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Identification of the Saline Free Zone in Southwest Region of Bangladesh by Limiting Salinity Level (< 1ppt) with Improved Flow Scenarios Using Mathematical Modeling

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Abstract The coastal area of the Ganges delta in Bangladesh is characterized by tides and salinity from the Bay of Bengal. Salinities in the Bangladesh coast are dependent on the annual rainfall, evaporation, freshwater flows discharging from upstream and the impact of climate change. Average salinity concentrations at the coast are higher in the dry season than in the monsoon, due to reduction in freshwater flow from the upstream. The higher salinity levels have adverse impacts on agriculture, aquaculture, domestic and industrial water use and so on. Hence, the simulation of the calibrated salinity model is carried out in this study to investigate the baseline condition of salinity and assessment of hydrodynamic condition which will reduce the salinity level at downstream portion of Southwest region of Bangladesh. Historical data and field measurements on salinity, water flow, water level and numerical modeling technique are applied to develop the hydrodynamic scenarios (mainly based on upstream discharge condition), which are simulated with the calibrated and validated hydrodynamic and salinity model. The scenario with increase in upstream flow through Ganges connected rivers is simulated to identify the saline free zone at the most south end zone. The simulation of the calibrated salinity model is carried out by limiting salinity level (< 1ppt) with improved flow scenarios by mathematical modeling technique. The saline free zone with different flow scenarios is assessed by MIKE One-Dimensional (MIKE 11) and MIKE Two-Dimensional (MIKE 21FM) Modelling system.

Keywords: *salinity, southwest, freshwater hydrodynamic, Mike 11, Mike 21 FM, Bay of Bengal, surface water*

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1. Introduction

The flow of the Ganges in Bangladesh reduced significantly due to withdrawal of water in the upstream at the Farakka Barrage. India commissioned the Farakka Barrage in West Bengal in 1975 to divert 40,000 cusec water of the Ganges River into the Bhagirathi-Hooghly Rivers for flushing silt and improve navigability of Kolkata Port connected to the Bay of Bangal on the south [1]. The reduction of dry season flow in the Ganges has led to various water quality, ecological, hydrological and hydraulic problems in southwestern Bangladesh. The main impact of reduced low flow values has been the drop in hydraulic head of the Ganges River system, and the consequent increase in salinity in southwestern Bangladesh Rivers [2].

In dry season, when the flows of upstream water reduce drastically, the saline water goes up to 240 kilometers inside the country and reaches to Magura district. Presently around 31 Upazilas of Jessore, Satkhira, Khulna, Narail, Bagerhat and Gopalganj districts are facing severe salinity problem. Agricultural activities as well as cropping intensities in those Upazilas have been changing; as a result, farmers cannot grow multiple crops in a year [3]. Salinity in the river system of southwest coastal region increases steadily from December through February, reaching maximum in the late March and early April [4]. About 20% of the net cultivable land of Bangladesh coastal region is affected by different degrees of salinity [5]. The impact of salinity on crop production as well as aquatic environment is well documented [6].

The increase of salinity in the Ganges distributaries has also led to ecological impacts on the world's largest mangrove forest, the Sundarbans is about 10,000 km^2 in southwest Bangladesh and West Bengal of India [7]. Salinity levels increased in the Sundarbans when intake-mouths of the Mathabhanga, Kobadak and other rivers that used to bring fresh water from the Ganges to the south were silted up and thus lost their connection with the Ganges. Therefore, the result of increase salinity and alkalinity has damaged vegetation, agricultural cropping pattern and changing the landscapes in the Sundarbans region [8].

Therefore, in this study the baseline condition of salinity has been investigated and assessment of hydrodynamic condition has been carried out which will reduce the salinity level at downstream portion of Southwest region of Bangladesh.

1.1. Study Area

The study area encompasses the entire Southwest (SW) area of Bangladesh bounded by the Ganges and the Padma in the north, the east extending into the Bay of Bengal to the south and the international border in the west. The Gross Area of the Southwest (including South central) region is 41,500 km^2 [9]. The study area map is presented in Figure 1.

