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HYDRODYNAMIC SCENARIO'S TO REDUCE THE SALINE WATER INTRUSION IN THE SOUTHWEST REGION OF BANGLADESH

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Abstract

Salinity in Bangladesh coastal area is dependent on tidal flow, rainfall intensity, evaporation, freshwater flows from upstream and the impact of climate change like sea level rise (SLR). Due to the reduction in freshwater flow from the upstream rivers in the dry season, the average salinity concentrations in the coastal part are higher in dry season than in the monsoon. The flow of Ganges River within Bangladesh reduced significantly due to the withdrawal of water in the upstream boundary. The simulation of the calibrated salinity model for the Southwest region in Bangladesh has been carried out in this study to explore the hydrodynamic scenarios which may reduce the salinity level at the above mentioned area. The scenarios are based on different flow conditions and have been simulated with the calibrated and validated hydrodynamic and salinity model. The scenario considering the increase in upstream flow through Ganges and its connected rivers has been simulated to identify the saline free zone at the most southern end zone. Salinity level remains higher in the western part of the Southwestern region than that of the eastern part. The eastern part remains less saline since it receives freshwater flow through Arial Khan, Bishkhali and Buriswar Rivers. As a result, salinity levels in the region decreases from west to east. It was observed that the some of the major rivers of Southwest would be saline free and all other rivers will have significant reduction of salinity due to increase in flow of fresh water through the Ganges and its distributaries.

Keywords: *augmentation, Bay of Bengal, freshwater, hydrodynamic, MIKE 11, MIKE 21 FM, salinity, southwest.*

Introduction

Bangladesh is a low-lying, riverine country located in South Asia with a largely marshy land coastline of 710 km (441 mi) on the northern littoral of the Bay of Bengal, formed by a delta plain at the confluence of the Ganges (Padma), Brahmaputra (Jamuna), Meghna Rivers and their tributaries. About 700 rivers including tributaries flow through the country constituting a waterway of total length around 24,140 km.

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 (BWDB, 2012). 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 (Rahman and Ahsan, 2001).

The study area encompasses the entire Southwest (SW) area of Bangladesh bounded by the Ganges and the Padma in the north and in the east extending into the Bay of Bengal to the south and the international border to the west. The Gross Area of the Southwest (including South central) region is 41,500 km2 (IWM, 2003). 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 km2 in southwest Bangladesh and West Bengal of India (Siddiqi, 2001; Lacerda, 2001). The Bangladesh portion of Sundarbans covers an area of 6017 km^2 of mangrove forests, wildlife sanctuaries and sand bars, out of this 1905 km^2 are made up rivers, creeks and canals (Wahid, 1995; Katebi, 2001). 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 (Hoque *et al.,* 2006).

In the recent years, groundwater based water supply in coastal area is suffering from a number of major problems mainly arsenic contamination, lowering of the water table, salinity and non-availability of suitable aquifers (PDO-ICZMP, 2004).

Salinity in the river system of southwest coastal region increases steadily from December through February, reaching maximum in the late March and early April (EGIS, 2001). About 20% of the net cultivable land of Bangladesh coastal region

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is affected by different degrees of salinity (Karim *et al.,*1990). Most of the lands remain fallow in the dry season (January–May) because of soil salinity (Mondal, 1997). 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 (Shamsuddoha and Chowdhury, 2007).

Methodology

The approach of the study is to develop hydrodynamic scenario to reduce the saline water intrusion in the southwest region of Bangladesh.

a) Data collection on precipitation, evaporation, water level, discharge, salinity and river cross-section

b) The principal modelling tools used in the study was the one-dimensional and two-dimensional (1-D and 2-D) modelling systems, MIKE11 and MIKE 21FM of DHI. The salinity developments of southwest region of Bangladesh take place during the dry period.

c) To achieve the objectives, the simulation of the calibrated and validated salinity model has been carried out by increasing upstream flows which are connected with Ganges River for limiting salinity of Southwest region of Bangladesh.

d) Scenario-1 (baseline condition, 2011-2012) has been simulated to explore the present salinity intrusion. Scenario-2 (Minimum flow through Gorai River) has been simulated to understand the worst condition for salinity intrusion. Finally, Scenario-3A, Scenario-3B and Scenario-3C (flow through Ganges connected Rivers) has been conducted to identify the saline free zone with improved upstream flow and dredged river bathymetry condition. Three simulations have been done under this study which is described in Table 1.

