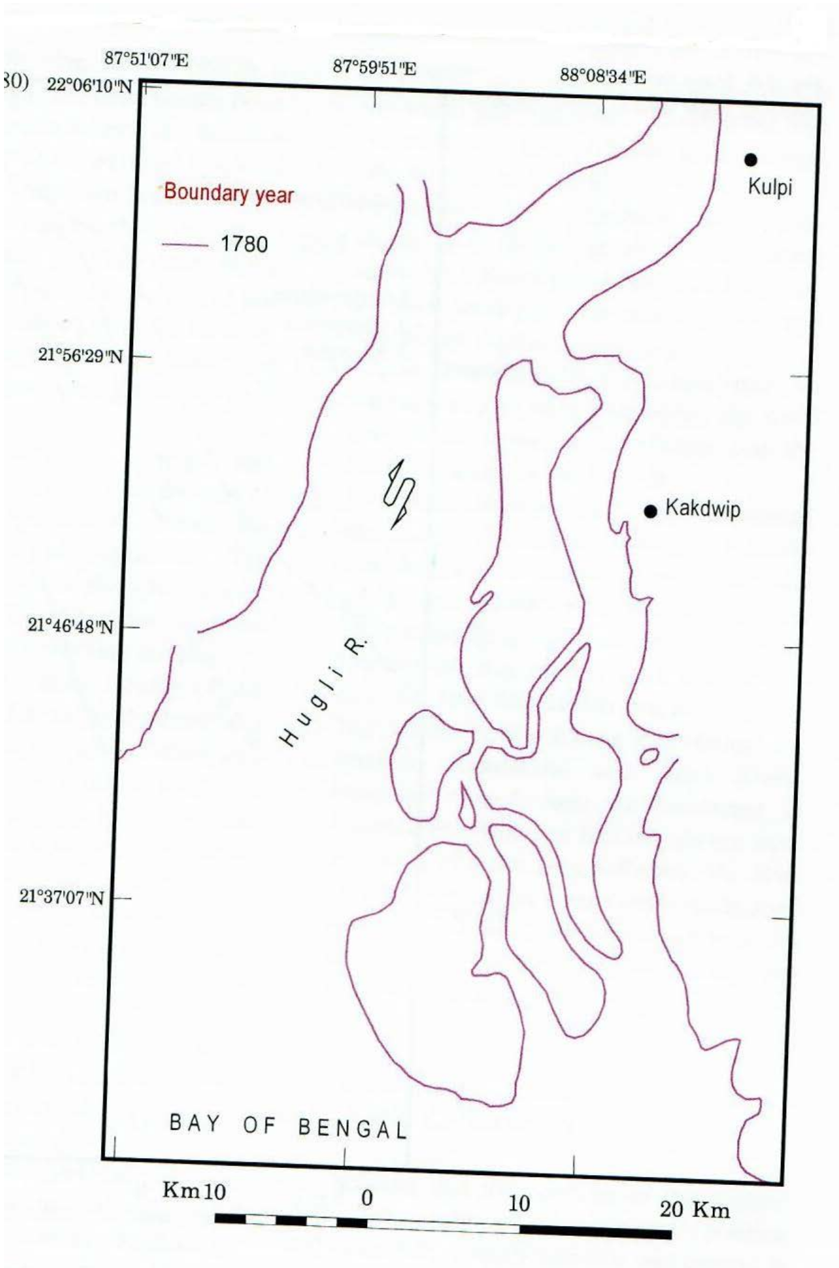
West Bengal Accelerated Development of Minor Irrigation Project (WBADMIP)

This project is being implemented under Water Resources Investigation & Development Department (WRI & DD) with the financial support of The World Bank. The aim of the project is to enhance agricultural production of small and marginal farmers in the project area. This would be achieved through Strengthening community-based institutions i.e. Water User Association (WUA) on irrigation management, operation and maintenance, Construction and development of minor irrigation schemes (surface & ground water). Support to agricultural development, including provision of agricultural services, encouraging crop diversification and use of new technologies, and creating income generating opportunities (Source: http://www.wbadmip.org/index.php# accessed on 28.11.18).

Number of water detention structures (WDS) has been constructed by the Project Implementation Unit in different districts. However, the thrust area of the project is western part of West Bengal, although some WDS have also been constructed and created in Sundarbans region, some of which are also described in this report under a different sector. A GIS database for surface water resources, which are freshwater resources only, has been created and uploaded in Web (WBADMIP Web GIS) for use of the registered users (Source : http://103.16.143.46/GISWEB/map1.htm accessed on 18.11.2018). It is understood that details of water bodies for Sundarbans are not included in this database since that is not the thirst area for this project.

River Network, its Discontinuities and Future Possibilities

It has already been described that many channels flowing through the Sundarbans are not rivers in strict sense of fluvial geomorphology. A river is supposed to have a source, outfall, catchment area, many tributaries and distributaries in its lower reach (Rudra, 2018). Unlike the general characters of the rivers, the creeks receive water supply from the downstream that is from sea or ocean. Water flowing in creeks is induced from the sea, and the flow is governed by the tide-velocity asymmetry and thus a two-way flow occurs. Most of the six major channels in Sundarban can be broadly identified as tidal creeks with the exception of Ichhamati – Haribhanga river which receives feeble supply of freshwater during peak of monsoon (Rudra, 2018).



oghly River

A detail discussion on the process of silting up of the rivers leading to subsequent discontinuity of the channels has been described by Rudra, 2018. It has been estimated that 15% of one billion tonnes of sediments reaching the Bengal basin is sequestered annually and does not reach the sea (Goodbred Jr. & Kuehl, 1998). Sundarban creeks are 'Flood Dominated' estuaries (Bhattacharyya et al, 2013). The silt laden tidal water travels upto the northern fringes during high tide condition and get static once the low tide starts. The suspended sediments get enough time to get deposited on the river bed through flocculation process. Thus, a process of accretion operates to build up floodplain. The deposition of silt gradually blocks the flow of the river and the old river/ creek bifurcates or splits up around obstructions, thus forming numerous channels, tidal creeks and distributaries. The cross-channel (locally called *Duani*) connecting two larger creeks face faster decay due to head on collision of the tidal waters leading to settling down of sediment load (Rudra, 2018). In this process, many creeks have been filled up during last two centuries. In the process, many of the freshwater channels carrying upland discharges and passing through Sundarbans got silted up and chocked leading to reduction in freshwater supply in Sundarbans. As a result, the freshwater supplies in Sundarbans had decreased to a large extent in Sundarbans which has an immense impact on increment in salinity of the surface waters along the creeks.

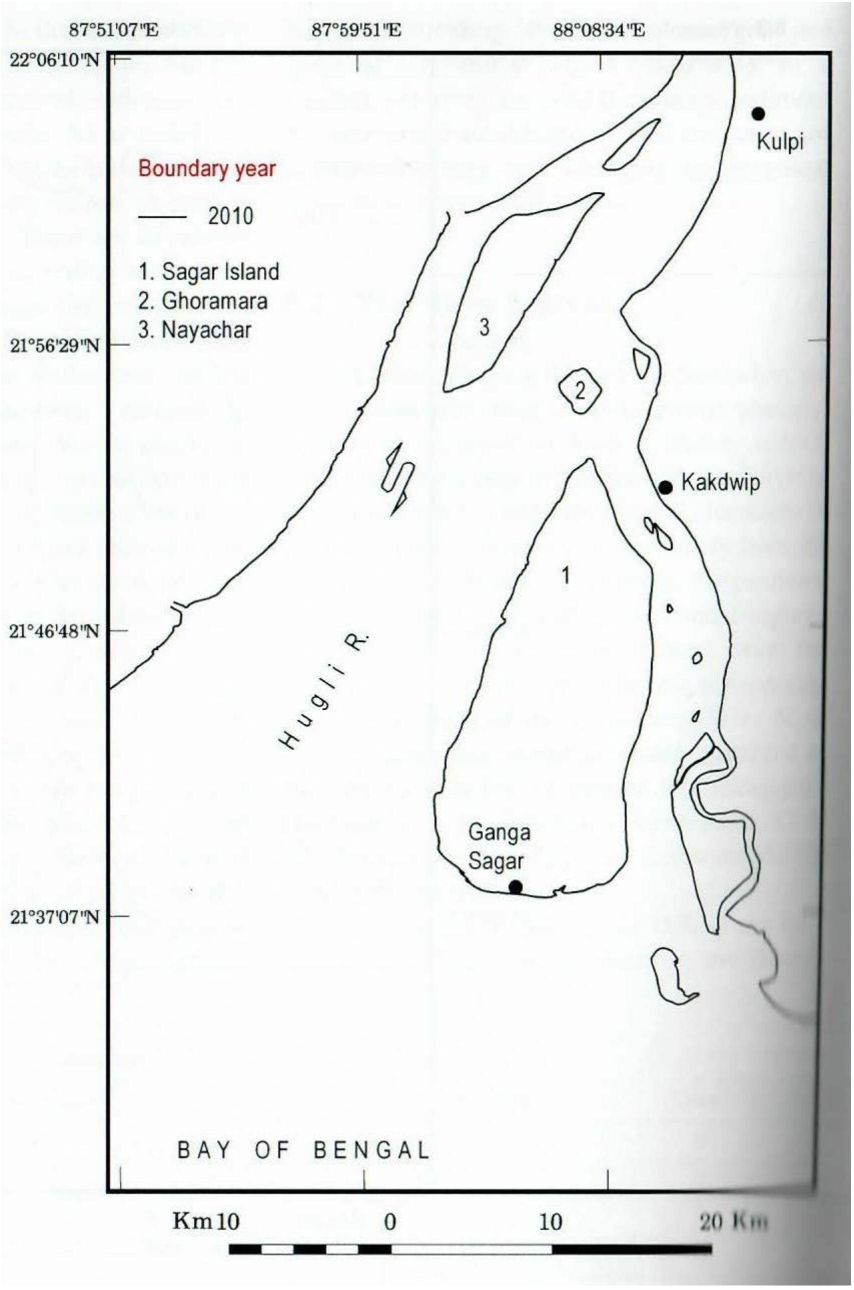


Figure – 4 : Map showing changing Sagar Island and Hooghly River as in 2010 (Source : Rudra, 2018)

In most of the cases, the major rivers of Sundarbans had lost their headwater connections and in the process had transformed into creeks without any freshwater discharge except the storm water in the immediate catchment during monsoon. This has increased the salt stress on the biodiversity of Sundarbans especially on the mangrove community. Mangroves in the central portion of Indian Sundarbans are facing stunted growth with considerable saline blanks within the forested part. Thus, once dense mangrove forest is getting gradually transformed into sparse and in some areas even degraded due to increment in salinity. Effects of climate change and consequent sea level rise is also playing a considerable role in this game, but complete loss of headwater discharge in the once

ortant reason behind increment in salt stress along the entire Sundarbans. In many places, anthropogenic interventions and unplanned reclamation of the channels carrying freshwater to these once mighty rivers are the major reasons for stopping the freshwater discharge in these rivers. Even part rejuvenation of these channels may help in increasing freshwater supply in Sundarbans and help in adaptation in the backdrop of climate change. Thus, without discussing the river network and its discontinuity, no discussion of freshwater inventory can be objective in manner.

<u>River Network</u>

The prevailing freshwater flow into the Sundarbans depends on the hydrological conditions of these river systems. Some are receiving limited freshwater and some are completely cut

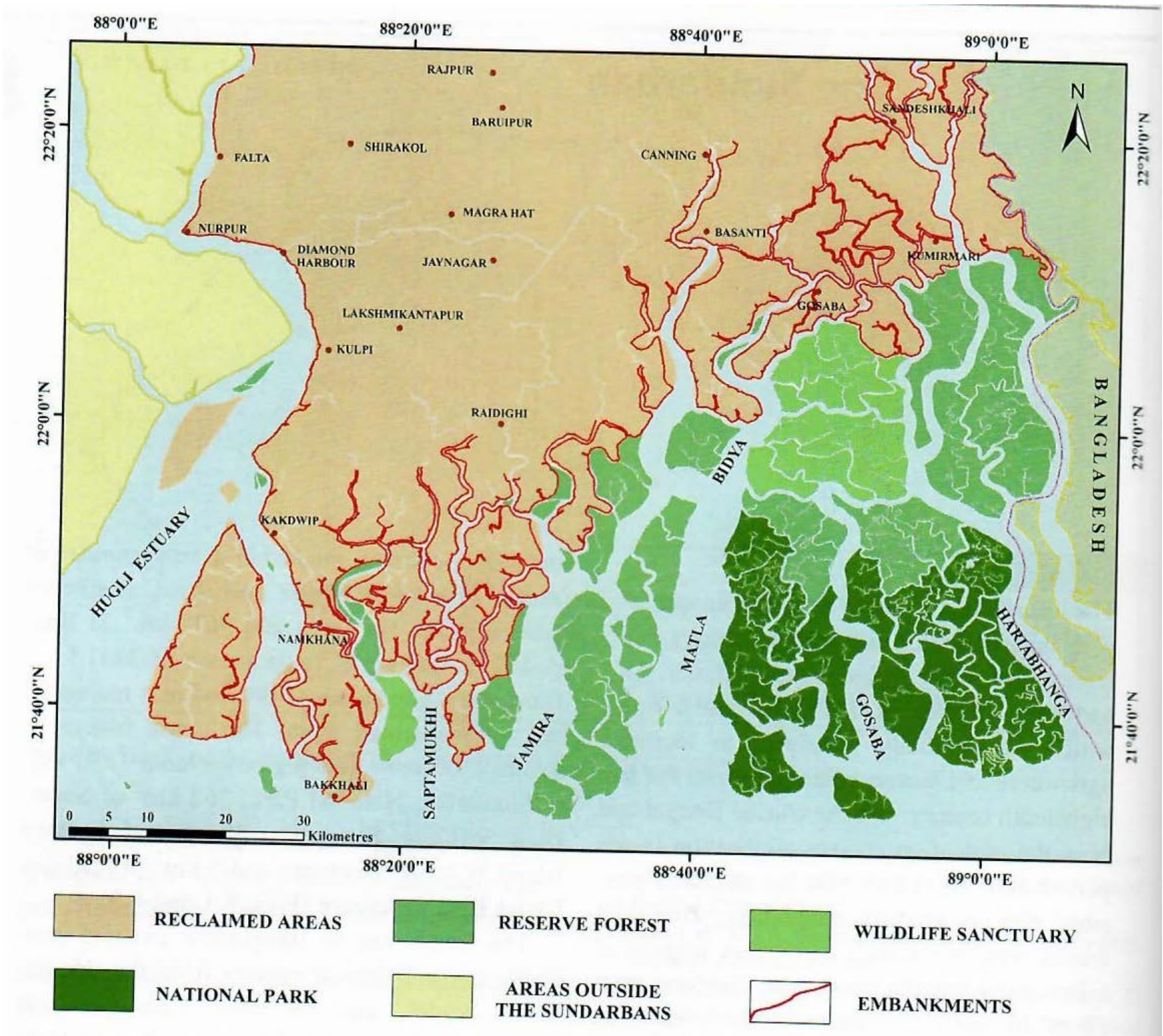
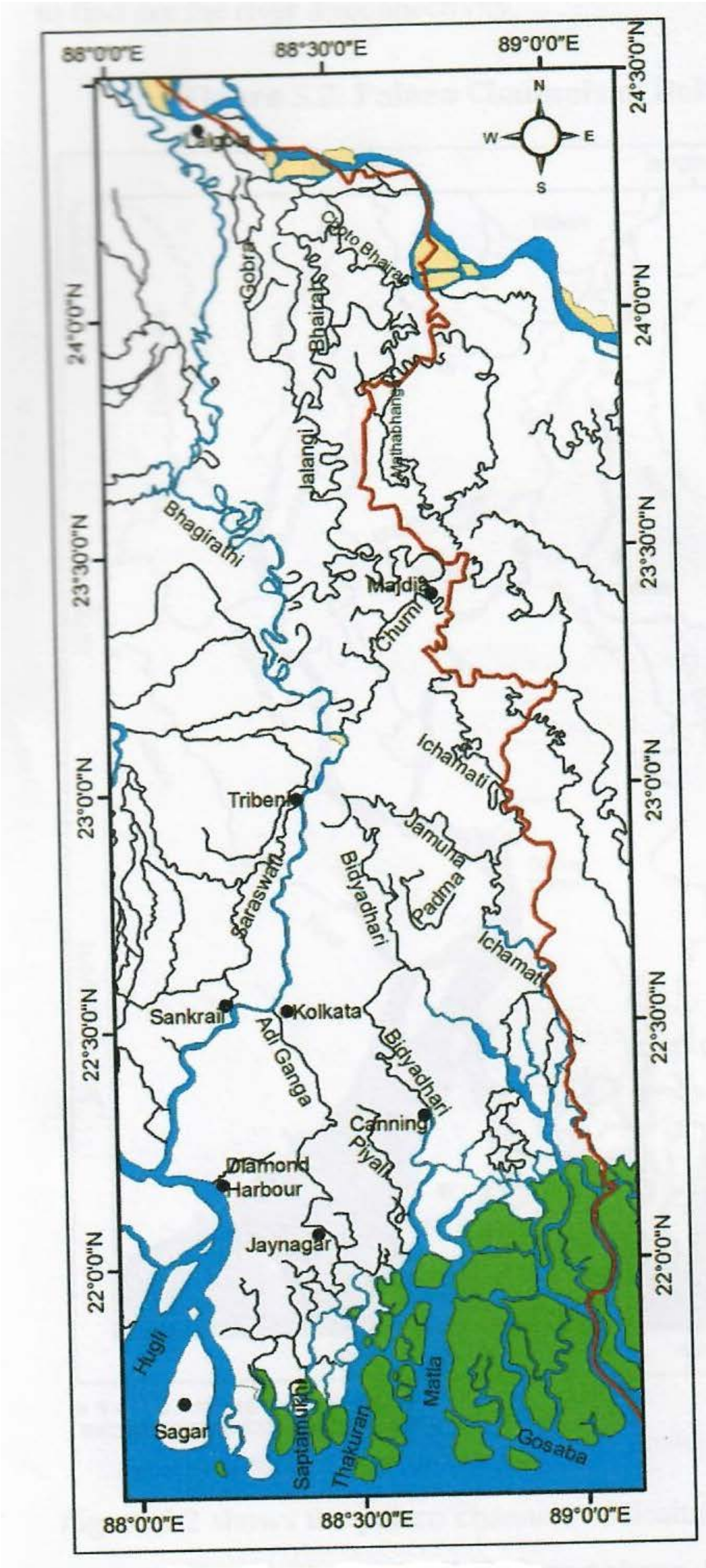


Figure – 5 : Major Rivers and Creeks flowing through Indian Sundarbans (Rudra, 2018)

off from the upland discharge since they have lost their original connections with the Ganges system due to siltation at the off-take points. From the above figure, it is quite obvious that



Bhagirathi – Hooghly, Matla – Bidya and Ichhamati – Raimangal are the important running water flows in Indian Sundarbans.

