Asian Journal of Environment & Ecology

7(4): 1-19, 2018; Article no.AJEE.44216
ISSN: 2456-690X

Impact of Climate Change and Ganges Discharge on the Salinity of the Passur River, Southwestern Bangladesh

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Authors' contributions

This work was carried out in collaboration between all authors. Author FA designed the study, performed the statistical analysis, data analysis, managed the literature searches, wrote the protocol and wrote the first draft of the manuscript. Authors GSS, MIA and MSH provided the guidelines of the study and prepared the maps. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJEE/2018/44216
Editor(s):
(1) Dr. Wen-Cheng Liu, Professor, Department of Civil and Disaster Prevention Engineering, Taiwan Typhoon and Flood Research Institute, National United University, Taiwan.
Reviewers:
(1) Sandipan Ghosh, Chandrapur College, India.
(2) Abu M. Sufiyan, Riverside University Health System, USA.
Complete Peer review History: http://www.sciencedomain.org/review-history/26879

Original Research Article

Received 23 July 2018
Accepted 04 October 2018
Published 27 October 2018

ABSTRACT

The present paper embodies the possible impact of climate change and upstream discharge on the Passur River water at the Mongla point of Khulna division, south-western part of Bangladesh. The secondary data have been gathered from different sources and were analysed to understand the aforementioned situation. To establish the relationship, the long-term salinity data (1962-2015) have been taken into account as the dependent variable with other climatic variables' viz., temperature, rainfall, river discharge, tide level and also sea level change. The salinity of the Passur River increased persistently at a rate of 0.13 ppt/year from 1962 to 2015. Dramatic changes of salinity have been audited after the construction of Farakka barrage (1975), which apparently increased from 0.35 ppt to 7.05 ppt in 2015. A continuously increasing relation has been observed in salinity with both the temperature and the position of sea level. Notwithstanding the inconsistency of rainfall data, an inverse relation was also noticed between salinity and rainfall, i.e., salinity increases with

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the decrease in rainfall. The relation between freshwater discharge at the Hardinge Bridge Point of the Ganges River and subsequent salinity in the Passur River has been compared establishing that the long-term gradual and abrupt decrease in discharge has a direct impact on the increasing trend of the salinity of this River. On the basis of foregoing results and observations, an attempt has been made to generate an equation that may predict the future scenarios of the salinity, temperature and sea level changes for 2050. Nevertheless, a minor disparity in the data of various parameters, it may be concluded that the salinity, temperature and the sea level will be increased significantly in the near future. From the present findings, an immediate measure has to be taken to overcome the possible adverse impacts of the inevitable climate change.

Keywords: Bangladesh; river salinity; climate change; sea level rise; Ganges discharge; Farakka diversion; coastal vulnerability.

1. INTRODUCTION

Bangladesh, being a deltaic coastal country, is likely to be one of the most vulnerable countries of the world to salinity problem and consequent upon National Geographic [1], in the coming decades, Bangladesh ranks first as the most vulnerable nation to the impacts of Climate Change. From the past few decades, salinity encroachment in the coastal rivers has become a key concern in Bangladesh. The Passur River (feeds from the Gorai River which itself is a tributary of the River Ganges) is one of the major freshwater suppliers in the southwestern part. The river which is placed after the Meghna in size in the deltaic region is an important river route, and was active and carried sufficient water but now experiences severe drainage shortage in the dry season. Moreover, this river undergoes marked tidal influences, its water is saline throughout the year, but during the lean period, the concentration of salt is high [2]. The coastal belt of Bangladesh is characterised by excessive chloride concentration which exceeds the WHO drinking water standard (250 mg/L) and is unsuitable for drinking and even for irrigation [3]. For these reasons, the Passur River is chosen for this work.