Table 1. Summary of the scenarios used in the study

Scenario	Flow	Condition	
Scenario 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)	
Scenario 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	
Scenario 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

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. In our study the flow data of the right bank of Ganges River been collected and used for increasing the upstream flow and presented below in Table 2. The Gorai River Hydrograph for different flow scenario is shown in Fig. 1.

Table 2. Monthly Flow Diversions (m^3/s)

River	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Hisna	400	300	231	234	232	242	184	300	400	500	500	400
Gorai	2500	1000	225	227	225	230	194	500	2500	7600	7600	2500
Chandana	300	200	46	57	77	80	44	50	200	300	300	300
Total	3200	1500	502	518	534	552	422	850	3100	8400	8400	3360

(Source: BWDB, 2012)

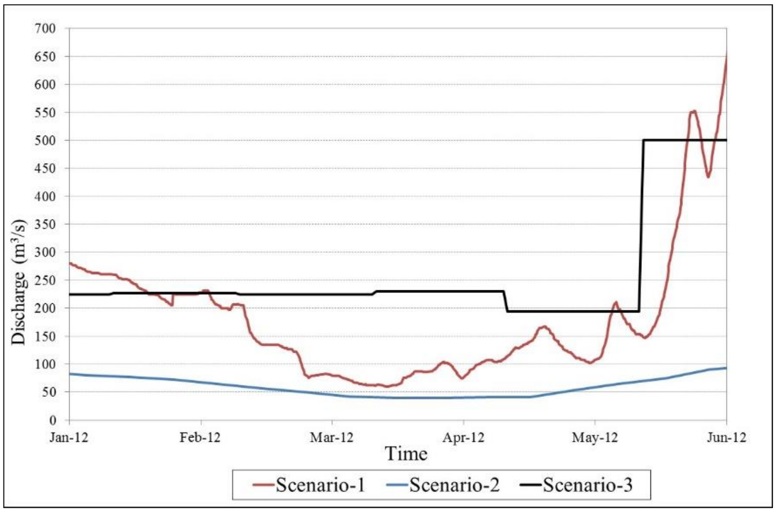

Fig. 1. Gorai River Hydrograph at different flow scenario

Data and Model used in the study

Data on salinity, water level, river cross-section and discharge were collected for consecutive two years considering monsoon and dry season under GRRP project by IWM. The bathymetric survey data were collected by IWM from different study. Historical hydrometric data such as water level and discharge were also collected from IWM, BWDB. Rainfall data were collected from BMD. In this study MIKE has been used for One-Dimensional and Two-Dimensional Modelling. MIKE11 was used for One-Dimensional model. Subsequently, MIKE21 FM was used for Two-Dimensional model. The salinity model, based on this hydrodynamic model, will describe the transport and advection of salinity. Fig. 2 shows the overall methodology of the salinity model. The existing one-dimensional Southwest Regional Model (SWRM) developed by MIKE 11 has been extended and updated with the dredged X-sections cross-sections to restore the flow thorough Ganges connected River of Southwest Regional rivers (Fig. 3). The calibrated and validated Bay of Bengal model (BoB) (Fig. 4) developed by MIKE 21FM has been used to generate the d/s boundary condition (Salinity) for southwest regional model.

The existing SWR Model has 230 river branches and 32 boundaries of which 12 are directly connected to the sea at the downstream. Whereas, the developed SWRM under this study contains total 39 boundaries, of which 27 are upstream and 12 are downstream boundaries. The 12 downstream salinity boundary for 1-D model will be used from the output of Bay of Bengal salinity model simulation.