Bhagirathi – Hooghly has a little contribution to feed as its link with the rivers which ran through Sundarban has been disconnected. Adi-Ganga, Bidyadhari and Ichhamati were one time the three major freshwater sources for Sundarban. But, presently all these rivers are almost in a dying condition. As already indicated, there is hardly any published literature available on this issue, except some small reports in newspapers and reportage like pamphlets being composed and circulated by local level organizations. However, best method to find out the river discontinuity in Sundarbans is to compare the old Survey of India topographic sheets available in different departments with the present satellite images, which can immediately reveal the actual points of discontinuity. Some existing literatures can definitely help in this issue.

l Delta

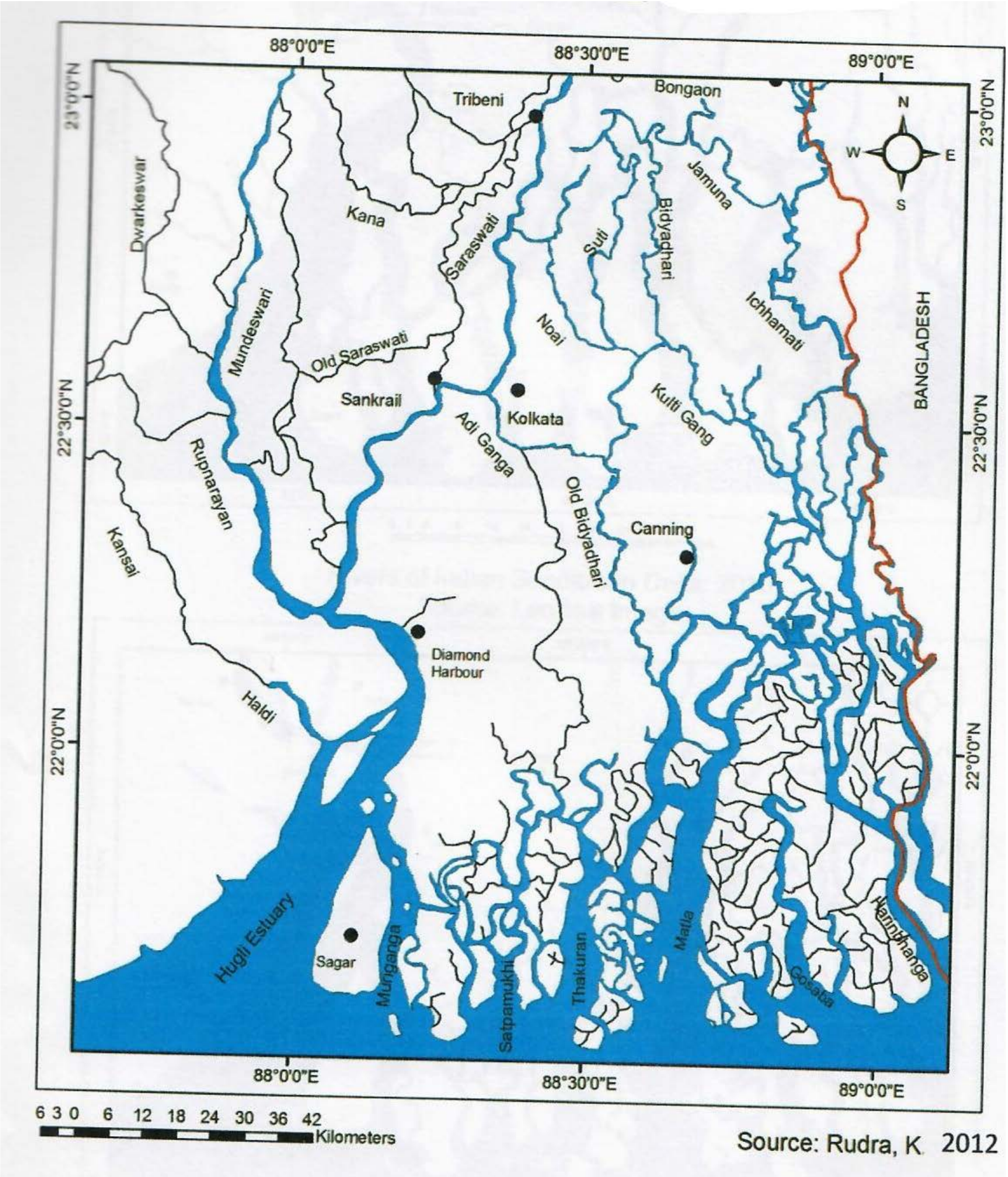
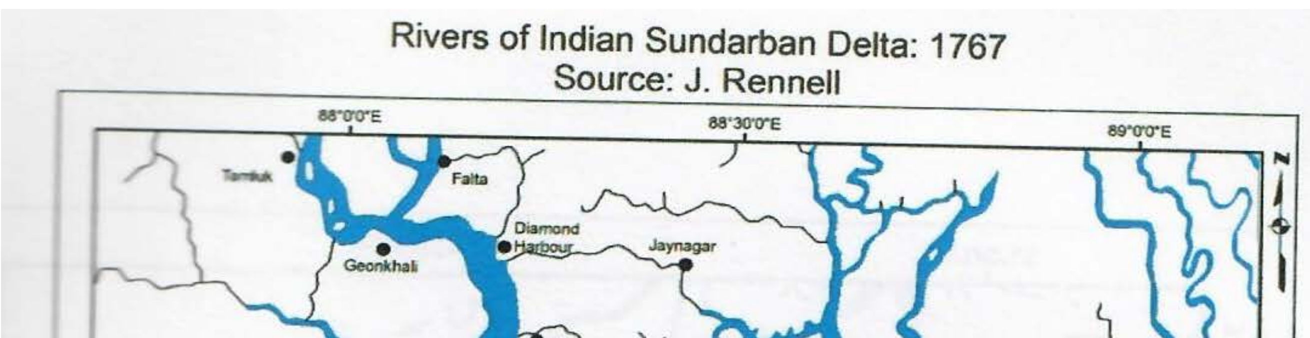


Figure – 7 : Paleo Channels of Deltaic West Bengal as identified from remote sensing images

Most of the channels are now disconnected from the parent rivers, as a result of which the freshwater upland discharges along the present rivers existing in Sundarbans have almost



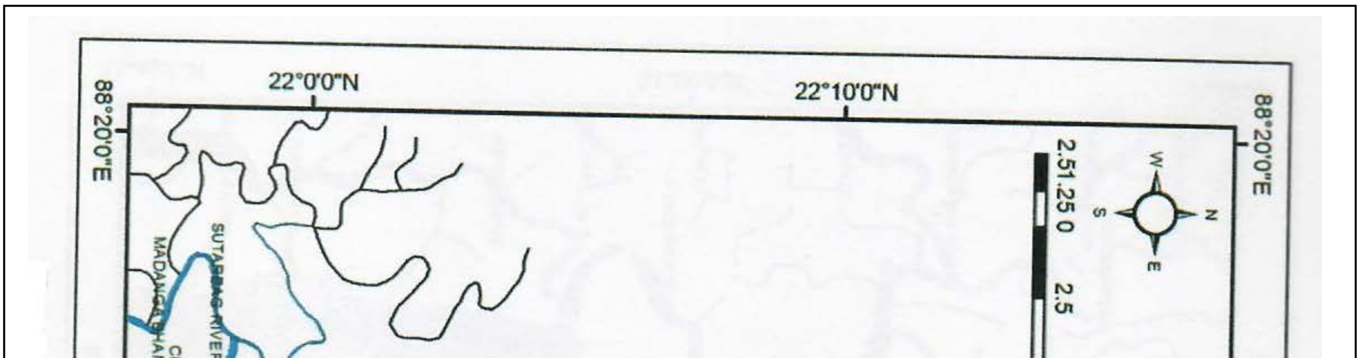

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Figure 9 : River Networks of Sundarbans in the Central Sundarbans as delineated from

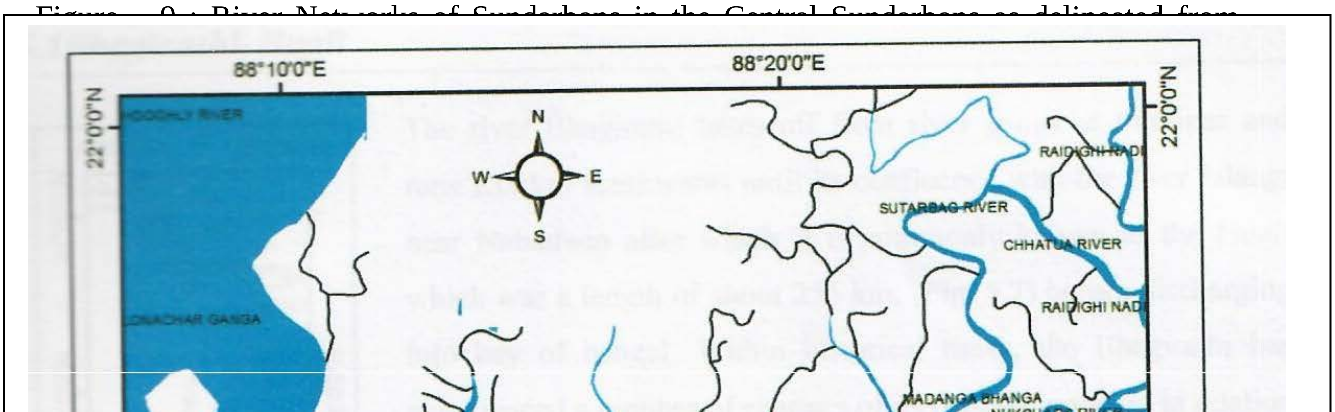
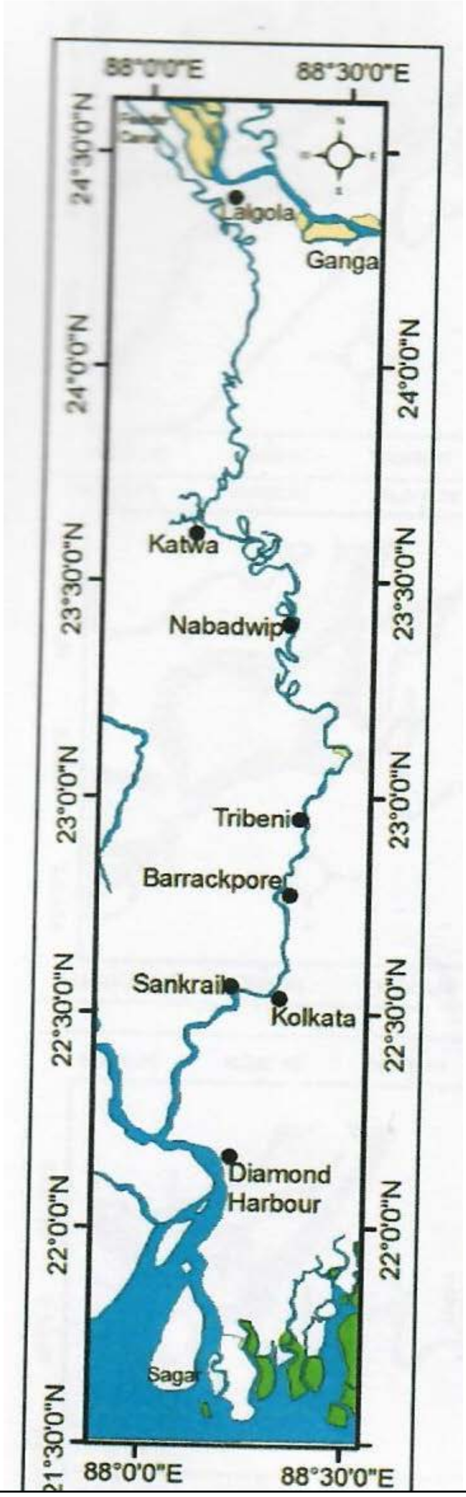


Figure – 10 : River Networks of Sundarbans in the Western Sundarbans as delineated from Survey of India Topographic Sheets (Source : Bhadra, 2013)

From the Figures 9 and 10, it is quite obvious that hydrology of Sundarbans depend on these network of creeks and rivers. Distribution of water either from upland or from the sea depends on this network only. If some of these interconnecting channels get silted up at the off-take points resulting in discontinuity of the individual channels from the major rivers, then the entire system starts deteriorating. A short description of the major rivers can reveal the way outs to rejuvenate the system and accordingly individual rivers are discussed below:

Bhagirathi – Hooghly River System



The river Bhagirathi takes off from river Ganga at Mithipur and runs 233 km southwards until its confluence with the river Jalangi near Nabadwip after which it is commonly known as the Hooghly which has a length of about 256 km before discharging into Bay of Bengal. The Bhagirathi has undergone a number of changes in respect of its off-take points from the main Ganga or Padma River during the recent past. The well known off-take points are located at Dhulian, Suti, Giria (Bhadra, 2013). Interestingly, these off-take points were operative within last two hundred years or. The characteristic circumstance of such changes in off-take point was that once a new off-take point opened, the old one became defunct and ultimately closed. The present off-take point at Mithipur was formed after the closure of the Giria off-take point (Basu, 2005).

Dhulian off-take point was perhaps in operation long back, before 2000 B.C. (Bhattasali, 1941). But the off-take point together with the channel of the Bhagirathi, was found to have been completely engulfed by the Ganga, and there was no trace of the old Bhagirathi River anywhere. After the closure of Dhulian, the off-take point shifted to Suti, another point southeast of Dhulian (Bhadra, 2013). Thereafter as the Suti off-take point got closed, a new off-take point at Giria was opened by Bhagirathi (Basu & Chakraborty, 1972). After the off-take point at Giria got eroded by the River Ganga, the present day Mithipur off-take point opened up. Incidentally, this off-take point is situated in the south-east of previous Giria Off-take point and is about Dhulian (Bhadra, 2013).

Figure – 11: Bhagirathi – Hoogly River System

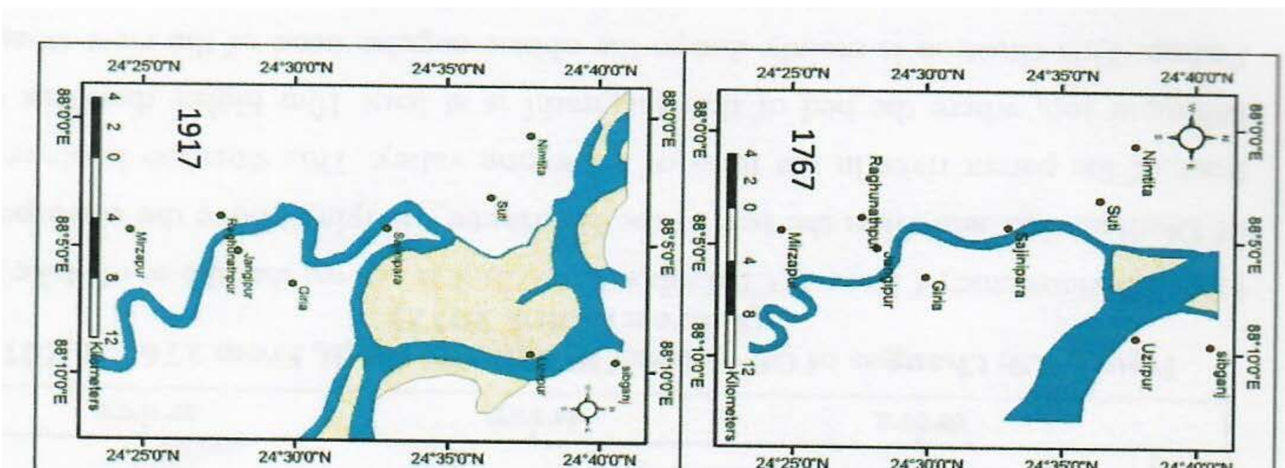


Figure – 12: Changes of Off-take Points of Bhagirathi – Hooghly River from 1767 to 2010 (Source : Rudra, 2012)

Thus, there is a constant shift of the off-take points to the south-east for a distance of about 45 kilometres.