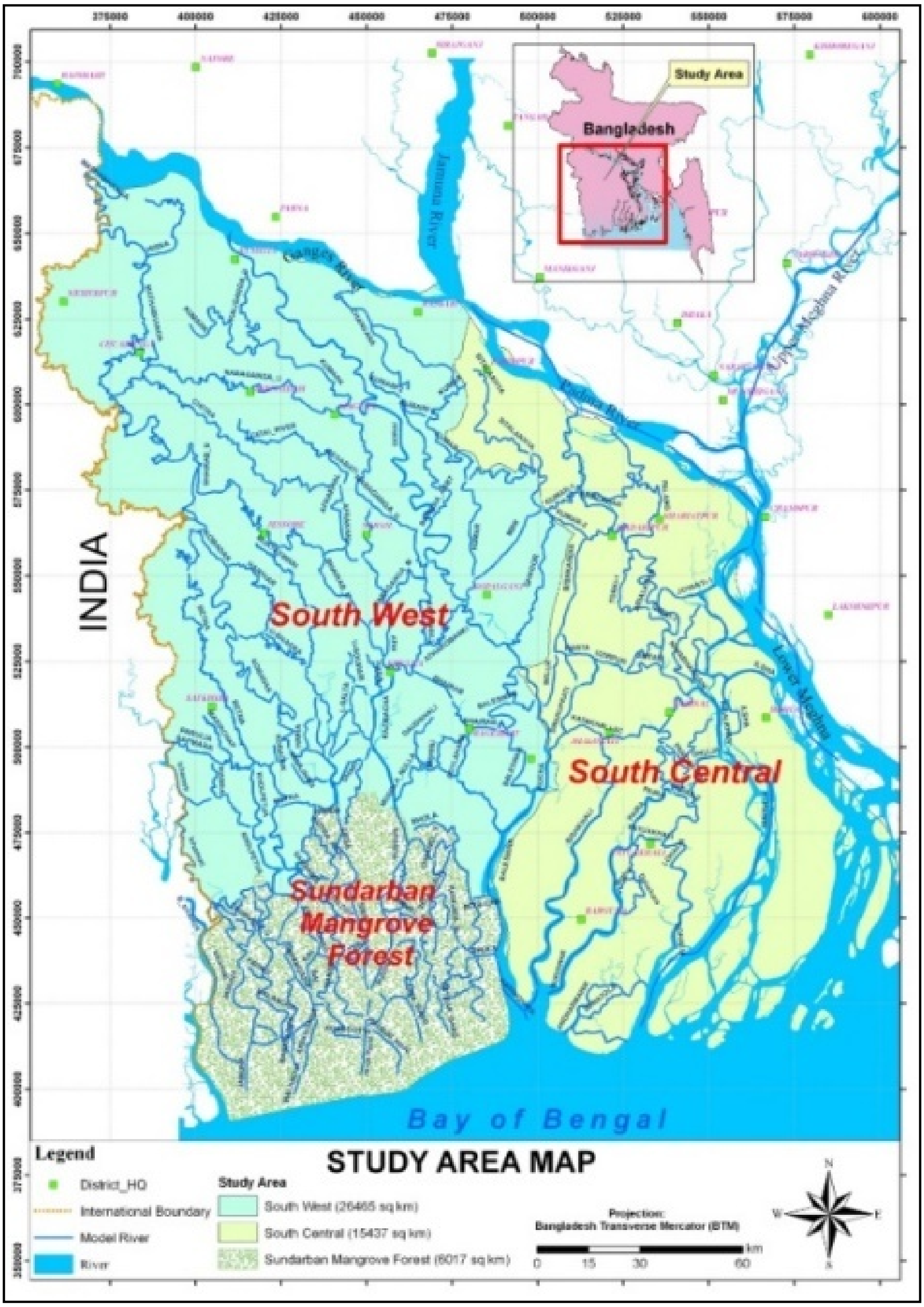


Figure 1. Study Area

2. Data and Methodology

2.1. Data

The data on salinity, water level, river cross-sections and discharge are used in this study as secondary data. The bathymetric survey data are collected by IWM from different study. Historical hydrometric data such as water level and discharge are also collected from IWM, BWDB. Rainfall data were collected from BMD. These collected data are utilized to establish baseline hydrodynamic and salinity conditions of the study area and for calibrating and validating the Southwest Regional Model. Based on irrigation water demand, navigational requirement, fisheries requirement, salinity intrusion prevention criteria, BWDB has fixed the seasonal flow diversion amount from the Ganges to link channels through Ganges barrage operation.

2.2. Model Details

The principal modeling tools used in the study are the one-dimensional and two-dimensional (1-D and 2-D) modeling systems, MIKE11 and MIKE 21FM of DHI. The existing calibrated (Year 2012) and validated (Year 2011) Southwest Region Model (SWRM) developed at Institute of Water Modeling (IWM) are applied to assess the base line salinity condition (no upstream connection with Ganges River) of the area. As the salinity developments of southwest region of Bangladesh take place during the dry period, model simulations mainly concentrated for a six-month dry period from January to June.

The two-dimensional HD model of Bay of Bengal model (BoB) developed by MIKE 21FM covers the Meghna estuary and Bay of Bengal area. The calibrated and validated Bay of Bengal model are used to generate the d/s boundary condition (Salinity) for southwest regional model. The developed SWRM under this study contains total 39 boundaries, of which 27 are upstream and 12 are downstream boundaries. The 12 downstream salinity boundaries for 1-D model will be used from the output of Bay of Bengal salinity model simulation.