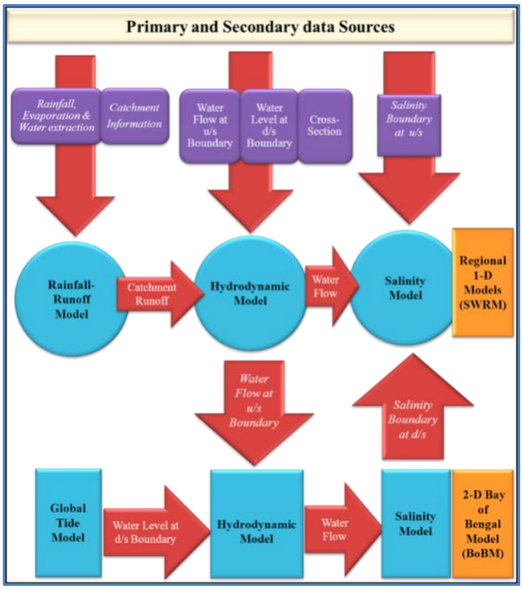

Fig. 2. Methodology of the salinity modeling.

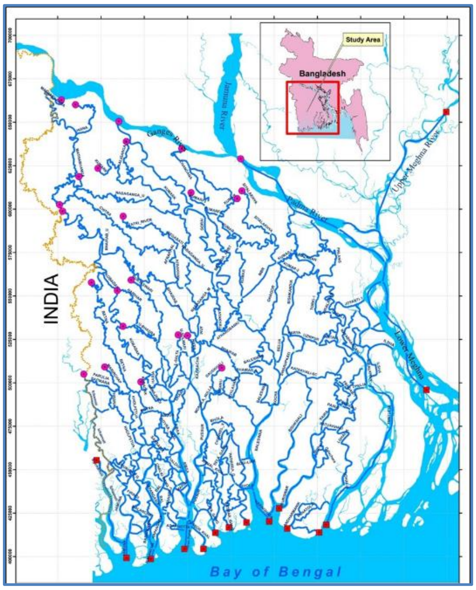

Fig. 3. Southwest Regional Model Domain.

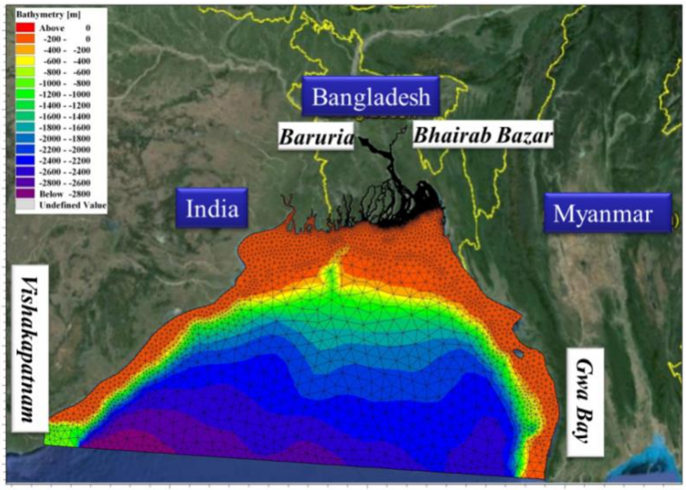

Fig. 4. Bay of Bengal Model Domain (BoBM)

MIKE 11 hydrodynamic equations

The equations which are solved for the flow simulations are called Saint Venant equation. These are derived from the Navier Stokes equation. Saint Venant equations are:

$$\frac{\delta q}{\delta x} + \frac{\delta A_{fl}}{\delta t} = q_{in} \qquad \text{Eq. (1)}$$

$$\frac{\delta q}{\delta t} + \frac{\delta\left(\alpha \frac{q^2}{A_{fl}}\right)}{\delta x} + gA_{fl}\frac{\delta h}{\delta x} + gA_{fl} I_f = \frac{f}{\rho_w} \qquad \text{Eq. (2)}$$