It is interesting to note that in all these off-take points including that at Mithipur, the bed of Bhagirathi is lying at least at a higher level of 10 meters than that of the Ganga. As a result, the off-take points of Bhagirathi are getting silted up hampering the regular flow of water from the parent river Ganges except in the rainy season. With the reduction of upland discharge, Bhagirathi-Hooghly River was also turned into almost a seasonal river active during monsoon period only. The tidal action was also felt beyond Nabadwip at that time and accumulation of sediments through tidal action accentuated since Hooghly River is flood dominated in nature meaning high tide is of shorter duration than low tide. Salinity along the Hooghly River was also increasing due to lesser amount of upland discharge compared to the tidal flow coming from the Bay of Bengal. Although a portion of the deposited sediments were washed away during monsoon period with higher upland discharge, but on an average about 7.9 million tons of sand choke up the river system per year (Basu, 2005).

With less amount of water available in the main Bhagirathi River for a quite long period of time, most of the distributary channels of Bhagirathi, which are the main source of discharge of freshwater in Sundarbans got dried up and even got disconnected from the main Bhagirathi River leading to salination of the entire Sundarban region. Farraka barrage and the feeder canal were constructed to discharge 40,000 cusecs of water and started operation from 1972. However, another barrage at Jangipur was also simultaneously constructed to stop the outflow of water from the Bhagirathi to the main Ganga River. Further, it has been pointed out that agreed amount of 40,000 cusecs to Bhagirathi channel from the Ganga River as per 1996 agreement between India and Bangladesh is hardly available throughout the year (Rudra, 2010). Thus, the situation did not improve to the extent as was envisaged before the construction of the Farakka barrage.

The situation described above is extremely important to improve the present day scenario of salinity in Sundarbans. The major Rivers like Matla, Bidya etc. which used to once carry considerable amount of freshwater and discharges into the Bay of Bengal are presently devoid of that freshwater subsidy from the upland areas. These mighty rivers have already been transformed into creeks, as per the definition given at the beginning of this subsection. As a result, the saline stress along the entire Sundarbans is increasing day by day. The situation can improve, only if the freshwater discharge along these rivers be increased through interventions at the off-take points of different erstwhile rivers, which are being described subsequently.

Adi Ganga – Bidyadhari – Jamuna River System

Adi Ganga is a palaeo-distributary of Bhagirathi – Hooghly, which has even been reported even in the mediaeval Bengali literatures (Mangal Kavyas) as an important navigational channel. Its degraded course is still traceable for 36 km downstream of Kolkata up to Surjyapur in the South 24 Parganas District. During the last 500 years or so, the river Adi Ganga, as the name implies, the "Original" Ganga had been flowing from Kolkata towards southeast to meet the Bay of Bengal (Roy et al, 2017). Presently, it takes off from the river Bhagirathi – Hooghly at Hastings, Kolkata as a narrow stream and flows in southern direction towards Kudghat. The channel has lost its identity at Garia. South of Garia, the original Adi Ganga Channel has been converted into a series of ponds aligned in a north-south direction. From Garia to Jaynagar, Suryanagar and even upto Gangajuyara, the same pattern has been found to continue. Interestingly, water of Adi Ganga is also considered even today as holy similar to that of Bhagirathi–Hooghly by the religious Hindus. All these indicate the antiquity of the Adi Ganga as the main channel of the Bhagirathi – Hooghly (Roy et al, 2017).

Figure – 13 : Changing Courses of Adi Ganga from Late 18th Century to 2009
(Source : Rudra, 2012)

In order to promote business, Mr. William Tolly, an officer of East India Company dug a 27 km long canal eastward during 1775 – 1777 from Garia to Samukpota via Tentulberia, Gangajoara and Nayabad village with the objectives to connect the Adi Ganga with the river Bidyadhari which would also serve the purpose of transferring freshwater to Bidyadhari which passes through Sundarbans. River Bidyadhari was then a vibrant waterway linked with the Sundarbans and other areas of the then East Bengal (Roy et al, 2017). This

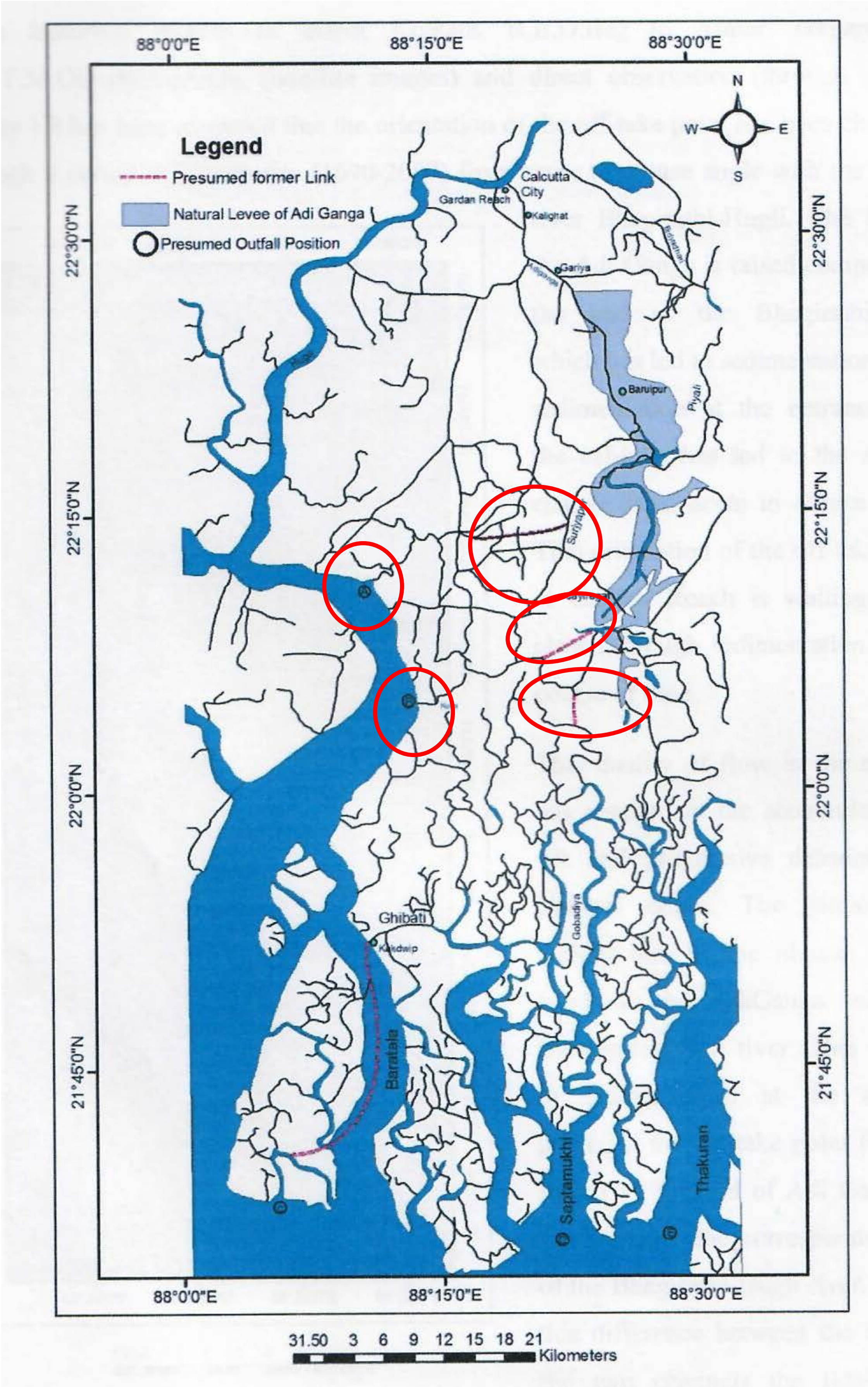


Figure – 14 : Course of Adi Ganga and its two earlier possible out fall positions (a) and (b) near Diamond Harbour and Kulpi respectively (Bandyopadhyay, 1996) canal is now known as Tolly Nullah and the place from which it starts is named Tollygunge after William Tolly. It needs to be understood that at that time Adi Ganga was still a mighty river.

In a non-scale map prepared during 1615, by the Portuguese sailor Jao de Barros and another one prepared by Van den Broecke in 1660, the river Ganga (meaning Bhagirathi – Hooghly) is shown as a wide channel flowing from North to South, from present day Hastings lying near Fort William through the land area now occupied by the remnant Adi Ganga. Bandyopahyay, 1996 while trying to track the Adi Ganga Palaeo-channel has tracked it up to Surjyapur and beyond which towards the south, its link with Bay of Bengal is only presumed by former likely links with two outfall positions near Diamond Harbour and Kulpi (Kulpi Canal).

It is understood from the literature that the principal course of the lower Bhagirathi-Hooghly system has changed during last 400 years or so. During 15th to 17th Century, the Bhagirathi used to get divided into three branches – namely the Bhagirathi itself, which used to follow the present Hooghly Channel upto Hastings and then used to pass through the now decayed Adi Ganga, the Saraswati to the west and the Jamuna – Bidyadhari to the east (Fig–13) (Hunter 1876; Reaks 1999 & 1959; Wilson 1895).

As per mediaeval history, earlier the European traders used to reach the then Calcutta from the Bay of Bengal through the river Adi Ganga (then known as River Ganga) through Sundarbans. Due to complaint regarding safety and security from wild animals and robbers, in the eighteenth century Nawab Alibardi Khan (ruler of Bengal from 1740 – 1756) employed some Dutch engineers to dig a westward canal to divert a part of the Ganga (Bhagirathi flowing through the present day Adi Ganga course) to the then dying river Saraswati of the Howrah District to open the channel of present day Hooghly to the Bay of Bengal. This linkage resulted in a gradual but conspicuous reduction of the channel width and discharge of the original River Ganga to the south and southeast of the area from near present day Hastings. With the time of passing of time, this canal dug by the Dutch engineers towards west direction evolved as the main channel of the Ganga, now called Hooghly River, flowing towards Diamond Harbour after a westerly bend near Hastings. As a result, Adi Ganga ultimately became an abandoned channel.

But, there is lot of debate and difference of opinion among the researchers regarding the possible outfall of Adi Ganga. Sherwil, 1858 suggested that below Surjapaur, the river used to be broken into different mouths and the principle outlets being Baratala, Saptamukhi and Thakuran; while Reaks 1919, 1959 suggested that the Adi Ganga splits into number of branches, one of which running into the lower Hooghly at Diamond Harbour. Rudra, 1981 & 1986 suggested that the river used to flow due south into sea along the Gobadiya creek through Saptamukhi estuary. Bandyopadhyay, 1996 suggested that there may be two possibilities of outfall of Adi Ganga either through Kulpi Creek (also suggested by Mukherjee, 1986) or at Diamond Harbour. Whatever might be outfall at that time, the decay of Adi Ganga has resulted in loss of freshwater to the present day Sundarbans to a large extent, which needs to be understood carefully before suggesting any recommendations for carrying freshwater to Sundarbans.

<u>Jamuna & Bidyadhari</u>

Jamuna takes off from Bhagirathi – Hooghly near Tribeni. It flows towards east in a zigzag way and joins Ichhamati near Tipighat. Bidyadhari presently originates near Haringhata in Nadia district and then flows through Deganga, Habra and Barasat areas of North 24 Parganas before joining the Raimangal River in the Sundarbans. This river has been the major drainage system of North 24 Parganas and Kolkata.

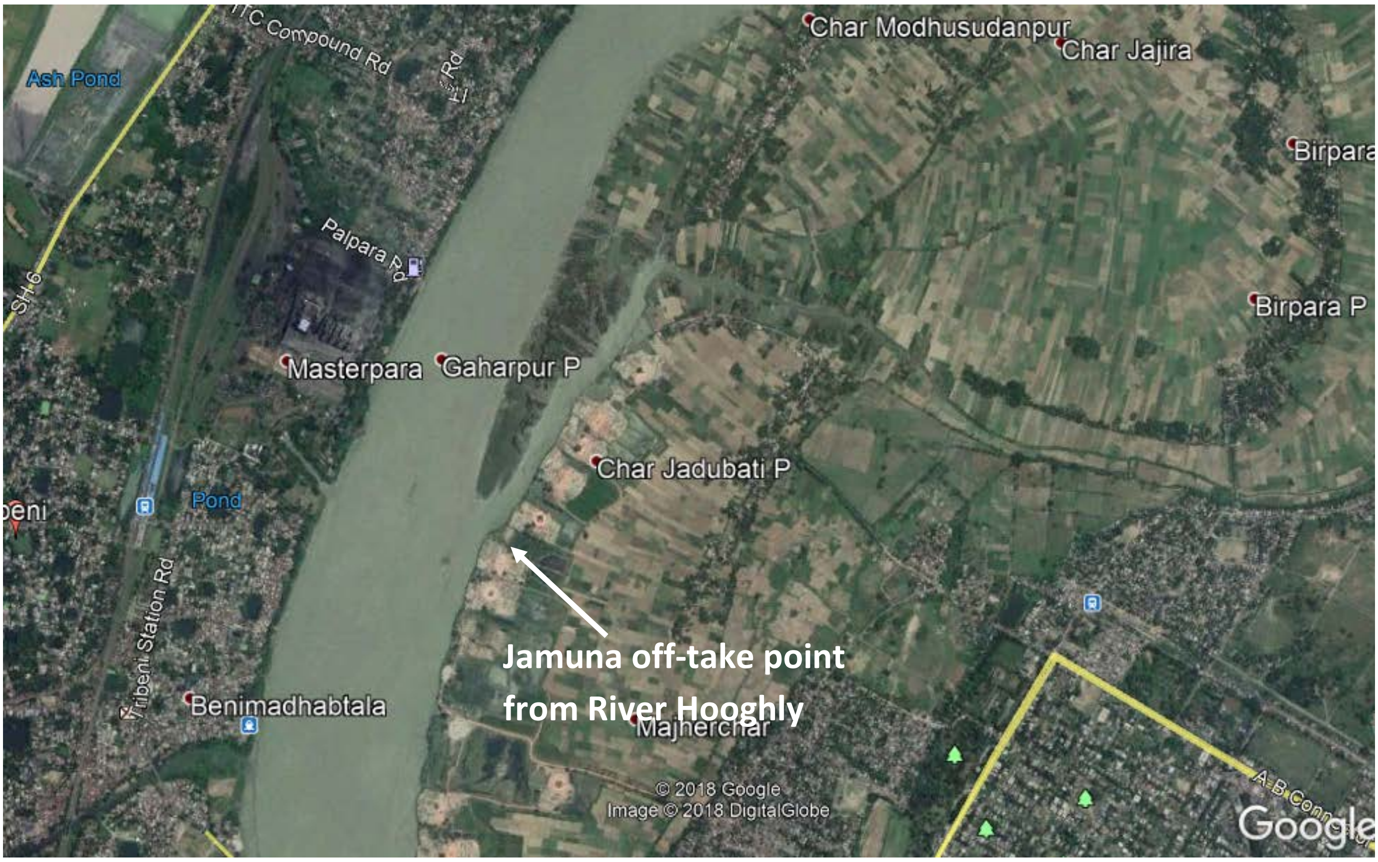


Figure – 15: The present day decayed condition of Jamuna River immediately after off-take from Hooghly River near Tribeni

Jamuna River was one of the main branches of the Ganga. Jamuna was perhaps the most important delta builders in those days and contributed towards building a major portion of Sundarbans. The Bidyadhari, on the other hand was an important spill channel of the Jamuna and was responsible for tidal regime towards the eastern side including the erstwhile East

Kolkata Wetlands. Important channels like Nowai, Sunti and Nonagong which once connected Bidyadhari with the Jamuna and were the major conduit of freshwater to the Bidyadhari River can still be traced within a span of few kilometres from the presently abandoned course of Jamuna. The Kultigonj which now constitutes the outfall of the Nowai, Sunti and Nonagong, formerly got water from Bidyadhari, probably opened up much later than Bidyadhari (Biswas, 2001).

Human interference like discharge of entire city sewage from Kolkata City into the Bidyadhari River has accentuated the rate of sedimentation over the river bed. The large number of fisheries in the lower part of Bidyadhari and other low areas contributed towards free flow of tidal prisms in Bidyadhari and thereby contributed towards the deterioration of the River Bidyadhari.

Figure – 16 : Meeting point of Piyali River with Matla in Sundarbans

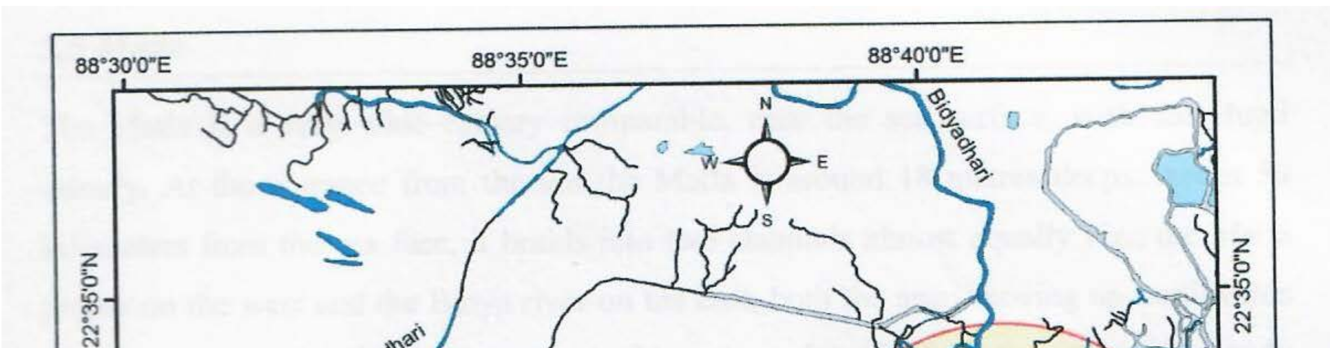


Figure – 17 : Sewage Canal of Kolkata City stopped the natural flow of Bidyadhari River; Bidyadhari at Ghusighata near the outfall point of seawage from Kolkata; off-take of Piyali and Head of Matla encroached by Fisheries (Source : Bhadra, 2013)

Matla at a point which is about 32 km south of Canning Town. The course of Piyali is not traceable properly above the Piyali Station. It has also been disconnected from its parent river Bidyadhari. A closure at the outfall of Piyali protects the river from natural tidal movement and also contributed towards its natural decay. Freshwater supplies from Bhagirathi River earlier reached the Matla River through this conduit via the Bidyadhari River.