The simulation of the calibrated and validated salinity model is carried out to investigate the saline free zone in southwest region of Bangladesh by limiting salinity level (< 1ppt) with improved flow scenarios. The model simulation is conducted from November 2011 to June 2012. Several runs are simulated with the calibrated and validated hydrodynamic Model and Salinity Model. Scenario-1 (base line condition, 2011-2012) is simulated to explore the present salinity intrusion. Scenario-2 (Minimum flow through Gorai River) is simulated to understand the worst condition for salinity intrusion. Finally, Scenario-3A, Scenario-3B and Scenario-3C (flow through Ganges connected Rivers) are conducted to identify the saline free zone with improved upstream flow and dredged river bathymetry condition. Scenario-3B and Scenario-3C are conducted for the sensitivity of Ganges flow in salinity intrusion. Three simulations conducted under this study are described in Table 1.

2.3. Model Calibration and Validation

Flow roughness is the major parameter for the calibration of hydrodynamic model. Manning's M (Inverse of Manning's roughness n) is used as the calibration parameter for the calibration of the one-dimensional mathematical models. Hydrological year of 2012 is used for the calibration of the base model. Calibrated hydrodynamic model is validated for year 2011 hydrological year. The locations of water level, discharge and salinity measurement are given in Figure 2. The plot of calibration and validation of Southwest Regional Hydrodynamic & Salinity Model against Water Level, Flow & Salinity are shown in Figure 3. The validation location and Correlation factor "R" has been given in Table 2.

Table 1. Summary of Scenarios

Scenario	Flow	Condition	
1	Base line Scenario	• Simulation of calibrated and validated Southwest Regional Model (Nov 2011 to June 2012) • No upstream connection with Ganges River • Apply existing upstream and downstream flow condition (2011-12)	
2	Minimum flow through Gorai River	• Baseline Model (Scenario-1) simulated with minimum flow through Gorai River • All other river (Hisna, Mathabhanga and Chandana) are disconnected at dry season with Ganges River	
3	Flow through Ganges connected rivers	3A	• Flow through Gorai, Hisna and Chandana based on Ganges barrage study • Restoration of flow through the channels with dredged X-sections.
		3B	20% flow increase of Gorai, Hisna and Chandana River
		3C	20% flow decrease of Gorai, Hisna and Chandana River