With the diversion of freshwater in the upstream boundary, salinity has been started to accelerate sharply over the period in the coastal zone of Bangladesh. The level of river salinity was below 1 ppt in this part before 1975 whereas, at present the level of river salinity remains above 20 ppt during the dry season [4]. In particular, salinity ingress is likely to be more acute in the future for two reasons: a) freshwater flows from rivers in the Himalaya are predicted to decrease during the dry season and, b) the sea level rise [5]. The reduced flow of the distributaries of Ganges, especially in the Gorai, has an adverse effect in the Southwest part, particularly in the greater Khulna and climate change aggravates the problem by sea level rising [6]. There are robust evidences that sea levels have risen as a result of climate change based on observation from tidal gauges, paleo-indicators and satellite measurements [7]. This critical factor makes deltaic regions particularly vulnerable [8]. Sea level rise is caused by two processes: thermal expansion (ocean water expanding as it heats up) and additional water flow into the oceans from the polar ice cap melting. Both of these processes are currently being monitored [9]. In the coastal region, sea level rise results in saline water intrusion in the estuaries and groundwater which governs the availability of freshwater when the upstream flow is low. The effects are exacerbated by greater evaporation and evapotranspiration rate of freshwater as temperature increases [10].

This paper contains the salinity condition of the Passsur River form a long time when it was inconsiderable. A few Journals, scholarly articles, existing literature that are related to the present study have been extensively reviewed to provide a guideline and to recognize the works that are involved with the salinity of Bangladesh. Although different national and international authors' published various reports or surveys about river salinity and its consequences on agriculture, fisheries and livelihood of the coastal people, only a little work was made regarding the Passur River salinity associated with climatic factors and Ganges discharge. Salinity analysis of Sibsa-Passur and Rupsa- Passur were carried out by Md. Nazim Uddin et al. in [11] and by Shihab Hossain et al. in [12] respectively. Another thesis report is available that provided information about the state of surface water salinity that covers the entire southwestern river system including Passur. Here, different statistical analysis, mathematical model, hydrodynamic model and salinity model had been used by the author [4]. A research paper of Susmita Dasgupta under the World Bank Group focused on river salinity, and climate change is useful for the current study [13]. All the findings reveal that the salinity rate of the coastal rivers is increasing without any doubt.

According to a report of Intergovernmental Panel on Climate Change; 2007 [14], by the year 2050 temperature will increase more than 1.8°C and sea level will rise about 32 cm than the present. As a result, more than 20% of southern Bangladesh will be submerged by saline water [15]. Under such an alarming situation, it is most necessary to determine the magnitude of salinity encroachment due to climate change and to come forward to save the natural environment as well as people of South Western Bangladesh.

In this project work, an attempt has been taken to assess how salinity of the Passur River is governed by the volume of upstream freshwater discharge at Hardinge Bridge, local rainfall of Khulna, the strong tidal currents and sea level rise at Hiron Point, Bangladesh.

The specific objectives of the present study are

1. To determine the salinity levels.
2. To determine the relationship between climate change variables (temperature, rainfall), sea level rise and tidal effects with the salinity of the Passur River water.
3. To establish a relationship between the Passur water salinity and upstream freshwater discharge from the Ganges.
4. To delineate the future projections of salinity encroachment, sea level and temperature.
5. To find out a possible solution to overcome the problems related to salinity.

2. MATERIALS AND METHODS

2.1 Study Area

This study was carried out in the Passur River (104 km long) of Mongla within the Bagerhat district of Khulna division, Bangladesh (Map 2.2). The study area (21°49'-22°33' N and 89°32'-89°44' E) borders Rampal Upazila on the north, the Bay of Bengal on the south, Morrelganj and Sarankhola Upazilas on the east and Dacope Upazila on the west. Mongla, which has a population of 137,947 is covering 1461.22 km^2 of land. The weather in the port area is tropical with the temperature range of 80°C to 40°C and humidity range of 50% to 95% in both winter and summer respectively. This portion of the Bay of Bengal is trending to the southern part of Bangladesh and is characterised by sea level fluctuation, tidal channels and high chloride engrossment. Mongla is known as the second biggest seaport of Bangladesh which is located 48 km from the city of Khulna and lies 62 km north of the Bay of Bengal coastline. The distance of Mongla from Hiron Point is 76.7 km. Few rivers are crisscrossed through this area, among them, Passur is very important that receives freshwater through Gorai River.

2.2 Data Collection

The study was conducted mainly based on secondary data sources. The climatic data (rainfall and temperature of Khulna) for the period of 1981 to 2015 was collected from the Bangladesh Water Development Board and the world weather website [18]; different hydrological data was gathered from various sources to understand the baseline condition; salinity of the Passur River at Mongla point for the period of 1962 to 2015 was collected from BWDB, Sea water level data of Hiron Point for the year 1980 to 2015 was received from Bangladesh Tide Gauge, discharge of Ganges River at Hardinge Bridge area for the year 1962 to 2015 was gathered from both BWDB and IWM (Institute of Water Modeling), and tidal effect of the Passur River for the period 1980 to 2015 was collected from Bangladesh Tidal Chart. The further necessary secondary data was also used from the online publication, website, different books, government and international reports, maps, scientific journals, research thesis and news articles etc. Salinity ranges have been forecasted from the period of 2016 to 2050.