It is also unfortunate that river Bidyadhari, which used to get considerable amount of freshwater from the Bhagirathi – Hooghly system through River Jamuna, which was once a major distributary channel of the river Bhagirathi also got disconnected from the River Jamuna with time. As a result, upland freshwater discharge through river Bidyadhari stopped completely. Even the relict river bed of the disconnected portion of Bidyadhari, Nowai, Sunti etc. have been completely reclaimed and being used presently for agricultural purposes by the local people. Bidyadhari has now been transformed into a tidal creek in true sense. Attempt of William Tolly to transfer freshwater from Adi Ganga to Bidyadhari is also not possible in the present scenario not only due to miserable state of the river Adi Ganga, but also due to the fact that the entire Tolly Nullah has been transformed into a stagnant pool of water. Condition has further deteriorated due to construction of concrete pillars for metro rail within the Tolly Nullah bed itself (Roy et al, 2017).

Although some attempts are presently being undertaken to rejuvenate Adi Ganga at the upper reaches like Panchpota, but that is too meagre and too late. Only a master plan of river linking work can really rejuvenate the entire Adi Ganga – Tolly Nullah – Jamuna River – Bidyadhari River system to push freshwater into Sundarbans.

Matla River System

This second largest estuary of the Indian Sundarban, next to the Hooghly estuary, is formed by combined flow of Karati, Rampura Khal, Atharbanki and Bidyadhari (Rudra, 2018). It flows for a length of 120 km from Canning to the Bay of Bengal. The Matla provided better navigational depth than Hooghly estuary in the mid-nineteenth century and Port Canning was built as a substitute to Kolkata Port (Rudra, 2018). But the port was abandoned within a decade due to rapid sedimentation.

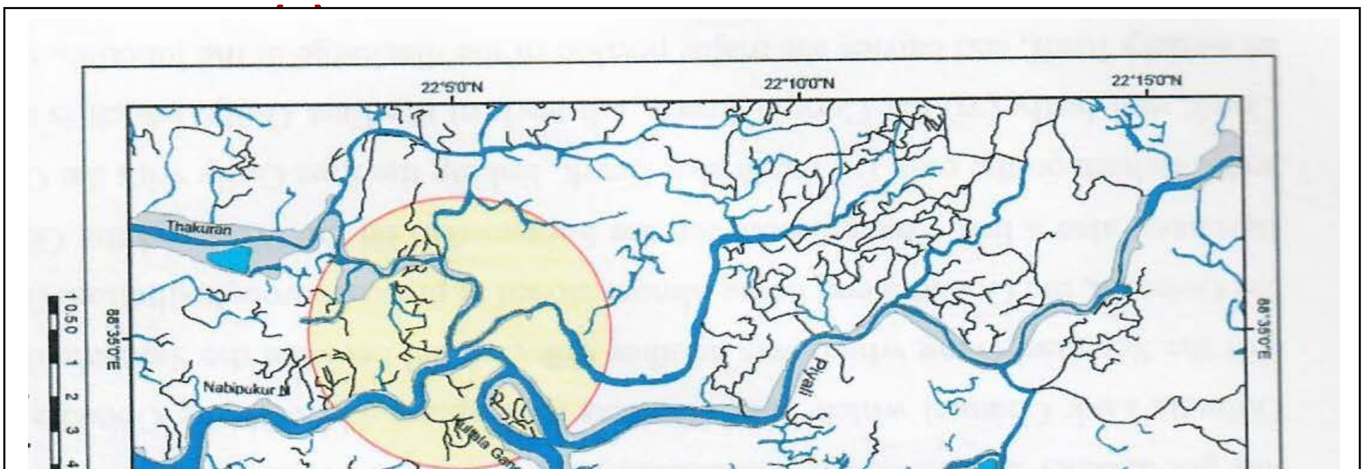
At the entrance from the sea, the Matla is about 18 meters deep (Bhadra, 2013). About 50 km from the sea face, it braids into two channels, almost equally, namely the Matla Proper in the West and the Bidya River in the east. Both the arms are moving northwards parallel to each other. At the northern inland end, the Matla meets three channels namely Bidyadhari in the west, the Karati River in the centre and the Atharbanki on the east. The Bidyadhari River in

Figure – 18 : Matla River at Canning from where it starts and getting almost lost within large number of fisheries which stop any upland discharge into it

There are a number of lateral connections of the Matla River on and from inland side. Some of these are the Belladona River, the Kultala River, the Piyali-Nabipukur River, the Bainchap Khal, the Kailkamari River, the Suia River, the Dulibhasan Gang, the Chulkati Gang, Gokhaltaki Gang etc. On the eastern bank also, there are likewise a number of lateral connections with further river systems (Maitra, 1968). Unfortunately most of these rivers are now in decaying conditions, although the tracts of these rivers are very well traceable in remote sensing images of high spatial resolution like Google Earth. As a result of overall decay of these channels carrying upland freshwater to Matla, there is practically no freshwater discharge at this moment to Matla River.

Thakuran River

It originates near Jaynagar and Mathurapur and flows towards south for a length of 80 km (Rudra, 2018). At its northern end, it connects the Matla and has linked with Saptamukhi. The



(b)

Figure – 19 : (a) Connection between Thakuran & Matla; (b) Disconnected path between Thakuran & Matla (Source : Bhadra, 2013)

The Jagadal gang at its upper end meets the main Thakuran River via Chitpat or Pakhiran Khal. Beyond this junction, the Thakuran gradually loses its width in its upward course and ultimately ends as a small channel to join Nabipukur – Piyali, a branch of the Matla, at a point where there is outfall of another inland channel called Nimania Khal from the north-west (Maitra, 1968).

The lateral branches or interconnections of the Thakuran in its seaward course from Nabipukur junction to the sea along the right bank i.e. the western side are:

1) The Kadrakhali Khal, an inland arm with another branch called the Damdama Khal both getting ended in the agricultural fields
2) The Moni River which is a fairly long arm towards the inland
3) The Pukchara, another arm with its upper portion above Nukchara junction being called the Raidighi, whose upper end meets the Moni River
4) The two ends of the Sibua Gang which forms a loop around the Paschim Sripatinagar Island, the lower end having connected with Chirpat or the Pakhirali Khal, a link Channel with the Kalchara-Curzon Creek system
5) The Ross creek, a small link between Jagdal Gang and the Thakuran and
6) The Jagdal Gang

Most of these rivers are having their origins in inland areas and were once carrying considerable amount of freshwater from the upland during their upper end interconnections previously. Now-a-days, only during monsoon season, the rainwaters flowing through these rivers from their individual catchments are getting discharged into the Sea through Thakuran and the Matla Rivers.

On the left bank, i.e. the eastern side, there are also a number of inter-connections with the next contiguous estuary, i.e. the Matla system through a number of meandering channels and loops. These loops are the Bainchapi Khal, the Gura Khal, the Kaikalmari – Ajmalmari – Suia River, the Dulibhasani Gang and the Chulkati Gang. These loops are inter connected amongst themselves and also with the Thakuran River through several channels like the Olian Khal which has connection with the Gura Khal, and thereafter with the Banichapi Khal and Kaikalmari river and ultimately with the Matla River (Maitra, 1968). Thus, these interconnections at the southern side help in distribution of water amongst the channels during high tide and low tide conditions making the hydrodynamic set up of the entire region quite complicated. At the same time, these interconnecting channels are extremely important so far as salinity of Sundarbans is concerned, since these channels ultimately determine the distribution of tidal water among various parts of Sundarbans adjoining Thakuran and Matla Rivers.

Saptamukhi River System

This was the older outlet of the Adi Ganga (Rudra, 2018). It originates near Sultanpur and offers outlet to the Thikara khal, the Banstala Khal, the Ghugudanga Khal and is connected with Muriganga through Hatania–Doania creek.

In the course of this river from the inland side towards the sea, there are several lateral branches or inter-connections with adjacent river systems on both sides. Towards the left i.e. the eastern side the major branches are : (i) the Panipura which has got another branch called Gandakata, both dying out in the inland side, (ii) the Gobadia Link Channel which inter-connects the Saptamukhi with the Gobadia River, (iii) the Selemari Gang which was another link channel between the Saptamukhi and the Gobadia, the Gobadia end being almost closed at present through siltation, (iv) the Barchara, also a link Channel between the Saptamukhi on the West and the Gobadia and Calchara on the east, (v) the Walsh Creek linking the East Gully with the Curzon Creek and lastly (vi) the Curzon Creek, a branch of the East Gully, which is almost an estuary itself and carries the major portion of the discharge at the junction (Bhadra, 2013).

On the right i.e. the western side tributaries are likewise (i) the Kalnagini Khal, (ii) the Ghughudanga Blind Creek, (iii) the Hatalia Doania or the Namkhana Creek which links the Western Gully with the Muriganga and (iv) the Chandaapiri River which joins the West Gully with the Patibunia River and Edwards Creek around the Fraserganj Island. In between the Hooghly – Baratala / Muriganga system and the Baratala – Ghughudanga Gang – Saptamukhi – West Gully, there is practically only one important link through Hatania Doania creek. The Namkhana Creek has another connection from the north with the Baratala River through the Ghiapati Khal which was originally a continuation of Kalnagini Khal forming a loop passing very close to Baratala River. Due to subsequent erosion, two off-takes of the Ghiapati Khal from the Baratala River has been formed, one at the north and the other towards the south. Another link between the Baratala and the Saptamukhi system through Kalnagini and Kakdwip Khal has now practically been closed due to deterioration of the Kalnagini in the middle reach. The mouth of Kakdwip Khal has also been badly deteriorated due the siltation (Mitra, 1968).

Saptamukhi braids right at the sea face into two arms, namely the East Gully and the West Gully moving up around the Lothian Island. The two gullies nearly meet each other at the shallow island called Sushni Char at the northern tip of the Lothian Island, but again separate themselves around the Prentice Island, which may be termed a northward extension of the Lothian Island beyond Sushni Char. At Sushni Char, two gullies remain separated during low tides, but get connected during high tide. Near the southern end of Saptamukhi, the river is quite wide and comparatively shallow in nature which has resulted in formation of a number of shoals.

<u>Ichhamati – Raimongal – Harinbhanga River System</u>

The Ichhamati River ultimately discharges through Kalindi – Harinbhanga. It is connected with Barakalagachi and Terobanki. Harinbhanga and Raimongal are combined together before meeting the Bay of Bengal (Rudra, 2018). It is a trans-boundary river which flows through India and Bangladesh and demarcates the boundary between the two countries. River Ichhamati takes off from Mathabhanga River near Majdia in Nadia District and flows for a distance of about 208 km to join the Kalindi River near Hasnabad in North 24 Parganas District. The River Ichhamati is almost disconnected at its off-take point from the Parent River leading to gradual depletion of upland discharge from the River Padma and heavy siltation in the bed of Ichhamati.

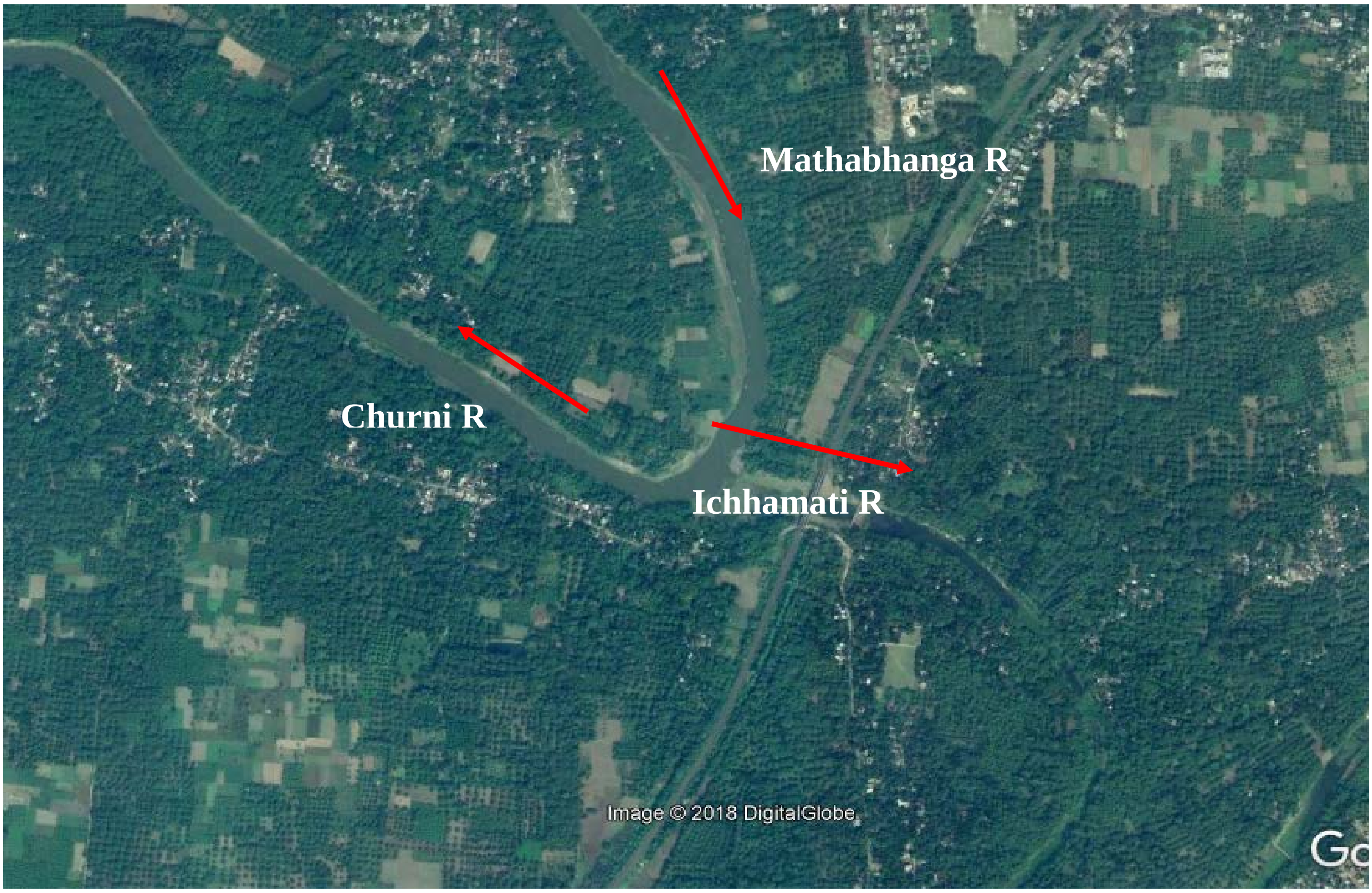


Figure – 20 : Icchamati River at off-take point near Majdia, Nadia

As a fall out of a railway accident in 1942 at the Majdia Rail Bridge (Rail Bridge no. 188) on the River Ichhamati, huge amount of debris and concrete wastes got deposited on the bed of Ichhamati River, within 200 meters of its off-take point. Railway authorities never bothered to clear that debris from the river bed resulting in a permanent barricade over the flowing water. As a result, the river Ichhamati got silted up and its bed arise to about 5.5 meters higher than that of Mathabhanga – Churni River and the entire freshwater flow from the parent river Mathabhanga got diverted to the Churni River and not coming in the Ichhamati River especially during non-monsoon months. In absence of upland discharge during major part of the year, the river Ichhamati has gradually been silted up and got deteriorated with time (Basu & Hawladar, 2008).

Tidal action along Ichhamati plays upto Bangaon. The lower reaches of this zone have been heavily silted up due to tidal effect. With tidal water, considerable amount of sediments are getting deposited on the river bed, particularly due to the fact that there is total absence of any upland discharge from the main river through the off-take point during non-monsoon season. As a result, every year the capacity of the river channel over the upper stretches of the tidal reach are getting decreased progressively. The relative transport capacity of the flood flows is high upto Tentulia and then is gradually reduced. It seems that considerable siltation in the upper reach near Tentulia will take place due to redistribution (Basu & Hawladar, 2008).

According to Basu & Hawladar, 2008, bed level of River Ichhamati in its middle reach near Bangaon town at a distance of roughly 40 kms upstream from Tippi point is at a lower depth than that at Tippi, the confluence point of River Ichhamati with River Jamuna upto Tentulia where the bed level is at a higher height. This has resulted in a reverse gradient where the bed level of upstream is much lower than that in the downstream areas. This is definitely an obstruction to the flow of freshwater to the Sundarbans, which needs to be looked into.

Concluding remarks

The above discussions clearly point out that there are still considerable options available to bring freshwater discharges into Sundarbans. It is to be noted that not only for the 4.5 million population, but even for maintaining the biodiversity of Sundarbans especially that of world famous mangrove forest, freshwater inflow is highly solicited. Mangroves are halophytic plants meaning they are salt tolerant plants and not definitely salt loving plants. Due to enormous salt stress, the mangroves of Indian Sundarbans are having stunted growth with less girth compared to those in the Bangladesh part. In the backdrop of saline ingress, arsenic contamination and possibility of saline intrusion into groundwater, the water policy for Sundarbans needs to be fine-tuned to meet the challenges. It has been advocated that assurance of an ecological flow (e-flow) of freshwater in the river channels are the major solution for this water starved region (Bhadra, et al. 2013).