Table 2. Validation locations and Correlation factor (R)

Calibration	River Name	Station	R
Water Level	Kocha	Pirozpur	0.91
	Lower Shoilmari	Batiaghata	0.90
	Kazibachar	Ancharia	0.95
	Rupsa	Khulna	0.92
Flow	Pussur	Akran Point	0.94
	Sibsa	Akram Point	0.90
	Pussur	Mongla	0.90
Salinity	Pussur	Mongla	0.99
	Sibsa	Nalian	0.97

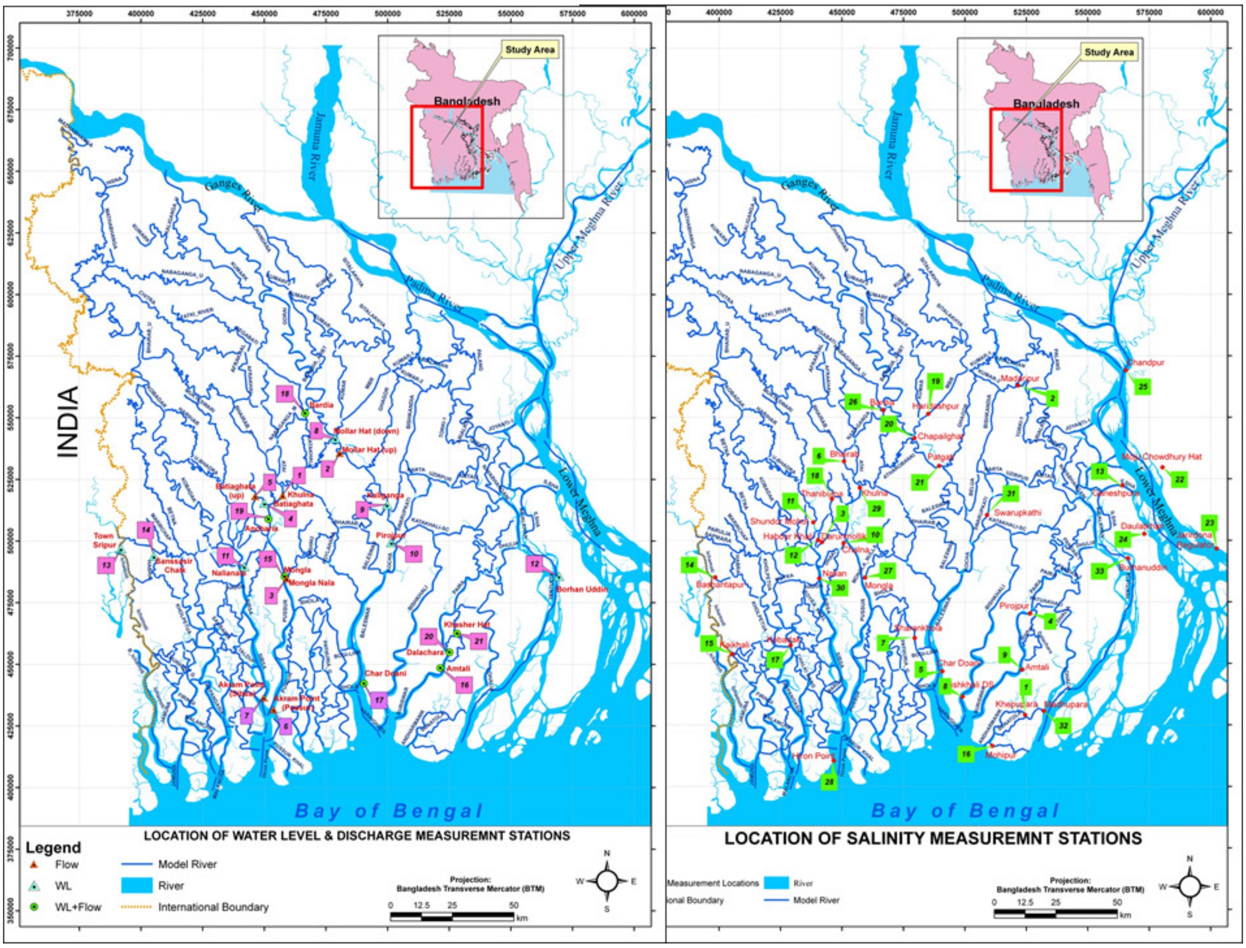


Figure 2. Location of Water Level, Discharge & Salinity measurement Stations (Source: Institute of Water Modelling (IWM))