Where, q (Discharge); A_{fl} (Flow area); q_{in} (lateral inflow); h (water level); α (momentum distribution coefficient); I_f (Flow resistance); f (Momentum forcing) and ρ_w (Density of Water). Equation (1) is called the continuity equation; Equation (2) is called the momentum equation

MIKE 11 advection-dispersion equations

The advection-dispersion equation is solved numerically using an implicit finite difference scheme, which, in principle, is unconditionally stable and has negligible numerical dispersion. It solves the following advection-dispersion formula:

$$\frac{\partial AC}{\partial t}+\frac{\partial QC}{\partial x}-\frac{\partial}{\partial x}\left(AD\frac{\partial C}{\partial x}\right)=-K.A.C+q_L.C_L \quad \text{Eq. (3)}$$

Where, C (concentration); D (dispersion coefficient); A (cross-sectional area); K (linear decay coefficient); C_L (source/sink concentration) and q_L (lateral inflow). The Equation (3) is presented above briefly described in Reference Manual, DHI (2014).

Model calibration & 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 has been used for the calibration of the base model. The locations of water level, discharge and salinity calibration are given in Fig. 5.

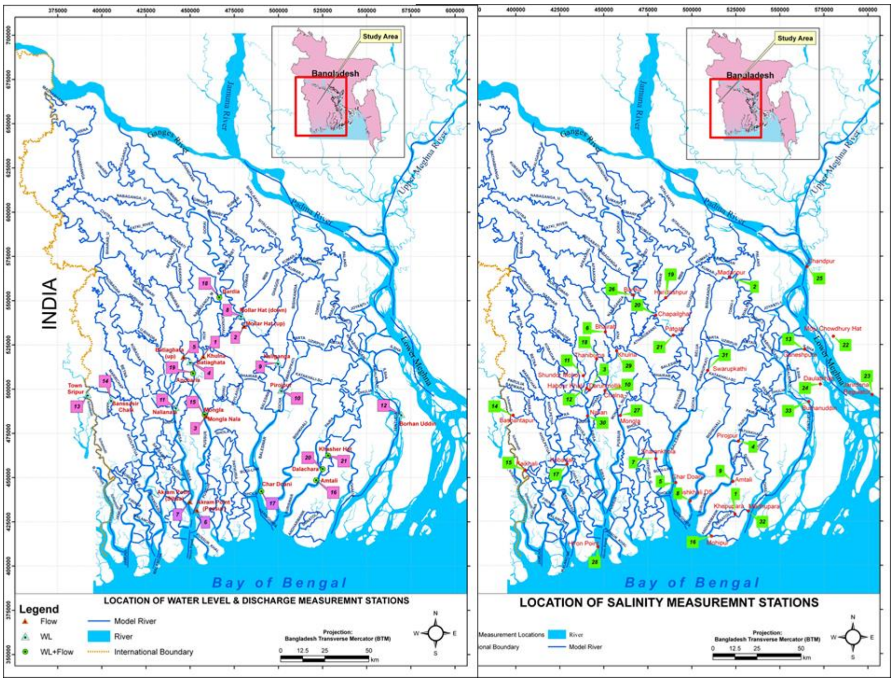

Fig. 5. Location of Water Level, Discharge & Salinity measurement Stations (Source: IWM)

Sample of water level, discharge and salinity Calibration plots of Southwest Regional Model against water level are shown in Fig.6. Under this study all the units of water lever are in (m PWD), discharge and salinity flow are in (m^3s^{-1}) and all the units of salinity are in (ppt). Calibrated hydrodynamic model for year 2012 is validated for year 2011 hydrological year. The validation location and Correlation factor "R".

Table 3. Validation Location and Correlation factor "R".