The collected data accuracy ware then carefully examined and verified before using for trend and correlation analysis. To quantify the relationship between the salinity level in this river (dependent variable) and different independent variables, a variety of statistical techniques including multiple linear regression, bivariate regression, correlation have been used. Regression analysis was computed to show the relationship status of the dependent variable (salinity) with the independent variables (river discharge, tidal level and, local temperature and rainfall). All the data processing and analysis were done using GIS, SPSS (Statistical Package for the Social Sciences) software, MS Excel etc. The trend lines were drawn using MS Excel to show the changes in salinity and other climatic and hydrological factors. The statistically significant differences between the variables were carried out by ANOVA Test, and the linear correlation between two variables was studied using Pearson's correlation coefficient in SPSS.

Fig. 2.1. South western part of Bangladesh [16]

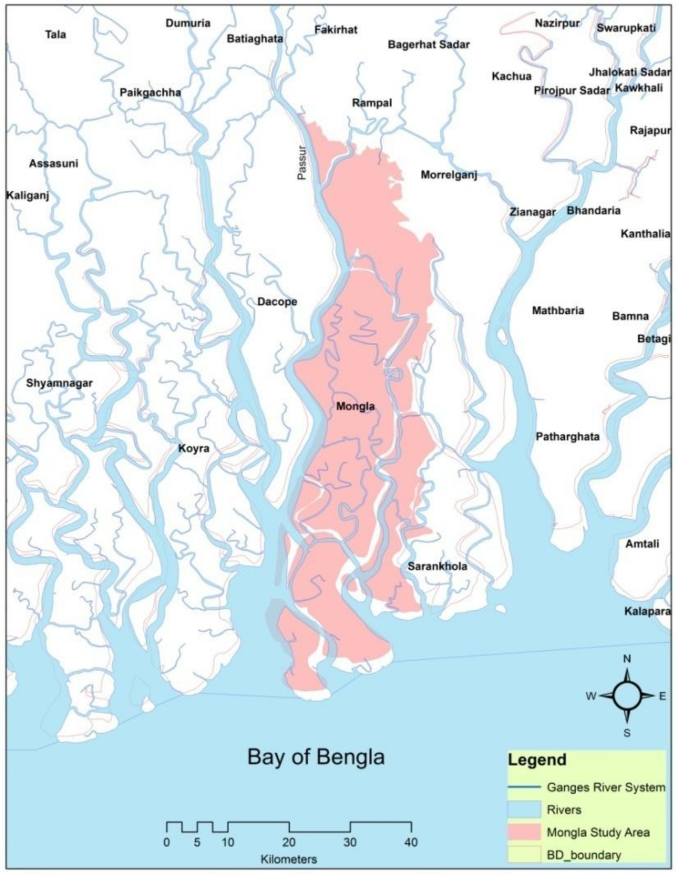


Fig. 2.2. Location map of the study area

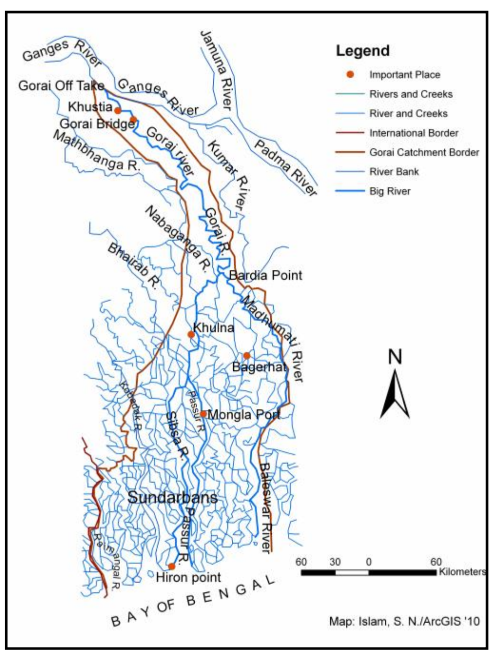


Fig. 2.3. River network map of the southwestern zone of the coastal area [17]