Restoration of decayed river channels (Bhadra et al. 2014) is essential to ensure freshwater flow from up stream. 11 such major disconnections have been identified from field and remote sensing study (Bhadra et al. 2014) in the feeder river system of Sundarbans. Some of these examples are reconnection of River Ichamati off-take at Majhdia, the rejuvenation of Bidyadhari-Suti-Nowaii system and Jamuna river system can greatly benefit the people of Sundarbans. Thirty years back, the first detailed study on possibility and potentiality of increasing the freshwater supply in Sundarbans suggested building a closure dam in the mouth of Saptamukhi by River Research Institute, Government of West Bengal (Delf Hydraulics to

GoWB, 1968). One of the essential components of the project was to create a freshwater reservoir which would provide the required fresh water for various uses. The reservoir was proposed to be constructed on the portion of the River Saptamukhi bounded by the proposed Saptamukhi North and the Saptamukhi South Dams. Though such a reservoir could not be built due to several constraints, such concepts may be reconsidered and implemented to ensure a freshwater supply in the Sundarban. Time has now come to make a comprehensive study on this particular aspect and to prepare and implement a master plan to bring freshwater to Indian Sundarbans.

Groundwater As a Source of Freshwater

It has already been described that Sundarban is formed by sedimentation of the Ganga and its tributaries. In spite of plenty of surface water, the availability of freshwater or in other words, potable water is practically nil from the surrounding rivers due to high salinity problem. Rivers are saline in nature and ground water is also saline in shallow aquifers. Salinity of the water limit's its use in domestic as well as agricultural sector. The local people always depend on available groundwater for domestic needs. Thus, groundwater is considered as an important source of freshwater in Sundarbans, if not the only source in some areas. That is why discussion on groundwater is so important. But there are some inherent problems in extraction of groundwater in Sundarbans. Some of these issues are discussed below:

CRZ Notification and Drinking Water Supply

This fragile coastal part of West Bengal is being looked after by as many as three agencies namely: (i) Sundarban Biosphere Reserve Directorate (ii) Department of Sundarban Affairs, Government of west Bengal concerning mostly with policy decisions and (iii) Sundarban Development Board, an autonomous body under Department of Sundarban Affairs for carrying out developmental activities in the human inhabited region. Developmental activities, conservation as well as utilization of natural resources in Sundarbans are not only guided by the abovementioned regulations concerning protected areas alone. There is a separate regulation in India, which is known as Coastal Regulation Zone (CRZ) Notification, 2011, which governs different activities relating to coastal zone including creation and construction of assets and amenities required for the local population for extraction of groundwater even for drinking water supply. So any kind of proposal of extraction of groundwater even for the specific purpose of Drinking Water Supply must be in line with that special regulation so that the same can be implemented in Sundarban region.

As per the CRZ notification, the Central Government declared the following areas as CRZ and imposed with effect from the date of the notification (6th January, 2011) certain restrictions on the setting up and expansion of industries, operations or processes and the like in the CRZ,-

i) The land area from High Tide Line (hereinafter referred to as the HTL) to 500mts on the landward side along the sea front.

ii) CRZ shall apply to the land area between HTL to 100 meters or width of the creek whichever is less on the landward side along the tidal influenced water bodies that are connected to the sea. The distance up to which development along such tidal influenced water bodies is to be regulated shall be governed by the distance up to which the tidal effects are experienced which shall be determined based on salinity concentration of 5 parts per thousand (ppt) measured during the driest period of the year and distance up to which tidal effects are experienced shall be clearly identified and demarcated accordingly in the Coastal Zone Management Plans (hereinafter referred to as the CZMPs). Likewise, there are other three clauses also.

Further explanation was also given that 'tidal influenced water bodies means the water bodies influenced by tidal effects from sea, in the bays, estuaries, rivers, creeks, backwaters, lagoons, ponds connected to the sea or creeks and the like'.

In case of inhabited islands of Sundarbans, open sea is far away and all the islands are encircled with innumerable creeks and rivers. Thus, in case of the populated islands of Sundarbans, the width of CRZ is maximum 100 meters from the High Tide Line (i.e. embankments) along the fringes of the islands following the approved CZMP of West Bengal. All CRZ area within SBR has been declared as CRZ-I (A) or CRZ-I (B), i.e. ecologically most sensitive areas. The drinking water installations and related amenities should conform to this regulation. There are several relaxations for the public utility systems like Drinking Water Supply system for the coastal communities living in Sundarban region. However, for all such installations, specific approval should be sought from the State Coastal Zone Management Authority of West Bengal.

Geology

Indian part of Sundarbans is the eastern and southern part of Bengal Geosyncline (stable shelf in the west and deep basin in the east) bordered in the west by the Indian shield, which is separated by a series of buried basin marginal enechelon faults. Intensive Geophysical surveys and deep drilling data in this alluvial plain of West Bengal revealed that the extensive sub-aqueous basaltic lava (Rajmahal Trap) is overlying Permo-Carboniferous coal bearing Gondwana sediments of continental environment. Later geological history is the repetition of marine transgressions and regressions which were the major phenomena controlling the depositional environment during the evolution of this basin. The sediments overlying the trap were deposited mainly in the continental environment. The drainage system originated from Indian shield (Chhotanagpur plateau part) was the then geological agents of sediment transportation and deposition. The first evidence of transgression in the basin is during Cretaceous but upper Cretaceous was a phase of regression. Other phases of transgressions are early Palaeocene (local), Eocene (extensive), late Oligocene-Miocene (extensive), and

Pliocene(two phases - early and late Pliocene). Late Palaeocene, late Eocene-early Oligocene, mid Miocene, and upper most Miocene were the phases of regressions. Although the Quaternary was in general in regressive phase but oscillatory environment was also there at that time. The Eocene Hinge Zone, a zone of tectonic flexure and fault, passing Kolkata-Ranaghat-Mymensingh separates the relatively stable shelf from the deeper basin of the geosyncline. Post Eocene eastward tilting cause very thick pile of stratigraphic horizons in the eastern part.

The South 24 Pgs and North 24 Pgs districts are located on the lower deltaic plain on the composite Ganga delta and are covered by the Quaternary sediments deposited by the Ganga and its tributaries. The top of the alluvium is clayey in nature. Fine sand and silty clay capping also occurs in small patches in the alluvium. The generalized stratigraphic sequence of the district is given in the table as follows:

Table – 17 : Generalized Strtigraphic sequence in Indian Sundarbans

Period	Age	Litho units	Composition
Quaternary	Recent	Younger alluvium	Sand, silt and clay, pale grayish often silty.
	Pleistocene	Older alluvium	Sand fine to coarse, clay, silt with kankar, gravel grayish to brownish grey

A succession of Tertiary and Mesozoic formations within the depth zone of 350-4000 m is established by drilling by the Standard Vacuum oil company. The Mesozoic floor was encountered at a depth of 3529 meters below ground level (bgl) at Jalangi in Murshidabad district and could not be traced even at a depth of 4041 meters bgl at Port Canning in south 24 paraganas district indicating the gradual thickening of alluvium southeastward towards the sea (Sensarma & Bhattacharyya, 2013).

The Pleistocene floor which is established at 183-189 m bgl from the palaeontological evidences at Bazitpur ($22^0$45’: $88^0$30’) and Khamarkulla ($23^0$03’: $88^0$46’), North 24-Pgs is expected to be at greater depth towards the south (Sensarma & Bhattacharyya, 2013)

.Sub-surface Geology

The bore holes drilled down to the maximum depth of 614 m bgl for ground water exploration in the region reveal a succession of coarse to fine grained sand, clay and kankar and their various admixtures with localized patches of gravel and cemented sand grains.

The sub-surface geology in the southern part, found to be consisting of a thick succession of unconsolidated sediments comprising clay, silt of various colors, sands of various colors and grades and gravel. The top surface in this tract is marked by an effective clay blanket whose thickness varies from 15-76 m towards the eastern part of this tract around Karbala and its thickness is only 6 meters around Kashinagar.

Underlying the clay blanket occurs a huge thickness of sediments which are composed of gravel, fine to coarse sands, silt and clay. In Diamond Harbour-Namkhana area, a significant gravel horizon occurs within the depth ranges of 137-152 m bgl. This gravel horizon appears to have thickened east wards towards Karbala from 1.5-60 m within the depth range of 88-150 m bgl and appears to have pinched out further east and northwards as it is not encountered in the boreholes drilled at Baruipur, Canning and Kashinagar.

This gravel horizon may be considered as a marker horizon which is underlain by another extensive clay zone at varying depth. Beneath this clay, occurs a second group of aquifers in the depth ranges of 160-360 m with considerable aerial extent.

Hydro-geologically, this second group of aquifer is the most important as it contains considerable fresh water resources in the area where surface water as well as ground water occurring at shallow depth is significantly saline.

Hydrogeological set up

The Sundarban area is occupied by recent alluvium laid down by the river Ganga. There are three aquifer zones in Sundarbans. Here ground water occurs under the characteristic hydrochemical situation in which a fresh group of aquifers occur within the depth span of 160 – 360 m bgl, sandwiched between saline aquifers (Sensarma & Bhattacharyya, 2013). The shallow one within 60 m below ground level (bgl) has layers of fresh and brackish water intercalations. The second zone occurring between 70 – 160 m bgl is brackish to saline. The third aquifer zone, fresh in nature, occurs in the 160 to 400 m zone (Bhadra, 2013).

Figure – 21: Hydro-geological set up in Sundarbans

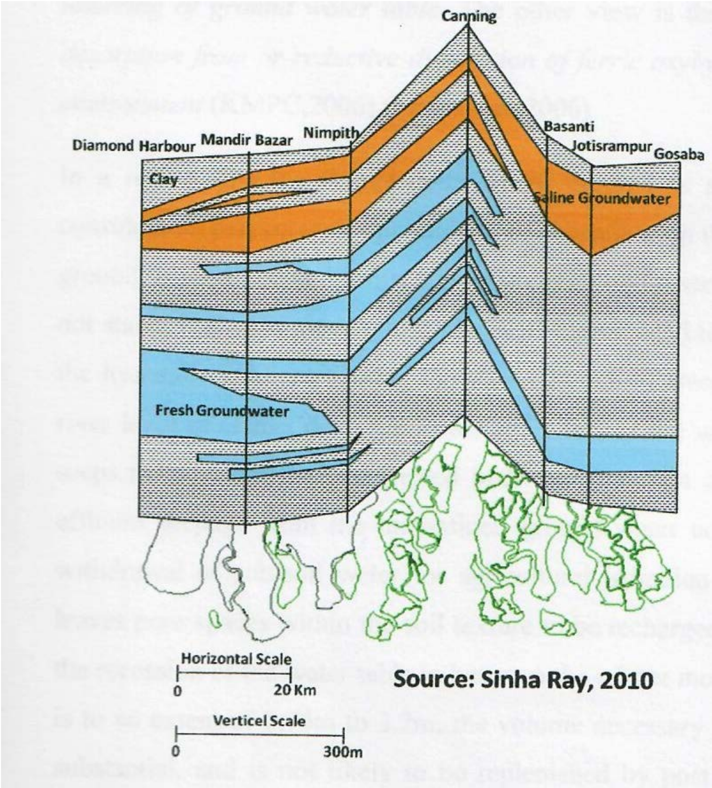


Figure – 21: Hydrogeological Set Up of Sundarbans

The top saline water aquifers are separated generally from the underlying fresh water group of aquifers by a thick clay layer varying in thickness from 4 m at Gangasagar to 120 m at Kultali, although the general thickness of the clay blanket is 20 to 50 m. Disposition of sub-surface fresh/ saline aquifers in the study area right from Diamond Harbour in the north-west to Gosaba in the east has been depicted with the aid of lithological and hydrochemical data obtained from 7 bore holes, already observed by Central Ground Water Board.

The upper aquifer occurring within 10 to 160 m bgl is brackish/ saline in nature except in the area around Haroa (North 24-Parganas district). There are three separate brackish/saline water aquifers having thickness varying from 10 to 20 m between the depth span of 10 to 160 meters bgl in the tract of Ganga Sagar–Namkhana–Rudranagar–Kakdwip which do not persist up to Mathurapur. Again, there exists two separate brackish water aquifers of 10 to 30 meters thickness as in Nimpith down to a depth of 90 m bgl, the bottom most aquifer extends from Nimpith to Sandeshkhali and again from Basanti to Gosaba through Canning where it attains a maximum thickness of 85 meters.

The deeper fresh group of aquifer lies beyond 160 meters bgl and there exists four separate ground water bearing aquifers within the depth span of 160 to 490 m bgl separated by clay blanket whose thickness vary between 40 and 150 meters as found at Ganga Sagar. The thicknesses of the individual aquifers vary between 10 to 30 meters at different places. The upper three aquifers extend in a tract of Rudranagar – Kakdwip – Mathurapur – Kultali. Five separate fresh water aquifers have been registered at Canning within a depth between 160 to 400 m bgl. Only the bottom most aquifer extends up to Gosaba in the east attaining a thickness of 45 m. The rest of the aquifers extend towards south east from Canning. The upper most aquifer existing within the depth span of 160 to 190 m bgl extend towards north east up to Sandeshkhali where it attains a thickness of 90 m.

The tube wells in the area, normally tap the fresh deeper aquifers within a depth of 169 – 360 m bgl with a yield around 100–120 m^3/hour for a draw down 6 – 12meters, having Transmissivity & Storativity values in the range of 500 – 1500 m^2/day and 0.15 x 10^{-3} to 1.0 x 10^{-3} respectively. (Sensarma & Bhattacharyya, 2013)

Ground Water Condition

Ground water occurs in confined condition below a confining blanket of clay of 20m – 50m thick in parts of Sundarban area lying in the southern & south–eastern part of North 24 Parganas district. In these areas, fresh water bearing aquifers occur within a depth between 250 m to 350 m depth.

The presence of sandy clay within a depth of 60 m in Sandeshkhali, Hingalganj and Hasnabad block represents aquitard zone where small diameter tube wells with low yield are feasible. However, these tubewells may not serve the purpose of continuous yield, as is expected from such tubewells in village areas.

In the district of South 24 Parganas, water bearing formations are present within the Sundarban region with Quaternary and Tertiary sediments. Sand of various grades and gravel at places constitute the aquifer materials. Ground Water generally occurs under semi–confined to confined conditions. Thus, there exist three aquifer zones – in general the shallower one occurs at a depth of 60m, mostly brackish in nature. The second aquifer occurs within a depth of 70m – 160m which is also in general brackish in nature. The third aquifer, more or less fresh in nature, occurs below a depth of 160 m to 400 m bgl.

Strata to be tapped for safe drinking water

Thus, for the purpose of safe drinking water supply, the strata below 170m bgl should be tapped in Sagar, Gosaba, Patarpratima, Kultali, Mathurapur–I & II, Kulpi, Diamond Harbour, Canning– I & II, Kakdwip and Namkhana blocks within the Sundarban Biosphere Reserve.

A question is always asked about the danger of developing coastal aquifers which may ultimately result into saline water ingress to the otherwise freshwater bearing aquifers. In Frazerganj, Namkhana block and Sagar Island (Sagar block), it has been found that piezometric surface of the deeper aquifer rises quite significantly during high tide time and the same recedes to the original position during low tide conditions. If ground water is tapped at the depth of 250-350 m and the piezometric surface lies within 5 m, it is apparent that ground water is moving in the coastal front with high piezometric head of more than 200 m. Unless the piezometric head is lowered to that extent, reversal of hydraulic gradient facilitating saline water ingress may not take place. Considering this hydrological aspect of ground water, tapping these aquifers for drinking water supply may be carried out without any hesitation. Even, these aquifers may be tapped for agricultural purposes provided, low water intensive crops are grown only.

Shallow Aquifers

The yield potential and aquifer characteristics of shallow aquifers (within depth of 100m bgl) are determined by hydrological tests carried out in the study area. The highlights of analysis of hydrological tests as carried out by Center for Ground Water Studies along the Sundarban region are as follows:

Table – 18: Yield Potential and Aquifer Characteristics of Shallow Aquifers in Sundarbans (Source : Sensarma & Bhattacharyya, 2013)

a) Depth of the tested wells	30m to 50m bgl
b) Discharge of the wells by 5 H.P. pump	$25m^3$/hour to $40m^3$/hour
c) Draw down after 300 to 400 minutes of pumping	0.90m to 2.50m
d) Drawdowns of observation wells located within 15m to 30m of pumped well	0.10m to 0.90m
e) Transmissivity (T)	$500m^2$/d to $2000m^2$/d
f) Storativity (S)	0.30×10^{-1} to 0.5×10^{-2}

The shallow aquifers are mainly developed by small diameter (38.1 mm diameter) tube wells fitted with 5 HP centrifugal pumps and are used for irrigation. Shallow tube wells fitted with hand – operated pumps are common for use in domestic purposes. However, a recent survey on groundwater level around Matla River shows groundwater in shallow aquifers in Canning, Kultali and Basanti Blocks is gaining water from the nearby river (Bhadra, 2013). The river appears to have changed from effluent condition (meaning gaining water from the groundwater) to influent condition (meaning contributing water to the groundwater) in the pre and post monsoon months. A water gradient prevails due to difference in these two water levels and saline water enters into the ground water aquifer.

Salt water intrusion is the major problem in shallow aquifers of coastal region. In the place where groundwater is being pumped from aquifers that are hydraulically connected to the sea or saline rivers, the induced gradients may cause the migration of saltwater from the sea toward freshwater aquifers on the land. So, there is a chance of freshwater become contaminated with saline water.