SI No	Calibration	River Name	Station	R
1		Kocha	Pirozpur	0.91
2	Water Level	Lower Shoilmari	Batiaghata	0.90
3		Kazibachar	Ancharia	0.95

SI No	Calibration	River Name	Station	R
4		Rupsa	Khulna	0.92
5	Flow	Pussur	Akran Point	0.94
6		Sibsa	Akram Point	0.90
7		Pussur	Mongla	0.90
8	Salinity	Pussur	Mongla	0.99
9		Sibsa	Nalian	0.97

Results and discussion

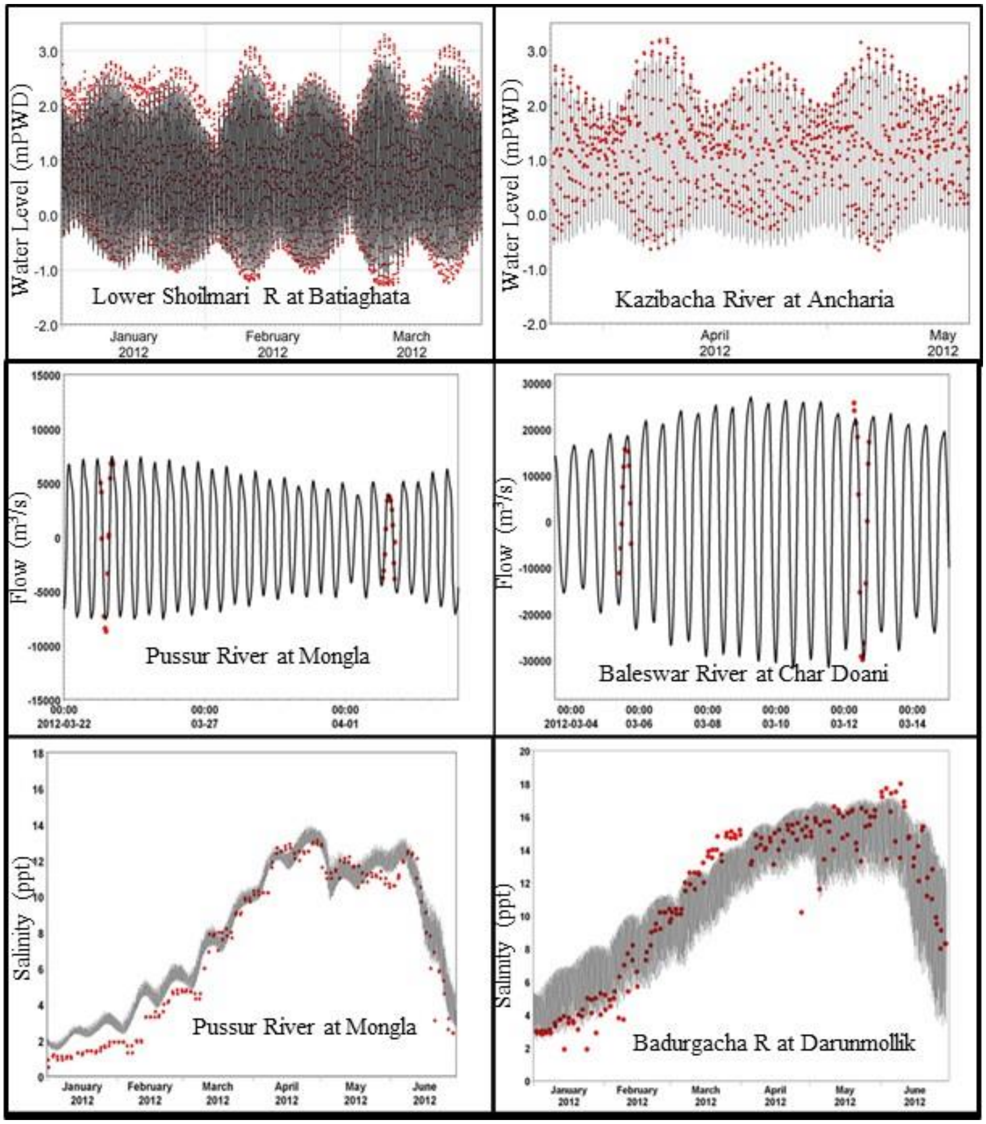

Fig. 6. Calibration of the Southwest regional model against water level, flow and salinity (2012).