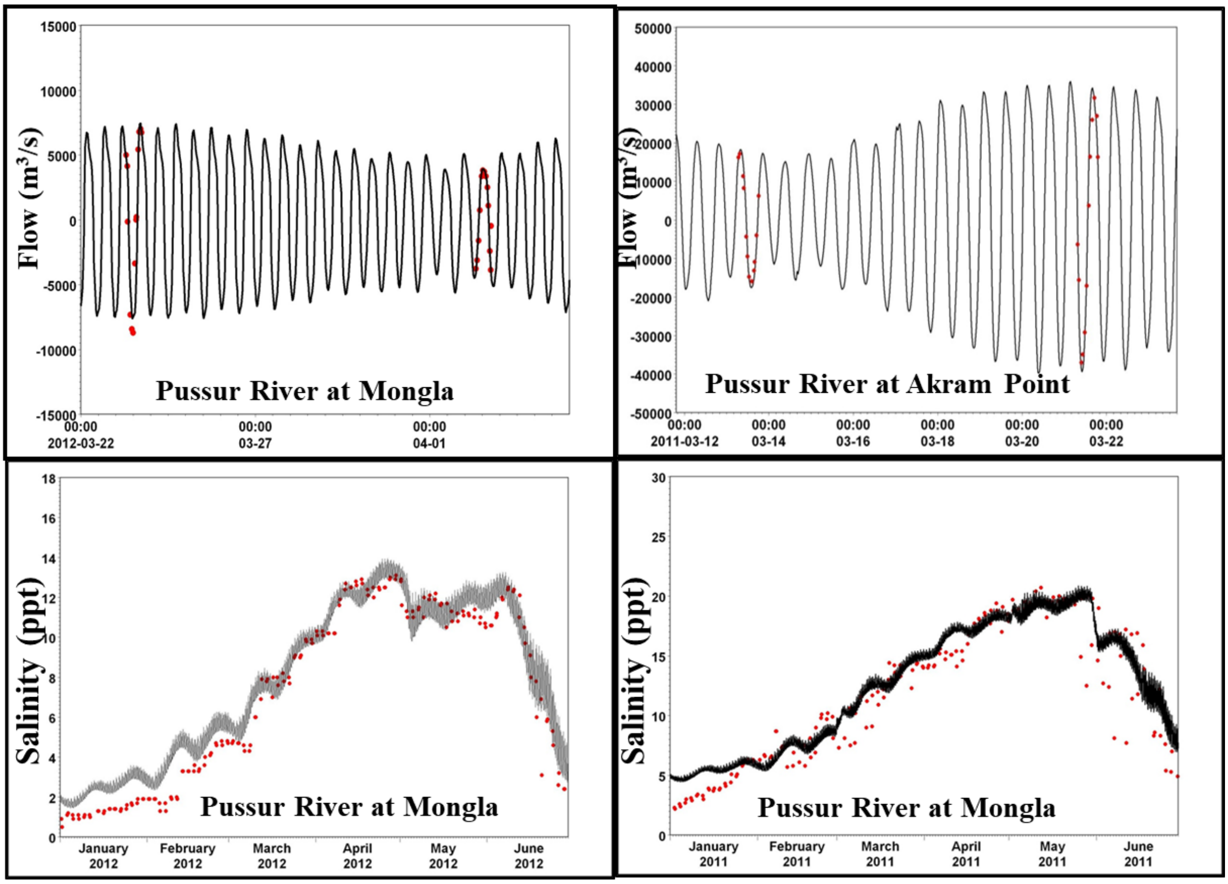


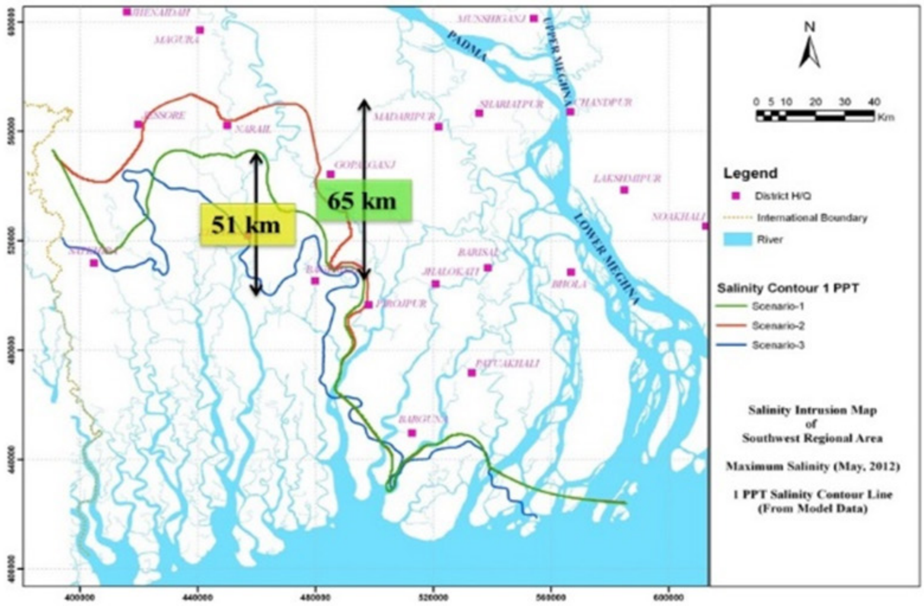
Figure 3. Calibration and Validation of Southwest Regional Hydrodynamic & Salinity Model against Water Level, Flow & Salinity (2011-2012)

3. Results and Discussions

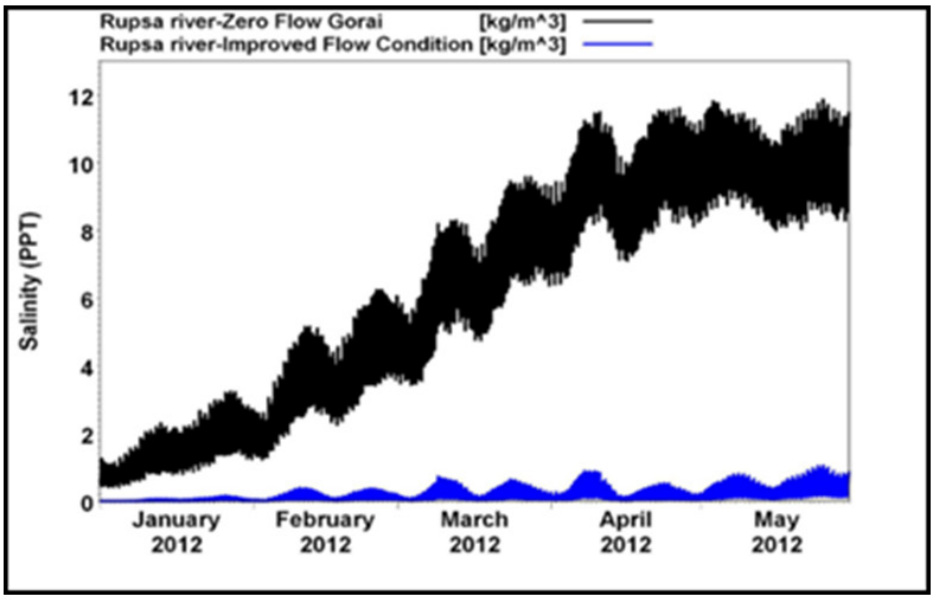
The model simulation is conducted from November 2011 to June 2012. The allowable salinity level for drinking water is 1 ppt, according to Environmental Quality Standard (EQS) of Bangladesh. If the limiting level of salinity level is 1 ppt than by increasing upstream flow (Scenario-3) 1900 sq. Km land will be saline free from base line (Scenario-1) condition. The saline free land will be 4200 sq. km by increasing upstream flow (Scenario-3A) if it is compared with Scenario-2 (Minimum flow in Gorai River) condition. The 1 ppt salinity line pushes 51.00km & 65.00km from north to south direction by increasing upstream flow (Scenario-3A) comparing with the scenario-1 and Scenario-2 flow condition respectively which has been presented in Figure 4(a).