Deeper Aquifers

The deeper aquifers are developed by medium duty and heavy duty tube wells (tapping 30m to 35m cumulative aquifer thickness) and are mostly fitted with high capacity (15 H.P. to 25 H.P.) submersible electric pumps. These wells are used for irrigation and drinking water purposes. In arsenic infested areas, hand pumps fitted deep tube wells (mainly cylindrical/Mark II type) are used for drinking purposes. Characteristics of deeper aquifers are determined by hydrological tests carried out in the study area by CGWS and the salient features are given below:

Table – 19: Yield Potential and Aquifer Characteristics of Deeper Aquifers in Sundarbans (Source : Sensarma & Bhattacharyya, 2013)

a) Depth of the tested wells	100 meters to 350 meters bgl
b) Discharge of the wells	$100m^3$/hour to $120m^3$/hour
c) Draw down after 300 to 1000 minutes of pumping	6 meters to 12 meters
d) Transmissivity (T)	915 m^2/d to 3000 m^2/d
e) Storativity (S)	0.3×10^{-3} to 1.1×10^{-3}

Chemical Quality of Ground Water

The qualities of ground water in deeper aquifers occurring within 160 m – 400 m depth are in general potable and are within permissible limits of BIS drinking water standards. The pH ranges between 7.8 to 8.2 indicating slightly alkaline nature of water. Iron concentration is high at isolated patches (about 7 mg/l). Electrical conductivity is within the range of 475-4450 micro mhos/cm with chloride content varying from 18-386 mg/l. Ground water in this aquifer is generally $CaHCO_3$ type with low sulphide, chloride and fluoride.

Arsenic Problem in groundwater

Over exploitation of groundwater has already brought forth the problem of arsenic poisoning in 104 administrative blocks belonging to eight districts of lower Gangetic plain, where presence of arsenic is beyond permissible limit (i.e. more than 0.01 to 3.24 mg/l). Incidentally, in all these cases, the occurrences of groundwater are mostly confined to shallow aquifer zones within 20-100 feet below ground level (bgl). In West Bengal, more than 26 million people are now at risk, although there are conflicting views about the possible cause of this menace. While one opinion is there which insists that arsenic in groundwater is due to the release oxidation of pyrite or arsenopyrite following the lowering of groundwater table due to over exploitation;

the other view is that arsenic is released due to desorption from or reductive dissolution of ferric oxyhydroxides in reducing aquifer environment (Mukherjee, 2006).

According to Mukherjee, 2006 and School of Environmental Studies, Jadavpur University, 8 blocks of Sundarban out of 19 are arsenic affected. These are Haroa, Hasnabad, Minakhan, Hinjalganj, Sandeshkhali II, Canning I, Canning II and Jaynagar I. More blocks and areas of North 24 Parganas district are vulnerable and affected than South 24 Parganas. Out of six blocks of North 24-Parganas under Sundarbans, five are already affected. This may be due to over exploitation of groundwater in these blocks for agriculture and other purposes. Incidentally, these blocks of North 24 Parganas use shallow tube well for Irrigation and even for drinking water purposes. But due to geological reasons, that is not possible in South 24 Parganas blocks as the groundwater is mainly saline to brackish in nature in shallow aquifers here.

The quality of groundwater in deeper aquifer has been monitored in last twenty years. It has been indicated that it does not contain high arsenic (Sensarma & Bhattacharyya, 2013). In fact, in Baruipur area this aquifer is being extensively tapped for last 25 years and found to be arsenic free. However, recent studies of Centre for Ground Water Studies indicate that shallow aquitards occurring within 20m-40m depth contains somewhat higher concentration of arsenic (> 0.01 mg/l < 0.05 mg/l). But this ground water is not used for drinking water purposes. It can be reasonably safely concluded that the aquifer occurring within 170-400 m depth contains arsenic free ground water and should be used for drinking water purpose. As a matter of fact, for a common man, withdrawal of groundwater is also not easy considering the depth from which it needs to be extracted. That issue has to be considered at the time of recommendation of extracting groundwater from a deeper level also.

Conjunctive Use of Groundwater and Surface Water

The people of Sundarbans are compelled to depend on groundwater to meet the drinking water demand and on rain water for agriculture and other needs. Conjunctive use of these water sources may help in sustainable water resource management in this region. Some of the well known techniques, but not being considered with due seriousness may also help in solving the problem of freshwater supply in Sundarbans. One such technique is Rainwater Harvesting.

Rainwater Harvesting

It has already been described that Sundarbans receives sufficient rain during monsoon period. This rainwater, which is otherwise getting discharged in the adjoining saline creeks and rivers, may be conserved to meet the public demand. The harvested rainwater may be utilised for domestic and agricultural purposes, even for drinking water purposes, after proper treatment (Gayen 2013; Mondal 2014). Large scale roof-top rain water harvesting is one of the major solutions to mitigate the water related problems in Sundarban. Renovation of the existing canals is also required. Rain water harvesting also restricts the over-exploitation of groundwater resource.

It has been estimated that there is a potentiality of harvesting of 45 mcm of rainwater from different types of roofs in Sundarban region (Hazra et al, 2015). 15.42 mcm rain water can be harvested in northern zone whereas 18.86 mcm and 11.28 mcm rain water can be harvested in central and southern zones respectively. This water has a potential to meet the domestic water demand in Sundarbans region partially.

Table – 20: Block wise rainwater harvesting potential in Sundarbans (Hazra et al, 2015)

Blocks		Potential Roof Top Rain Water Harvesting						Total Water (mcm)
		No. of HH Concrete Rf.	**Water (mcm)**	**No. of HH Asbestos Rf.**	**Water (mcm)**	**No. of HH Tiles Rf.**	**Water (mcm)**	
Northern	Total	37460	3.60	64484	5.17	104134	6.67	15.42
	Average	5351	0.51	9212	0.74	14876	0.95	2.20
Central	Total	37498	3.60	127329	10.18	79464	5.09	18.86
	Average	4687	0.45	15916	1.27	9933	0.64	2.36
Southern	Total	18277	1.75	18933	1.51	125269	8.02	11.28
	Average	4569	0.44	4733	0.38	31317	2.01	2.82
Sundarban	**Total**	**93,235**	**8.95**	**2.10,746**	**16.86**	**3,08,867**	**19.77**	**45.58**

HH : House Holds; Rf : Roof

Artificial Groundwater Recharge and de-salination

Excess rainwater can be recharged artificially within shallow aquifer to reduce its salinity. In due course of time this technique may help to reduce the salinity of shallow aquifer which can subsequently be utilised for agriculture and domestic purposes (Gayen 2009). Sundarban Development Board (SBD) has taken some initiatives to develop water related infrastructure in Sundarban. A few solar pumps and RO plants for desalination were installed for providing salt-free water in Sundarbans (Hazra et al, 2015). The RO plants however failed to produce potable water due to high concentration of silt in river water and high salinity (>15 ppt).It may be suggested that such type of desalination can be tried using silt free less saline (4 to 8 ppt) water of shallow aquifer. But at the same time, possibility of Arsenic contamination in water from shallow water needs to be verified before use. Conjunctive use of surface water and ground waters may be helpful for sustainable water resource management in Sundarbans.

Possibility of developing Piped Water Supply

It is understood that PHE Department Government of West Bengal is contemplating to execute piped water supply scheme in Sundarban area. Typically, the source of piped water supply schemes is a tube well. The depth of tube wells is about 300 meters, where non-saline water is usually available. Extensive river-based surface water schemes cannot be employed in the context of tidal rivers. Hence, only a few such schemes have been implemented in the Sundarbans. A few pond-based surface water schemes have been constructed, but most of them have been affected with saline water intrusion linked to effects of Cyclone Aila. A few habitations are also affected with arsenic, and they are provided with safe water by PHED through arsenic mitigation plants, which also incidentally address the salinity issues in those areas. Considering all these consequences, PHED is contemplating to do this presently with direct pumping systems.

The position of piezometric surface (within 5 m below ground level) has been favourably used in some cases where lifting the water with help of India Mark-II hand pumps (basement being at 3-5 m altitude from ground level) has been successfully done to store the water even at the top of 1st Floor of the building. In case mechanized pumping device is used for lifting ground water from deeper levels using submersible pumps, such storage of drinking water can be built up at small community level. Wastage of water can be minimized by effective awareness generation amongst the beneficiaries and involving the Community for operation and maintenance of these water supply schemes. This will only help in optimum utilization of such precious but scarce natural resources in Sundarban area.

Several other options exist for increasing access to water supply and sanitation in the Sundarbans, but before deciding on options, Public Health Engineering Department (PHED) of Government of West Bengal should update the status of water supply in the Sundarbans and identify the number of households requiring provision of safe water. The following are among the options that should be considered:

- For areas in which water supplies are highly saline, PHED should consider reverse osmosis plants that are provided with a pretreatment phase and ultraviolet radiation for disinfection. Solar power (as opposed to diesel generator sets) should be used to run these facilities. Such facilities will help in safe drinking water supply problem.
- Ponds that collect rainwater can be used to provide safe water. Bunds can be provided around ponds to prevent entry of saline water during cyclones, and the water can be treated using pressure filters; disinfection via hypo solution can be fed through hand pumps but this option should first be piloted.
- Wherever feasible, shallow tube wells should be recharged by harvesting rain water; this option should also be piloted first.
- Tube well maintenance is not done on a regular basis and should be improved. The maintenance is currently undertaken by PHED staff, but consideration should be given

to regularizing tube well maintenance by contracting it out to experienced NGOs; this is expected to reduce water contamination problems to some extent.

PHED can also enlist the services of NGOs in disseminating information regarding the availability of hand pump mechanics and spare parts' banks as well as for ensuring the participation of the community in the operation and maintenance of water supply schemes.

Priority should be given to improving water supplies and sanitations at schools. This issue deserves priority because of the central importance of education to long-term human development as well as employment prospects. Overall drinking water, toilets and separate spaces are present in only about 60% of the schools in Sundarban region (Sánchez-Triana et al, 2014), and the problem is particularly notable in primary schools.

Campaigns should be conducted to encourage domestic drinking water treatment. Because people's motivation to improve hygienic practices hinges on their ability to comprehend linkages between disease and hygiene, instruction on these linkages should be a part of any campaign. Interventions to improve domestic hygiene could help to reduce significantly childhood morbidity and mortality. One study showed that not even 10%of households surveyed in 8 blocks in the Sundarbans use appropriate drinking water treatment methods, such as boiling or filtering (Sánchez-Triana et al, 2014). Nearly 20% strain water through a cloth and 70% do not treat water at all prior to drinking. Interventions should be undertaken to help educate women, who are typically in charge of domestic water supply, food preparation and hygiene issues, on the positive health impacts of boiling water and the value of employing safe cooking methods and effective household hygiene practices in cutting disease, especially among young children.

Creeks and Silted Up Channels

Creeks, Embankments and Sundarban

It has already been described that Sundarbans is intersected by a complex network of tidal waterways and small islands. The GBM delta continues to grow by deposition of silt. In case of Sundarbans, it continues to grow by the deposition of silt mostly pushed back from the estuary by the tidal waves (Rudra, 2018). The deposition within the creeks is a bio-tidal process, as described by Rudra (2018):

> *"The fluvial sediments undergo metamorphism in estuarine environment. The organic matter present in seawater helps to flocculate and settle down suspended load. The shoals thus formed gradually emerge above low-tide level. The water in*

creeks during the high tides spills off the sediments on both shoals and adjoining the floodplain and thus facilitates colonization of the grasses and herbs. As the intertidal stretch achieves further height, woody mangroves occupy the area."

The shoals and banks ultimately gain such a height that allows inundation only during storm surge when on-mangrove climax vegetations cover the area (IWA 2017). The rate of accretion may be as high as 12 cm/year, as observed in Prentice Island (Paul 2002). Through this process, the islands in Sundarbans have been formed and emerged.

Entire area under the present day Sundarban Biosphere Reserve was completely covered under mangroves. During the sixteenth century, the local kings had permitted woodcutting and imposed levy on the export of wood from the forest of Sundarbans. During eighteenth century, the then British Government for the first time, granted lease and permitted the new settlers to reclaim and convert the mangrove forests into agricultural lands, fisheries, human settlements and development of Ports and Harbours. After the battle of Plassey in 1757, the British rulers took over the civil administration of Bengal in 1765. At that time, the British Rulers decided to reclaim mangrove-covered Sundarbans with the sole intention to increase the revenue collection and expansion of their business, although, huge unused agricultural land was available in Bengal at that point of time (Mondal, 1997).

The first effort to reclaim Sundarbans was made in 1770 by Claude Russel, Collector General, 24-Parganas who allowed the lessee with an initial period free of rent. Substantial progress was made by lessee and the neighbouring zaminders also busied themselves in reclaiming forests (De, 1990). The next effort was made in 1783 by Tilman Henckell, Judge and Magistrate of Jessore, who decided to lease out small plots directly to *ryots* (farmers). The scheme was opposed by the local zaminders who claimed the lands cleared by the grantees.

A detail history of reclamation of Sundarbans has been provided by W. W. Hunter (1875), as below:

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, 1871)

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, 1871)

A similar account of reclamation of Sundarbans has also been described in detail by O'Malley, 1914, as follows:

> 'The exigencies of space forbid any but a brief mention of the work of reclamation and development carried out in Sundarbans towards the close of eighteenth century by

> Tilman Henckell, who was Judge and Magistrate of Jessore in 1781, and had jurisdiction over the Sundarbans tract to the south. "His acquaintance," writes Sir James Westland (*Westland, 1871*) in his Report on the District of Jessore, "with every subject affecting his district was most intimate;…….. The idea of his administration was that it was the duty of Government to procure the peace and comfort of the mass of the inhabitants, though it might involve some harm in respect of the Company's commercial interests. These views were a little too advanced for his age, for there was then too great an inclination, on the part of Government officials, to look upon the natives as born only to be a means of profit to the Company. Mr. Henckell was never unmindful of his employees' mercantile interests, but he always set this before him as duty – to guard the then almost helpless natives from the oppressions to which they were subjected by the commercial officers of the Company, as well as by their Zaminders."
>
> In the Sundarbans, Henckell inaugurated a system of reclamation, which, after many vicissitudes, has converted large areas of forest into fertile rice fields. His object was to introduce a body of peasant proprietors, holding directly under Government and with this purpose he granted about 150 leases in 1785. At the same time, he established three stations in the heart of Sundarbans, in order to assist in their development by providing markets for the sale of produce and supply of boatmen plying along the waterways. One of these markets was situated at Henckellganj (now corrupted into Hinalganj) (sic), at the junction of the Jamuna and Kalindi in this district (*meaning the then 24- Parganas*), the other two lie in Khulna…"

"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 20th Century and perhaps it attained the present shape by that time.

During 1811-14, entire Sundarbans was surveyed by Lieutenant W. E. Morrieson and his results were corrected by his brother, Captain Hugh Morrieson in 1818. This formed the basis of all subsequent maps of this region (De, 1990). During this period, it became apparent to the then British authority that encroachment and reclamation of Sundarbans had been continuously progressing partly by lessees, but partly by unauthorized persons also. In order to identify these unauthorized encroachers and thereby increasing the revenue collection in the subsequent phases, number of surveys was carried out and in the process they identified the boundary of Sundarbans. F.E. Pargiter, one forest officer, has detailed the procedure of reclamation in the Calcutta Review of July, 1889 which indicated that "The first thing was to embank the lands." Such type of reclamation went on unabated throughout the nineteenth century, until it was declared as a reserve forest.

In 1862, Dr. Brandis, Conservator of Forests in Burma requested the Government to conserve the forests of Bengal and accordingly entire forest area in 24-Parganas District was first notified as protected forest on 7th December, 1878. Much of this was subsequently leased out by the then government for purposes of cultivation, but the boundaries of the remaining protected forests were fixed (Notification No. 4457-For, dated 9th April, 1926). Protected forests remaining in the Bashirhat Division of the district were declared reserved forests on 9th August, 1928 (Notification No. 15430) and those remaining in Namkhana Division on 29th May, 1943 (Notification No. 7737-For). Thus, officially reclamation of the Sundarban mangroves stopped before independence of India. Although even in the recent past, some areas were reclaimed like Jharkhali Island in Basanti Block, but reclamation in major scale stopped once the Sundarban mangrove forest was declared as protected forest.

This history of development of Sundarbans is extremely important to understand the present day problems. All the present problems of Sundarbans emanate including that of freshwater availability starts from this premature reclamation of the mangrove swamp and converting those reclaimed swamp into inhabited land, where presently about 4.5 million people live.

Although, embankments along these mangrove islands were erected to stop the inflow of the saline water inside islands, the '*poyans*', or the small channels and creeks were spared, as described by Hunter, 1875 above. These small channels and creeks still exist within the inhabited islands. However, as pointed out in literatures, due to continuous siltation along these creeks leading to decay of these channels and even to coalescence of number of islands. But, in most of the cases, the decayed channels still exist within the inhabited islands. These decayed channels may be a potential area for converting into freshwater reserves. Even those creeks, which are still active, can play an answer to the freshwater crisis.