Under this study, the one-dimensional hydrodynamic model is applied in order to evaluate the trans-boundary flow that will be sustaining the major rivers in the Southwestern region of Bangladesh. The Hydrograph of Ganges connected river represents the trans-boundary flow through Ganges River. It is assumed that the Ganges River flow distribute in Gorai, Madhumati and Chandana River. The Gorai, Madhumati, Mathabhanga and Chandana Rivers are now disconnected from the Ganges River in the dry season due to river bed aggradations at the mouth of their off-takes. All those rivers become dry or nearly zero flow under existing river condition. Flow Hydrographs of the Southwest major rivers for Scenario-3A are shown in Fig.7.

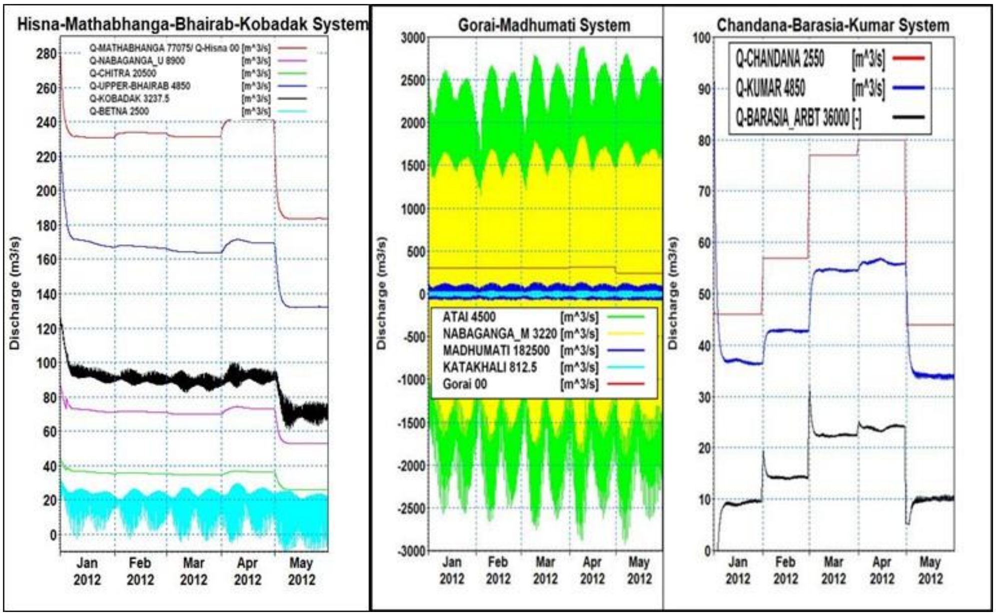

Fig. 7. Flow hydrograph for increased flow Scenario

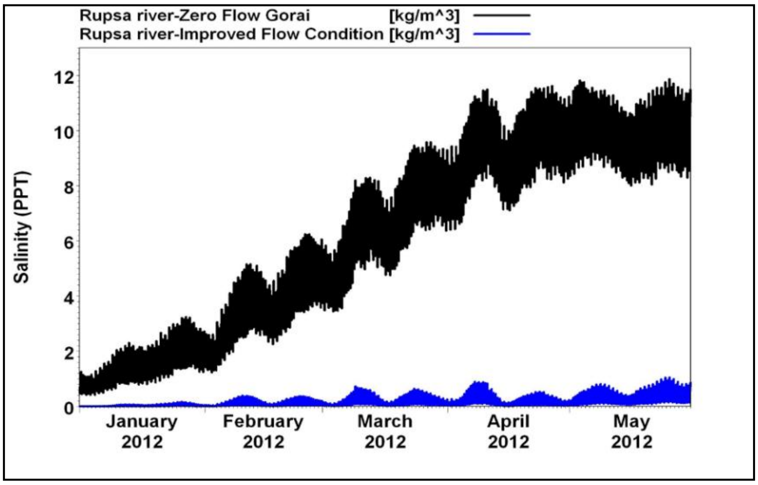

Fig. 8. Significant reduction of salinity in the improved flow condition

The model results indicate 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 Padma 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. Fig. 8 shows the significant reduction of salinity in the improved flow condition.

From the sensitivity analysis of Ganges connected River flow by model results indicate that with Scenario-3B (20% flow increase of Gorai, Hisna and Chandana River) and Scenario-3C (20% flow decrease of Gorai, Hisna and Chandana River) the saline free zone similar to Scenario-3A.

Conclusion

Salinities in the Bangladesh coast are dependent on the volumes of freshwater flows discharging from upstream. In 1975, India commissioned Farakka Barrage on the Ganges at about 17km upstream of the Indo-Bangladesh border to divert about 40,000 m3/s of flow into Bhagirathi-Hoogly river system. As a consequence of such a large-reduction of the available flow, the Ganges dependent area in Bangladesh was exposed to serious fresh water shortage. The withdrawal of freshwater flow has resulted in landward movement of salinity front in the Ganges dependent coastal area of Bangladesh. From this research paper, it can be revealed that 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.