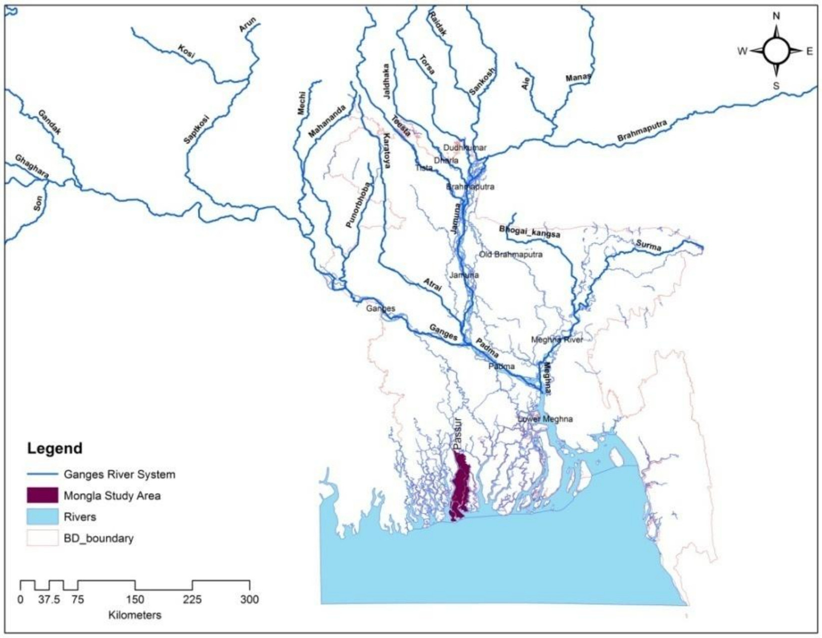
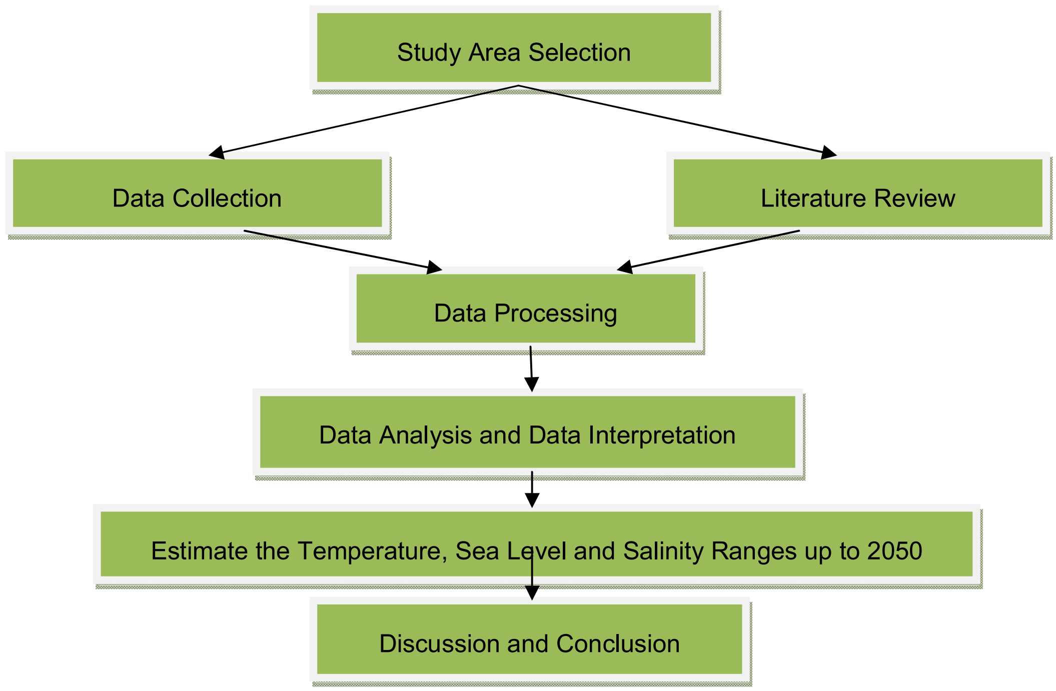