From saline to Freshwater – an innovative idea

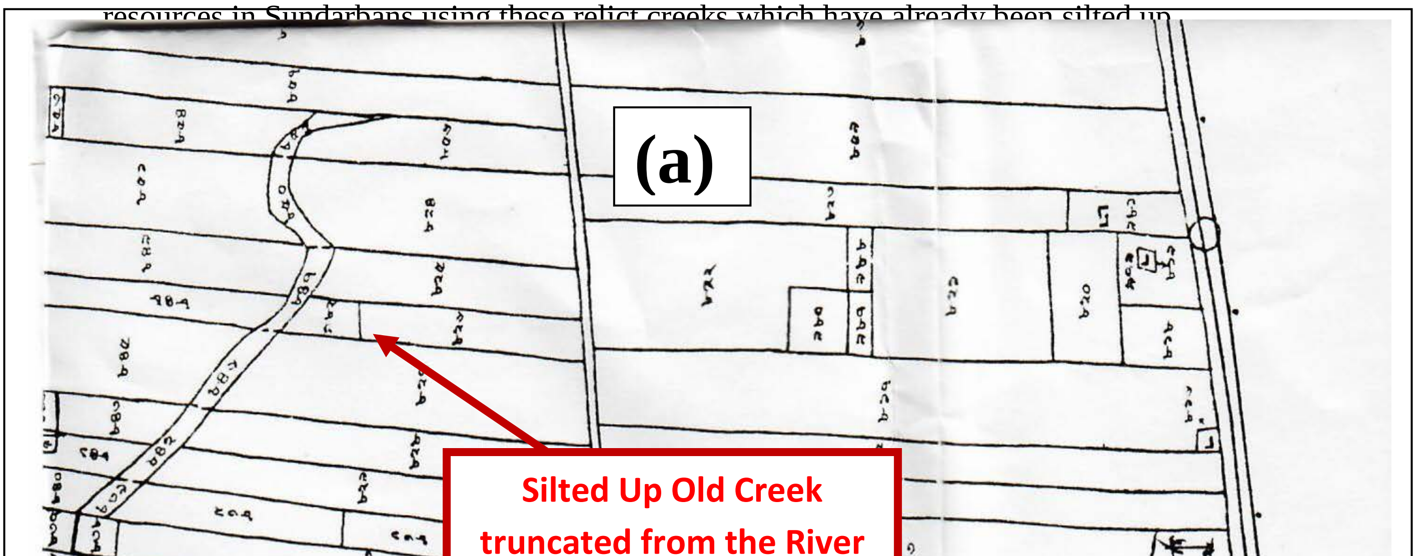
A recent experiment made under World Bank funded West Bengal Accelerated Development of Minor Irrigation ***Project*** (WBADMIP) (www.wbadmip.org). Under this project several relict water bodies in different parts of West Bengal were developed as "Water Detention Structure" (WDS) and rejuvenated for source of irrigation as well as fisheries. As the Aide Memorandum of the project after visit in early part of 2017 pointed out that even though in the WBADMI project it is difficult to include any 'Fisheries' related activity (since the project is essentially for Minor Irrigation), 'but where a large number of people live in poverty, and where fisheries is the only viable option to improve income of the people through the project', even such options can be explored. Accordingly, a shallow channel, basically a cut-off channel from the River Ganga, of about 3 km in length and 10 to 110 m in width covering an area of about 30 ha in front of three villages at Khatriya Nagar, Balagarh was ultimately developed into fisheries. Two other places were also developed. Some rules for cooperative were proposed to be changed for giving community ownership.

Following that experiences, some areas within Sundarbans have also been developed. Some of these schemes are as follows:

Water Detention Structure (WDS) scheme in Dakshin Radhanagar Mouza in Gosaba Block in South 24-pargans District in Sundarban region using a silted up water stretch (relict or old creek) has been implemented by desilting to create a freshwater body. This helps in agricultural practices of a total catchment area of 20 hectares. A Users' Association entitled Dakshin Radhanagar (WDS) Water Users' Association has been formed for monitoring of the WDS thus created under this scheme. In Satjelia Mouza under Gosaba Block, similarly another old creek, which became silted up with time has been developed to create a Water Detention Structure (WDS) of freshwater to cater a catchment area of 28 hectares. A Users' Association of similar nature has also been constituted here with the same objective. In case Sudhanshupur Mouza (J.L No. 101) under Gosaba Block, a similar nature of WDS scheme has been implemented to create freshwater reserve to cater the need of 21 hectares of land located in the catchment area of this WDS. Here also similar kind of Users' Association was constituted. Under these three schemes, in each area it was possible to bring large number of beneficiaries under livelihood development through different options using these freshwater reserves. In another block Basanti under Sundarban Biosphere Reserve in South 24-Parganas district, another Freshwater reserve was created at Naliakhali Mouza (J.L. No. 128) in another WDS scheme using a silted up creek to serve a catchment area of 21 hectares.

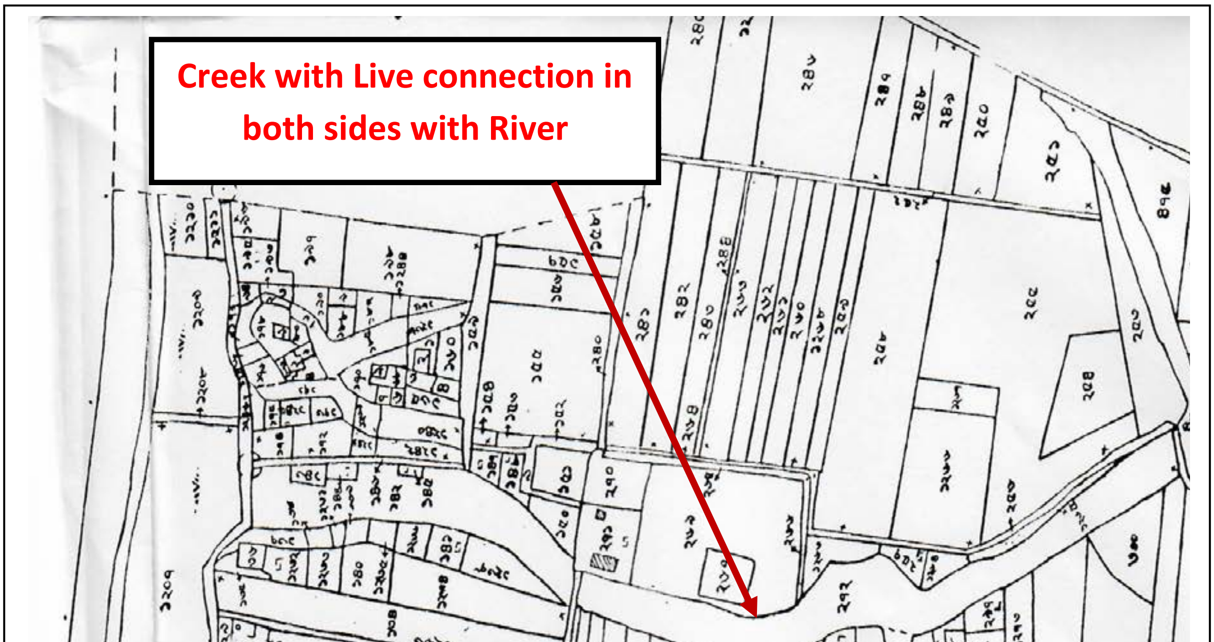
In North 24-Pargans District in Sandeshkhali-II Block, at Jaliakhali Purba Khanda Mouza (J. L. No. 45) was implemented utilising a silted up khal, locally known as 'Dainer Khal'. This khal (meaning small canal) is also a similar old creek, which got silted up with time. This WDS is now serving a total area of 66 hectares of catchment area meeting up the requirement of a large number of villagers on both sides of this WDS. Beneficiaries under this WDS scheme have come across to constitute the 'Jaliakhali Purba Khanda Dainer Khal WDS Water User Association'.

Above examples clearly indicate that there is enough scope of development of freshwater resources in Sundarbans using these relict creeks which have already been silted up.



Silted Up Old Creek, now disconnected from the river

Creek with Live Connection with River



(b)

Figure–22: Part of Mouza Maps of (a) Mahishamari (JL No. 35 sheet no. 2) and (b) Chandipur (JL No. 33 sheet no. 1) in Sagar Block, South 24-Parganas showing different types of creeks as potential areas for harvesting of freshwater with proper planning

Figure–22: Part of Mouza Maps of (a) Mahishamari (JL No. 35 sheet no. 2) and (b) Chandipur (JL No. 33 sheet no. 1) in Sagar Block, South 24-Parganas showing different types of creeks as potential areas for harvesting of freshwater with proper planning

From the above two mouza maps, the frequency and existence of such old creeks for development of freshwater development structures can be well understood. It has already been mentioned that there are altogether 1297 mouza covering 19 blocks of Sundarbans. Some of the mouza is covered by even more than 7 (seven) sheets. Thus, it is estimated that total number of cadastral sheets covering entire Sundarbans may be around 3,500 (Three thousand five hundred) or so. Although, total area covered under such old creeks has not been estimated either by digitisation of individual cadastral sheets covering the entire Sundarbans or by mapping using high resolution satellite images. But, even without any estimation or mapping, it can be very well understood that total area covered by such cut-off creeks or relict creeks, which are now mostly silted up at this moment. These areas can be developed as reservoir of freshwater structures.

It is interesting to note that Sundarban Affairs Department, Government of West Bengal has already excavated 411 km of derelict canals in Sundarbans for rejuvenating of these canals and as rainwater storage tanks (Bhadra, 2013). This practice has been going on for a long time as reflected in different documents of Sundarban Development Board (SDB, 1992). In this report under the progress in different development works, desilting and excavation of the old creeks and converting those into canals were standard practice. Although, there is no up to date accounts in this head, but handwritten notes on the progressive developments in this sector from 1992 to 2002 for some of the blocks have been noted. Details of this particular work for only fourteen blocks (out of nineteen blocks under Sundarbans) are there which are produced below in block-wise manner covering both North 24 Pargans and South 24 Parganas districts. Panchayat Samity/ Blocks under North 24 Parganas Districts under Sundarbans are described first followed by those of South 24 Parganas district, as follows:

Table – 21: Details of Canals restored in Hasnabad Panchayat Samity, North 24 Parganas (Source: SDB, 1992)

Serial No.	Name of Canal	Beneficiary Mouza	Length of Canal (in kms.)	Area receiving irrigation during Rabi Season (in acres)	Whether attached to Sluice Gates	Whether there is Water User Committee for proper water usages of the water body
1	Bayalmari Khal	Purbachak	2.80	19.96	No	No
		Rameshwarpur				
2	Chapatala Khal	Chapatala	1.50	10.70	No	No
3	Uttarchak Khal	Uttarchak	2.00	14.26	No	No
		Kha Pukur			NA	NA
4	Nimta Chakra Khal	Uttar Patli	4.88	195.2	NA	NA
		Khanpur			NA	NA
Total			**11.18**	**240.12**		

Table – 22: Details of Canals restored in Hingalganj Panchayat Samity, North 24 Parganas (Source: SDB, 1992)

Serial No.	Name of Canal	Beneficiary Mouza	Length of Canal (in kms.)	Area receiving irrigation during Rabi Season (in acres)	Whether attached to Sluice Gates	Whether there is Water User Committee for proper water usages of the water body
1	Banshtala Khal	Bishpur	3.00	21.39	No	No
2	Bhagariya Khal	Bishpur	2.00	17.30	No	No
3	Bankradoba Khal	Bankradoba	5.00	116.06	No	No
		Singerkati			No	No
4	Amtoli Khal	Shridharkati	1.8	61.60	No	No
5	Chingrikhali Khal	Kalitala	5.00	147.78	No	No
6	Kanmadhal Khal	Deuli	1.00	25.71	No	No
7	Paschimbahini Khal	Ramapur	1.51	41.51	No	No
8	Kelekathi Khal	Shridharkati	1.30	21.39	No	No
9	Dulduli Khal	Dulduli	1.00	38.00	No	No
10	Bhaganmari Khal	Ramapur	1.26	43.25	No	No
11	Kelinir Khal	Deuli	1.00	45.63	No	No
12	Pukuria Khal	Pukuria	0.50	15.83	No	No
13	Kalinagar Khal	Kalinagar	2.80	112.00	NA	NA
14	Charalkhali Khal	Charalkhali	1.50	50.00	NA	NA
15	Lebukhali Khal	Lebutala	1.30	52.00	NA	NA
16	Bhandarkhali Khal	Bhandarkhali	1.20	48.00	NA	NA
17	Boyarsingh Khal	Boyarsingh	2.20	88.00	NA	NA
18	Sandaler Bill Khal	Sandaler Bill	2.40	96.00	NA	NA
19	Shridharkati Khal	Shridharkati	1.80	72.00	NA	NA
20	Matia Khal	Matia	2.50	90.00	NA	NA
Total			**40.070**	**1203.45**		

Table – 23: Details of Canals restored in Sandeshkhali-I Panchayat Samity, North 24 Parganas District (Source: SDB, 1992)

Serial No.	Name of Canal	Beneficiary Mouza	Length of Canal (in kms.)	Area receiving irrigation during Rabi Season (in acres)	Whether attached to Sluice Gates	Whether there is Water User Committee for proper water usages of the water body
1	Chuchura Khal	Chuchura	1.8	51.90	No	No
2	Harkutia Khal	Chuchura	0.70	19.96	No	No
		Boyarmari				
3	Pashutala Khal	Agarhati	1.80	51.90	No	No
4	Badhumari Khal	Petua Dhani Hati	1.80	30.60	No	No
5	Boyarmari Khal	From Bahiram Pul to Boyarmari Abad	2.40	43.85	No	No
6	Boyarmari Kacharipara Khal		1.50	50.00	NA	NA
7	Ghoshpur Khal	Ghoshpur	3.05	121.00	NA	NA
8	Hatgachi Khal	Hatgachi	2.60	104.0	NA	NA
9	Gajaliya Khal		0.70	28.00	NA	NA
10	Rajbari Khal	Rajbari	3.40	13.60	NA	NA
Total			**19.75**	**514.81**		

Table – 24: Details of Canals restored in Sandeshkhali-II Panchayat Samity, North 24 Parganas District (Source: SDB, 1992)

Serial No.	Name of Canal	Beneficiary Mouza	Length of Canal (in kms.)	Area receiving irrigation during Rabi Season (in acres)	Whether attached to Sluice Gates	Whether there is Water User Committee for proper water usages of the water body
1	Lakhimari Khal	Bermajur	1.3	22.25	No	No
2	Baishnabkhali Khal	Korakati	1.1	14.66	No	No
3	Kanmari Khal	Uttar Khulna	1.0	11.41	No	No
4	Chandmaniya Khal	Dakshin Manipur	2.1	42.00	No	No
5	Atapur Baro Gatekhali Khal	Paschim Atapur	1.2	20.00	No	No
6	Jeliakhali Khal	Jeliakhali Purba and Paschim	1.5	28.56	No	No
7	Ankraberey Khal	Ankraberey	1.37	56.00	NA	NA
8	Tushkhali Khal	Tushkhali	0.81	32.5	NA	NA
9	Korakati Khal	Korakati	1.25	48.00	NA	NA
10	Kayratala Khal	Kayratala	1.06	41.00	NA	NA
Total			**12.69**	**316.38**		

Table – 25: Details of Canals restored in Sagar Panchayat Samity, South 24 Parganas District (Source: SDB, 1992)

Serial No.	Name of Canal	Beneficiary Mouza	Length of Canal (in kms.)	Area receiving irrigation during Rabi Season (in acres)	Whether attached to Sluice Gates	Whether there is Water User Committee for proper water usages of the water body
1	Gobindapur Khal	Nagendragunj	10.31	232.00	2	Yes
		Mahendragunj				
		Gobindapur				

2	Mandirtala or Bankipur Khal	Mandirtala	2.30	29.25	Yes	No
3	Jalkata Khal	Kharapara	1.40	21.98	No	Yes
		Shamantapara				
4	Harinbari Khal	Harinbari	3.05	65.94	Yes	Yes
		Naraharipur				
		Krishnanagar				
5	Krishnanagar Khal	Krishnanagar	3.05	55.57	No	Yes
6	Ghochar Khal	Khansaheb Abad	0.310	12.21	No	No
7	Sapkhali Khal	Sapkhali	3.60	54.00	Yes	Yes
8	Chapatala Khal	Chapatala	1.52	27.66	No	No
9	Suryabindya Khal	Gangasagar	3.01	78.75	No	No
10	Mansatala Khal	Gangasagar	1.60	36.60	No	Yes
11	Gangasagar Khal	Gangasagar	1.72	81.90	No	Yes
12	Mahishmari Khal	Mahishmari	3.90	272.50	No	Yes
13	Keoratala Khal	Gangasagar	1.50	56.25	No	Yes
14	Purushottampur Khal	Purushottampur	2.40	72.00	No	Yes
15	Shatbanki Khal	Chemaguri	4.61	129.37	No	Yes
16	Maitirchak Khal	Haradhanpur	1.10	31.62	No	Yes
17	Rudranagar Khal	Rudranagar	1.00	22.88	No	Yes
18	Kirtankhali Khal	Kirtankhali	6.10	171.56	No	Yes
19	Lalar Khal	Kirtankhali	0.80	18.00	No	Yes
20	Rashpur Basantapur Khal	Dhablat	1.49	60.00	No	Yes
21	Nag Sarobar Pukur	Purushottampur		6.00	No	Yes
Total			**54.774**	**1556.04**		

Table – 26: Details of Canals restored in Namkhana Panchayat Samity, South 24 Parganas District (Source: SDB, 1992)

Serial No.	Name of Canal	Beneficiary Mouza	Length of Canal (in kms.)	Area receiving irrigation during Rabi Season (in acres)	Whether attached to Sluice Gates	Whether there is Water User Committee for proper water usages of the water body
1	Tentulia Khal	Mousumi	0.81	8.64	No	Yes
2	Olaota Khal	Kusumtala	2.10	29.25	No	No
3	Bhashan Khal	Baliara	1.97	37.24	Yes	Yes
4	Rajnagar Srinath Khal	Rajnagar Srinath	1.24	17.20	Yes	Yes
5	Kumirar Khal	Gobindarampur	1.00	17.50	NA	NA
6	Panchergheri Khal	Dakshin Chandranagar	1.07	18.00	NA	NA
7	Helen Diversion Khal	Madangunj	0.70	29.00	Yes	No
8	Chunkuri Khal	Bishalakhipur	2.83	118.5	NA	NA
9	Budhakhali Khal	Budhakhali	3.67	146.8	NA	NA
10	Fatikpur Khal	Fatikpur	3.97	158.0	NA	NA
11	Prabartak Ashram Khal	Bakkhali	0.17	18.00	NA	NA
Total			**19.530**	**598.13**		