Scenario-1 looks improved condition then scenario-2 as because after capital dredging (2010-2011) of Gorai River increased upstream flow coming from Gangers River to Gorai River off-take. It is observed that after three years, dredging has improved the overall situation. The saline free river water could be used directly for agriculture, domestic water supply (with low cost water treatment) and industrial purposes. Table 3 shows that major reduction of salinity from the Scenario-1 (base line condition) and Scenario-2 (Minimum flow in Gorai River) to the increased upstream flow Scenario (Scenario-3A).

The pushdown of 1 ppt salinity contour line are shown in Figure 4 (a). Salinity level in the eastern part of the south-west area remains less saline because of diversion of a considerable fraction of the freshwater discharge from the Ganges River. Salinity levels in the region decreases from west to east as well as from south to north. Figure 4 (b) shows the significant reduction of salinity in the improved flow condition.



(a)



(b)

Figure 4. (a) Pushdown of 1 PPT Salinity Intrusion for different flow Scenario (Dry, 2012) (b) Reduction of salinity in the improved flow condition at Rupsa River

Table 3. Saline free zone in southwest region by limiting salinity level (< 1ppt) with improved flow scenarios (May)

River Name	Location Name	Easting	Northing	Salinity in PPT		
		BTM	BTM	Scenario-1 (Dry, 2012)	Scenario-2 (Dry, 2012)	Scenario-3 (Dry, 2012)
Atai	Arua	456041	532063	0.82-4.70	10.4-13.5	0.00
Bhairab L	Bagerhat	479848	503935	2.24-3.76	3.48-5.63	0.69-1.2
Bhairab U	Fulbari ghat	450845	532106	1.35-4.80	10.6-13.6	0.00
Bhola	Sharankhola	479758	459977	1.60-2.80	1.76-2.58	1.00-1.7
Chitra	Narail	450724	556942	0.18-0.63	1.52-5.85	0.00
Madhumati	Jalalbad	470014	552641	0.00-0.17	5.58-8.85	0.00
Nabaganga M	Bardia	467354	552893	0-0.30	6.88-9.35	0.00
Nabaganga M	Hamidpur	455731	542349	0.22-2.63	8.8-12.00	0.00
Rupsa	Khulna	455967	523133	2.16-7.64	12.2-15.1	0.00-0.9

4. Conclusions

Salinity intrusion is becoming a severe problem in the coastal areas around the world. Salinity is a key problem for domestic and agricultural water use during the dry period when irrigation needs are higher for “Boro” rice production and the salinity levels in the river systems are also high. The water is not usable for domestic purposes if salinity is higher than 1ppt, though it is still suitable for crop and livestock agriculture unless salinity exceeds 2ppt. The current study found that in Scenario-3A (increased upstream flow condition), some of the major rivers such as Gorai-Madhumati, Nabaganga, Chitra, Atai, Bhairab Upper, Rupsa would be saline free and all other rivers will have significant reduction of salinity due to increased upstream flow in Gorai River, Hisna River & Chandana River. Augmentation in the Gorai River flow reduces the salinity in the Pussur River and Sibsa River. Due to diversion of a considerable fraction of the freshwater discharge from the Ganges River, salinity level in the eastern part of the south-west area remains less saline. As a result, salinity levels in the region decreases from west to east as well as from south to north.

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