Fig. 2.4. Ganges to Passur drainage map

Fig. 2.5. Land use-Land cover map of the study area

2.3 Methodology



3. RESULTS AND DISCUSSION

3.1 Salinity of the Passur River

Spread and intensity of salinisation in the coastal regime is a threatening issue for the recent time. Salinity data of the Passur River system at Mongla point was investigated for both before and after declination of Ganges River water level. It expresses a sturdy association between salinity-river discharge and salinity-rainfall in the Passur River but others are not much strongly related. The amount of precipitation and force of upland freshwater through the Gorai-Madhumati maintains the salinity condition of the southwestern part by opposing away the saltwater front. It has been observed that river water salinity augmentation occurs with the increase of time. The salinity trend was tolerant (from 0.11 ppt to 0.35 ppt) at Passur-Mongla point until 1975 just before the construction of the Farakka Barrage (Fig. 3.1.1). The Ganges outflow during the lean (January-May) period has been reduced more than a quarter since the commissioning of the Farraka Barrage in the Ganges River which is outside of Bangladesh. This acute shortage of fresh water in the southwest region leads to instant salinity intrusion, and eventually, in 2015, salinity was 7.05 ppt. This observation clearly affirmed the potential contribution of rainfall and river discharge over the vast southern areas of Bangladesh.

The line graph delineates the amount of salinity of the Passur River at Mongla point for more than five decades since 1962 (Fig. 3.1.1). The quadratic equation $y=0.002x^2-0.008x+0.223$ shows that salinity increase with time and the coefficient of determination ($R^2=0.995$) is high, so a high percentage of variation of y is feasible to determine since its value is near 1. Here, the positive slope means the value of y increases as the value of x increases.

The regression results indicate that the test is highly significant, $F\ (1.52)=418.508$, $p< 0.05$, $R^2= 0.889$.

3.2 Tidal Effect and Salinity of the Passur

3.2.1 Monthly Tidal Effect and Salinity Relationship

The double line graph in the Fig. 3.2.1 gives information about the yearly tidal activity of the Passur River and salinity over a time span of 35 years starting from 1980, which depicts a slight increase in high tide. The Passur is a tidal river of the south-west region of Bangladesh. The Bay of

Bengal functions as an origin of salinity in the coastal estuaries. This coastal area lies at 0.9 to 2.1 meter above the mean sea level which suffers seriously from tidal flooding. In Mongla region, salt intrudes into the Passur River from the ocean through tidal effects, mixes with fresh water and makes it saline during low tides, it falls into the sea. The regression results indicate the test is collectively significant, $F (2.33) = 107.286$, $p<0.05$, $R^2= 0.867$.

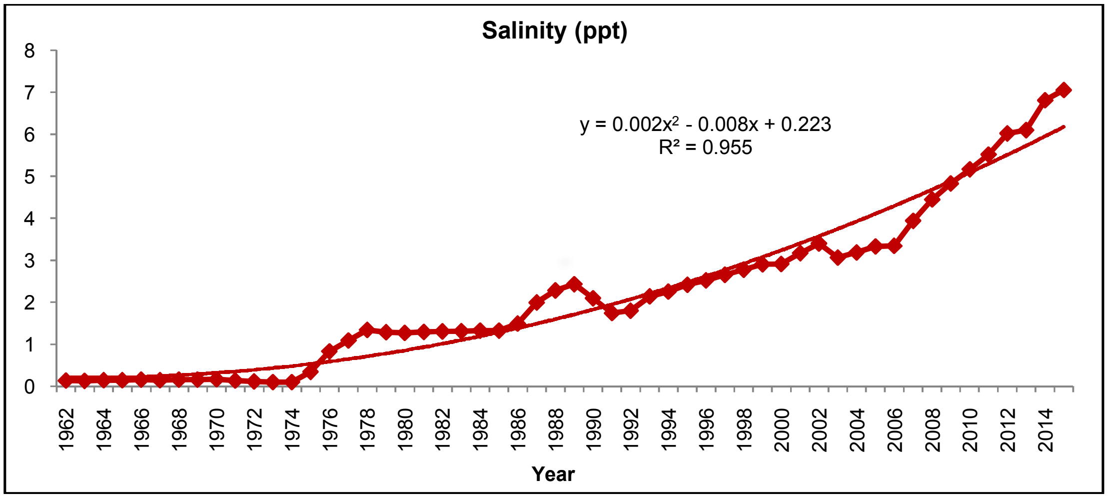


Fig. 3.1.1. Historical salinity of the Passur River at Mongla (From 1962 to 2015)