Table – 27: Details of Canals restored in Patharpratima Panchayat Samity, South 24 Parganas District (Source: SDB, 1992)

Serial No.	Name of Canal	Beneficiary Mouza	Length of Canal (in kms.)	Area receiving irrigation during Rabi Season (in acres)	Whether attached to Sluice Gates	Whether there is Water User Committee for proper water usages of the water body
1	Gajir Khal	Barodapur	1.90	18.45	Yes	Yes
2	Plot No. 910	Bhagwatpur	0.59	6.31	Yes	Yes

3	Gajir Khal	Meherpur	0.91	20.36	Yes	Yes
4	Gandar Godi Khal	Meherpur	1.67	30.69	Yes	Yes
5	Padmar Khal	Srinarayanpur	1.31	29.46	Yes	Yes
6	Nyakra Orani Khal	Chintamanipur	1.090	20.84	Yes	Yes
		Radhakrisna Nagar				
7	Haldarchak Khal	Meherpur	2.38	48.17	Yes	Yes
8	Durgakhali Khal	Jogendrapur	1.02	10.22	Yes	Yes
		Ramganga				
9	Piyari Khal	Gayadham	0.95	19.69	Yes	No
		Ramganga				
10	Plot No.1638 and 1641	Durgagobindapur	0.45	9.00	Yes	No
11	Plot No.1478 and 1598	Durgagobindapur	0.90	18.84	Yes	No
12	Paschimer Jheel Khal	Paschim Surendranagar	1.18	37.61	Yes	No
13	Singh Parar Khal	Shibnagar	0.75	9.48	No	No
14	Baidya Khal	Madhabnagar	0.30	5.52	Yes	No
		Shibnagar				No
15	Shukar Khal	Gangapur	0.67	11.50	No	No
16	Kumirmari Khal	Paschim Surendranagar	1.27	20.00	Yes	No
17	Hatgherir Khal	Shibnagar	0.42	11.34	Yes	No
18	Muragachia Khal	Kamdevpur	2.30	116.98	Yes	No
19	Banitala Khal	Lakkhipur	1.60	40.00	Yes	No
20	Pinprakhali Khal	Pinprakhali	2.60	78.00	Yes	No
21	Durgakhali Khal	Indraprastha	1.02	17.21	Yes	No
22	Saralda Khal	Digambarpur	1.68	56.25	Yes	No
23	Bandhabi Khal	Surendranagar	2.40	108.00	Yes	Yes
24	Ashwinipur Khal	Surendranagar	0.90	30.00	No	Yes
25	Balur Khal	Dakshin Kashipur	0.60	16.88	No	Yes
26	Fajur Khal	Bishnupur	1.40	50.63	Yes	Yes
27	Kharir Khal	Sripatinagar	0.74	28.00	NA	NA

28	Boinchbari Khal	Sripatinagar	0.55	20.00	NA	NA
29	Badar Khal	Surendranagar	0.42	16.00	NA	NA
30	Mecho Khal	Gayadham	0.55	20.00	NA	NA
31	Bhangar Khal	Paschim Sripatinagar	0.33	12.5	NA	NA
32	Doyar Khal	Kamdevpur	1.60	60.0	NA	NA
Total			**36.450**	**997.93**		

Table – 28: Details of Canals restored in Mathurapur-I Panchayat Samity, South 24 Parganas District (Source: SDB, 1992)

Serial No.	Name of Canal	Beneficiary Mouza	Length of Canal (in kms.)	Area receiving irrigation during Rabi Season (in acres)	Whether attached to Sluice Gates	Whether there is Water User Committee for proper water usages of the water body
1	Shubodh Gopal Bosur Khal	Nataberia	2.10	63.00	No	No
2	Kalitata Boyalberia Khal	Kalitala	4.44	118.80	No	No
		Ghosher Chak				
		Boyalberia				
3	Patnighata Khal	Patnighata	7.80	312.00	No	No
Total			**14.34**	**493.8**		

Table – 29: Details of Canals restored in Mathurapur-II Panchayat Samity, South 24 Parganas District (Source: SDB, 1992)

Serial No.	Name of Canal	Beneficiary Mouza	Length of Canal (in kms.)	Area receiving irrigation during Rabi Season (in acres)	Whether attached to Sluice Gates	Whether there is Water User Committee for proper water usages of the water body
1	Raidighi Khal	Nabagram	2.34	131.00	Yes	Yes
		Goalara				
		Raidighi				
2	Baribhanga Khal	Banitala	1.50	487.35	Yes	Yes

		Baribhanga	3.20			
3	Badar Khal	Choddoroshi	0.84	79.40	No	Yes
4	Bhojar Khal	Uttar Karalichak	1.05	85.10	Yes	Yes
5	Goalpara Khal	Choddoroshi	5.32	347.13	No	Yes
		Karalichak				
6	Jatar Khal	Baidyapara	1.54	97.00	Yes	Yes
7	Shital Maitir Khal	Dakshin Mudipara	0.54	36.45	No	Yes
8	Chatuar Khal	Kankan Dighi	2.85	230.85	Yes	No
9	Kalirgheri Khal	Paschim Jata	1.26	85.05	No	No
10	Chenchkar Khal	Batishwar	5.52	521.64	Yes	Yes
		Kashinagar				
11	Charagangar Khal	Ghatbakultala	6.00	468.00	Yes	Yes
		Balarampur				
12	Panchamgherir Khal	Nandakumarpur	0.81	51.00	Yes	Yes
13	Kailashpur Khal	Kailashpur	1.02	79.00	Yes	No
14	Balir Khal	Uttar Kumrapara	1.88	127.00	No	No
15	Bichalir Khal	Mahishgo	0.70	45.15	No	No
16	Biallish Bighar Khal	Mahishgo	0.29	27.40	No	No
17	Mannar Khal	Damkal Purba	1.05	40.0	NA	NA
18	Shimanar Khal	Shridharpur	1.17	46.8	NA	NA
19	Baradanagar Khal	Baradanagar	0.26	8.5	NA	NA
20	Padmar Khal		0.923	39.00	NA	NA
Total			**40.063**	**3032.82**		

Table – 30: Details of Canals restored in Kultali Panchayat Samity, South 24 Parganas District (Source: SDB, 1992)

Serial No.	Name of Canal	Beneficiary Mouza	Length of Canal (in kms.)	Area receiving irrigation during Rabi Season (in acres)	Whether attached to Sluice Gates	Whether there is Water User Committee for proper water usages of the water body
1	Balir Khal	Kaikhali	0.96	34.56	No	Yes

2	Kripakhali Khal	Gopalgunj	1.28	63.45	No	Yes
3	Bhangar Khal	Gopalgunj	1.25	102.06	No	Yes
4	Urer Khal	Shyamnagar	8.28	269.32	No	No
		Debipur				
5	Shankir Khal	Deulbati	2.79	115.42	No	No
		Durgapur				
6	Hemantakumar Khal	Jalaberia	1.80	52.65	No	No
7	Shaheb Molla Khal	Kaorakhali	3.03	150.63	No	No
		Kharibari				
8	Marygunj Khal	Marygunj	2.88	166.64	No	No
9	Baj Barantalar Khal	Kishorimohanpur	0.42	16.70	No	Yes
10	Shamantar Khal	Kishorimohanpur	0.81	33.41	No	Yes
11	Binodpur Khal	Binodpur	0.30	14.06	No	Yes
		Ambikanagar				
12	Baikunthapur Khal	Baikunthapur	0.50	33.65	No	No
13	Pacha Patar Khal	Madhya Gurguriya	1.38	74.52	No	No
14	Bhubaneshwari Khal	Bhubaneshwari	2.70	99.22	Yes	Yes
15	Debipur Khal	Debipur	0.60	33.75	No	No
16	Gayener Khal	Debipur	2.07	121.10	No	No
17	Mahish Got Khal	Debipur	0.69	32.50	No	No
18	Kanmari Khal	Madhya Gurguriya	0.84	32.0	NA	NA
19	Golam Hussein Sardar Khal	Kharibari	2.70	108.0	NA	NA
20	Gabtala Khal	Gabtala	2.28	88.00	NA	NA
21	Thakurani Khal	Gabtala	2.50	90.00	NA	NA
22	Shikarir Khal		0.87	35.00	NA	NA
Total			**40.93**	**1766.64**		

Table – 31: Details of Canals restored in Kakdwip Panchayat Samity, South 24 Parganas District (Source: SDB, 1992)

Serial No.	Name of Canal	Beneficiary Mouza	Length of Canal (in kms.)	Area receiving irrigation during Rabi Season (in acres)	Whether attached to Sluice Gates	Whether there is Water User Committee for proper water usages of the water body
1	Khejuria Khal	Kashiabad	3.06	62.42	No	No
2	Narkeldanga and Tar Shakha Khal	Harandranagar	2.984	46.23	Yes	No
3	Makarpara Khal	Uttar Kashiabad	2.540	34.76	Yes	No
4	Akhaynagar Khal	Akhaynagar	0.750		Yes	No
Total			**9.334**	**143.41**		

Table – 31: Details of Canals restored in Joynagar-II Panchayat Samity, South 24 Parganas District (Source: SDB, 1992)

Serial No.	Name of Canal	Beneficiary Mouza	Length of Canal (in kms.)	Area receiving irrigation during Rabi Season (in acres)	Whether attached to Sluice Gates	Whether there is Water User Committee for proper water usages of the water body
1	Tulshighata Hobga Khal	Mollar Chak	1.10	15.67	Yes	No
		Tulsighata				
		Chunapukur				
2	Kharibari	Kharibari	3.51	110.56	No	No
3	Nalgola Khal	Shonatikari	2.37	298.85	Yes	Yes
	Chapaliya Khal	Bhuban Khali				
4	Bhuban Khali Khal	Radhabhallabpur	7.10	319.50	No	No
		Bhuban Khali				
5	Chupri Jhara Khal	Chupri Jhara	4.20	357.00	Yes	Yes
	Shonatikari Khal					

6	Kulberia Khal	Manir Tath	2.91	116.00	NA	NA
7	Thakurani Khal	Radhabhallabpur	2.70	108.00	NA	NA
8	Mulor Hath Khal	Chunar Pukur	2.00	80.00	NA	NA
Total			**25.890**	**1405.58**		

Table – 32: Details of Canals restored in Gosaba Panchayat Samity, South 24 Parganas District (Source: SDB, 1992)

Serial No.	Name of Canal	Beneficiary Mouza	Length of Canal (in kms.)	Area receiving irrigation during Rabi Season (in acres)	Whether attached to Sluice Gates	Whether there is Water User Committee for proper water usages of the water body
1	Kasturi Khal	Dayapur	0.32	9.00	Yes	Yes
2	Malshabhangi Khal	Dayapur	3.20	150.00	Yes	Yes
3	Dutter Khal	Mitrabari	5.985	409.00	No	Yes
		Lux Bagan				
4	Kakmari Khal	Lacol Bagan	1.59	127.03	No	No
5	Birajnagar Khal	Birajnagar	0.50	15.00	No	No
6	Balir Khal	Bali	1.35	32.06	No	Yes
7	Bedana Khal	Monmathnagar	0.61	24.02	No	No
8	Moukhali Khal	Chandipur	2.482	180.90	No	Yes
9	Taranagar Kamarkhali Khal	Taranagar	1.57	43.84	No	No
10	Mohaner Khal	Kumirmari	0.50	19.69	No	No
11	Bonabobir Khal	Kachukhali	0.87	26.13	No	No
12	Pakhirala Khal	Gosaba	2.95	9.70	NA	NA
13	Rajapur Khal	Rajapur	2.48	91.00	NA	NA
14	Gayener Gheri Khal	Bipradaspur	2.01	80.5	NA	NA
15	Shahapur Khal	Shahapur	0.7	28.00	NA	NA
16	Arampur Khal	Arampur	0.97	39.00	NA	NA
Total			**28.087**	**1284.87**		

Table – 33: Details of Canals restored in Gosaba Panchayat Samity, South 24 Parganas District (Source: SDB, 1992)

Serial No.	Name of Canal	Beneficiary Mouza	Length of Canal (in kms.)	Area receiving irrigation during Rabi Season (in acres)	Whether attached to Sluice Gates	Whether there is Water User Committee for proper water usages of the water body
1	Bonbibi Khal	Nirdeshkhali	3.20	150.00	Yes	Yes
		10 no. Kalahajra				
2	Nebukhali Khal	Gagramari	14.45	812.81	Yes	Yes
		Kalahajra				
3	Bhomramari Khal	Fulmalancha	1.85	93.66	Yes	No
4	Choradakatiya Khal	Choradakatiya	2.7	125.39		No
5	Goladagra Khal	Manshakhali	2.01	94.22	Yes	Yes
6	Bhagankhali Khal	Kathalberai	0.90	26.25	No	Yes
7	Panikhali Khal	Panikhali	3.00	112.50	No	Yes
8	Charabidya	Charabidya	3.50	146.56	No	Yes
9	Ashakhali Khal	Ashakhali	1.85	118.12	No	No
10	Radhagobind Khal	Radhagobindpur	1.41	26.44	Yes	No
11	Uttar Mokamberia Khal	Uttar Mokamberia	9.40	528.75	Yes	No
12	Dholarkhali Khal	Bharatgarh	1.53	86.03	Yes	No
13	Mahshpur Khal	Maheshpur	1.51	35.30	Yes	No
14	Abalkhali Khal	Amjhara	1.20	33.75	Yes	No
		Taldaha				
15	Sitanathchaker Khal	Chunokhali	1.40	78.75	Yes	No
		Sitanathchak				
16	Banmali Khal	Jhorkhali	3.773	212.23	Yes	No
		Banmalipur				
17	Jhorkhalipukur Khal	Jhorkhali				

18	Dakshin Mokamberia Khal	Masjidbati	2.38	133.87	Yes	No
19	Radharanipur Khal	Jyotishpur	1.41	26.44	No	Yes
		Radharanipur				
20	Goladharia Khal		1.905	76.00	No	No
Total			**59.358**	**2917.07**		

Interestingly, all these works have been carried out at ground level without any policy decision. It would have been better if a policy decision in this regard be undertaken after making a systematic survey based on cadastral sheets and making a concrete assessment regarding potentiality of such endeavour in creating freshwater detention structure in Sundarbans. That can solve the problem of freshwater in Sundarbans to a great extent.

Creeks with Live Connections with Rivers

Even the creeks which are well connected with the large rivers and through which tidal actions play on daily basis can also be disconnected from the main rivers as an adaptive measures in the backdrop of climate change (Bhattacharyya et al, 2013). A radical solution has been prescribed to accommodate the future sea level rise which states that 'It may also be tentatively concluded that the practice of closure of headwater creeks with flap sluices to produce freshwater reservoirs could also be seen as a potential management tool. Such creek closure reduces tidal prism in the main channels and thus provides accommodation space for future sea level rise. It may be concluded that limited use of this small-scale technique could be beneficial, but experience in other estuarine systems indicates that closure of larger channels can have a significant impact on the tidal processes of the outer estuaries, and lead to irreversible changes in their morphology' (Bhattacharyya et al, 2013).

It has been reported that in the forest part of 4267 km^2 of Sundarbans, about 2180 km^2 is actually under mangrove forest canopy, while rest area i.e. 2087 km^2 is mostly creeks and rivers, as estimated through use of remote sensing technology (Bhattacharyya, 2015). So, in the forest area, almost 49% of the area is under water. However, this only accounts for the major creeks and rivers around the forested islands. During the time of estimation, the smaller creeks and rivulets, which pass through the individual islands for carrying tidal water, were not considered. In that eventuality water covered area will definitely increase.

In case of the remaining 5,400 km^2 of non-forested area, more precisely reclaimed forest, human inhabited region along the north and north-western fringe of mangrove forest, most of the major rivers and creeks around the inhabited islands have been silted up and having smaller widths. So, the ratio of land part and water part will be definitely different and land portion will be much higher. However, the creeks and cut-off creeks within the inhabited islands are of interest for construction of WDS as future source of freshwater in Sundarbans. Unfortunately, so far no such estimation of area coverage by these water bodies within the islands has been attempted.

However, looking at different mouza maps under different blocks and examining the area coverage by these water bodies, it can be conservatively estimated that at least 0.01% to .0.05% of the land portion of inhabited part of Sundarbans is covered under small creeks, cut-off creeks and silted up creeks cumulatively. Thus, there is a potentiality for development of more than 5,000 hectares of present day saline water bodies into freshwater reservoirs in coming days. With a depth of 3 meters or so, total capacity of Water Detention Structures can be at least 15,000 cum spreading over different islands. In reality, area covered under such water bodies may increase, if proper survey and mapping be made using high resolution satellite image.

In case of any policy decision be adopted for creation of WDS using these water bodies, individual schemes need to be scrutinised and examined in respect of coastal environment. There will be no question of conversion of any creek which leads to any mangrove patch, whatever may be area of the patch. In that eventuality, conversion of these creeks etc. into freshwater WDS will practically not hamper the natural tidal flow along the main rivers and thereby not hamper the tide dynamics in the region. Rather, it can be presumed that with sea level rise, such action can be considered as an innovative adaptation strategy in Sundarbans to save the life and livelihood of 4.5 million people.

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