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References

BWDB (2012), Ganges Barrage Study Project (Feasibility Report – Main Report). Bangladesh Water Development Board, Dhaka.

EGIS (2001), Envronmental & Social Impact Assessment of Goari River Restoration Project. Bangladesh Water Development Board.

Hoque, A., Sarkar, M. S. K. A., Khan, S. A. K. U., Moral, M. A. H. and Khurram, A. K. M. (2006). Present Status of Salinity Rise in Sundarbans Area and its Effect on Sundari (Heritiera fomes) Species. *Research Journal of Agriculture and Biological Sciences*, 2(3): 115-121.

IWM (2003). Sundarban Biodiversiiity Conservation Project Surface Water Modelliiing. Final Report. Institute of Water Modeling.

Karim, Z., Hussain, S. and Ahmed, M. (1990). Salinity Problems and Crop Intensification in the Coastal Regions of Bangladesh. *BARC Soil Publication*. No.33: 63.

Katebi, M. N. A. (2001). *Sundarbans and forestry.* Haider, R. (Ed.): Cyclone '91 – An Environmental and Perceptional Study. BCAS, Dhaka. P.79–100.

Mondal, M. K. (1997). *Management of soil and water resources for higher productivity of the coastal saline rice lands of Bangladesh.* University of the Philippines, Los Banos, Philippines.

PDO-ICZMP (2004). *Living in Coast-Problems, Opportunities and Challenges.* Program Development Office for Intregated Coastal Zone

Management Plan.

Rahman, M. and Ahsan, M. (2001). Salinity constraints and agricultural productivity in coastal saline area of Bangladesh. *In Proceedings of the Annual Workshop on Soil Resources*.14-15 February, 2001. Soil Resources Development Institute, Dhaka, Bangladesh (p. 1-14).

Shamsuddoha, M. and Chowdhury, R. K. (2007). *Climate Change Impact and Disaster Vulnerabilities in the Coastal Areas of Bangladesh.* Coastal Association for Social Transformation Trust, Dhaka, Bangladesh. P.32.

Siddiqi, N. A. (2001). *Mangrove Forestry in Bangladesh.* Institute of Forestry and Environmental Sciences, Nibedon Press Limited, Chittagong, Bangladesh. P.201.

Wahid, S. M. (1995). *Hydrological Study of the Sundarban.* UNDP/FAO Project BGD/84/056, Department of Forest, Dhaka, Bangladesh.