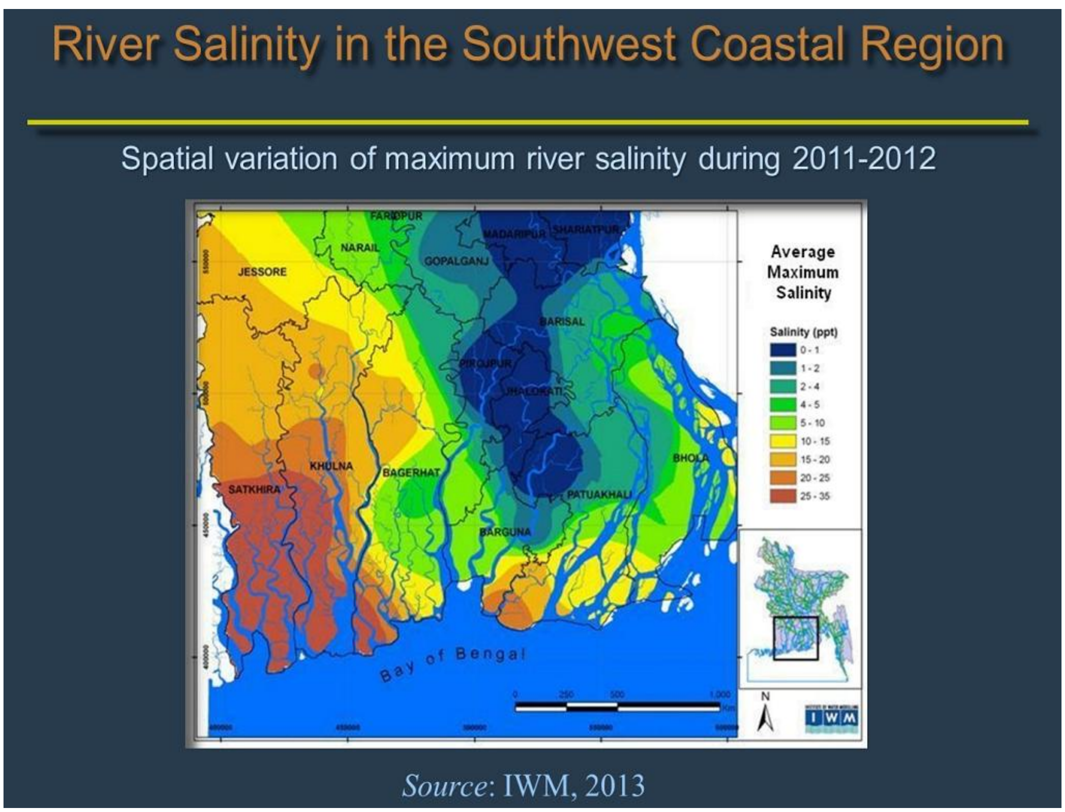


Fig. 3.1.2. Salinity of coastal rivers (Source: IWM)

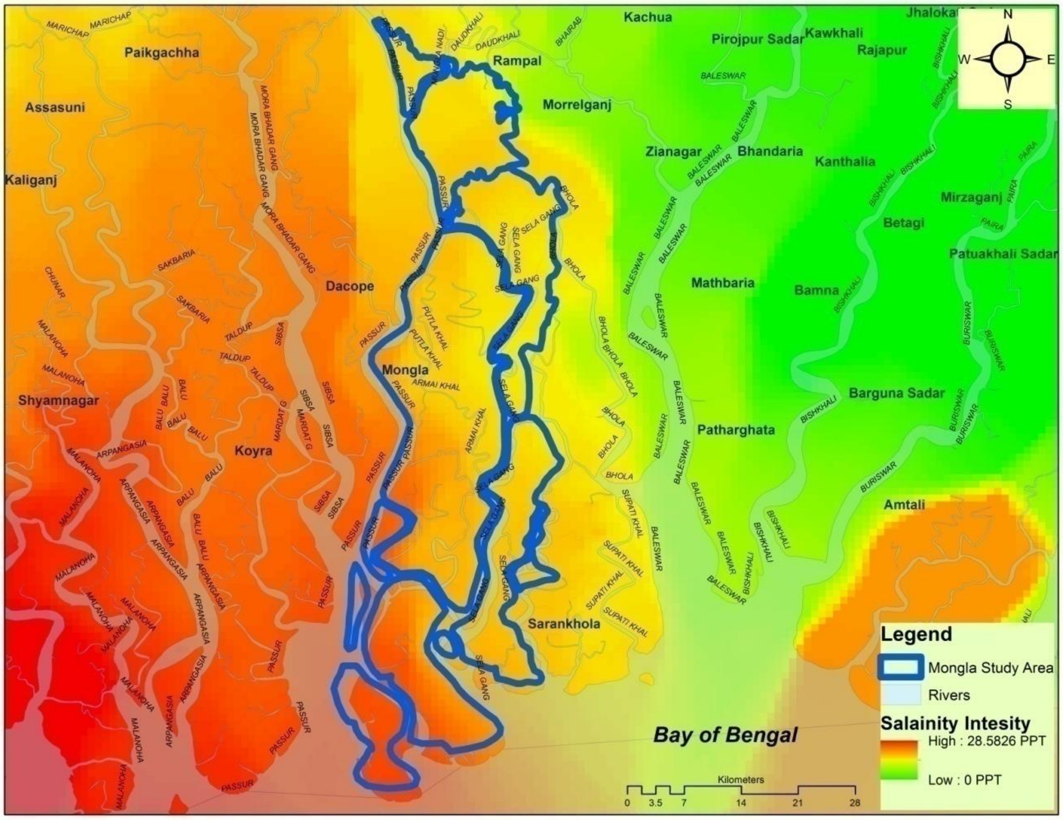


Fig. 3.1.3. Salinity of the study area for the year 2015

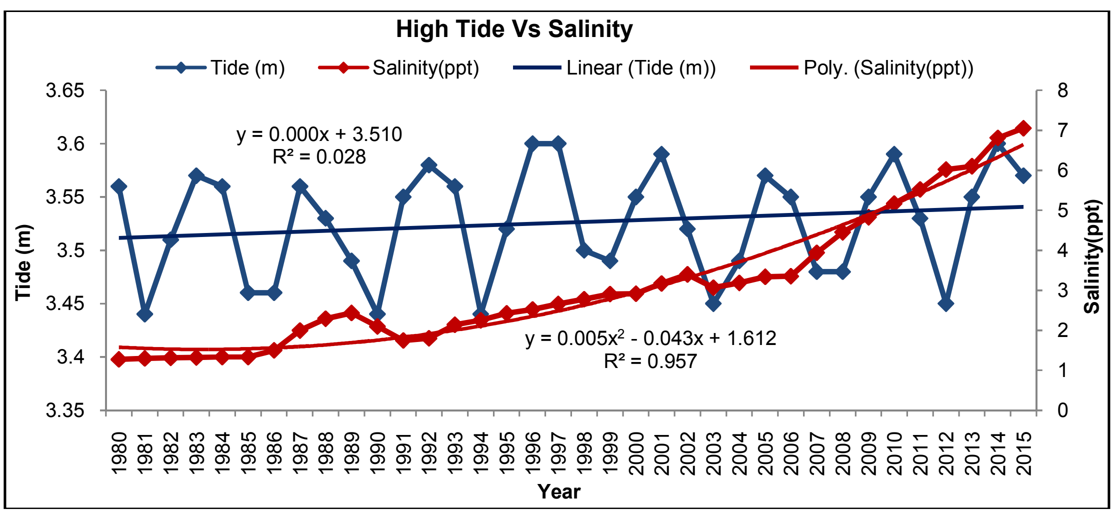


Fig. 3.2.1. Yearly high tide versus salinity at Passur River (From 1980 to 2015)

And the other Fig. 3.2.2 represents the relationship between salinity and monthly high of 2012. The annual relation between high tide and salinity gives evidence that higher salinity (up to 20 ppt) starts to increase from January and reaches its peak in May and though the magnitude of the tide was high, with the advent of monsoon it starts to recede. Nevertheless, the ascendant sea water is proceeding tidal flooding more roughly with time. When rainfall and freshwater flow decreases, this progressive tide can make the situation worse. The regression results indicate that the model is not statistically significant, F (2.9).= 1.881, p= 0.20, R^2= 0.295.

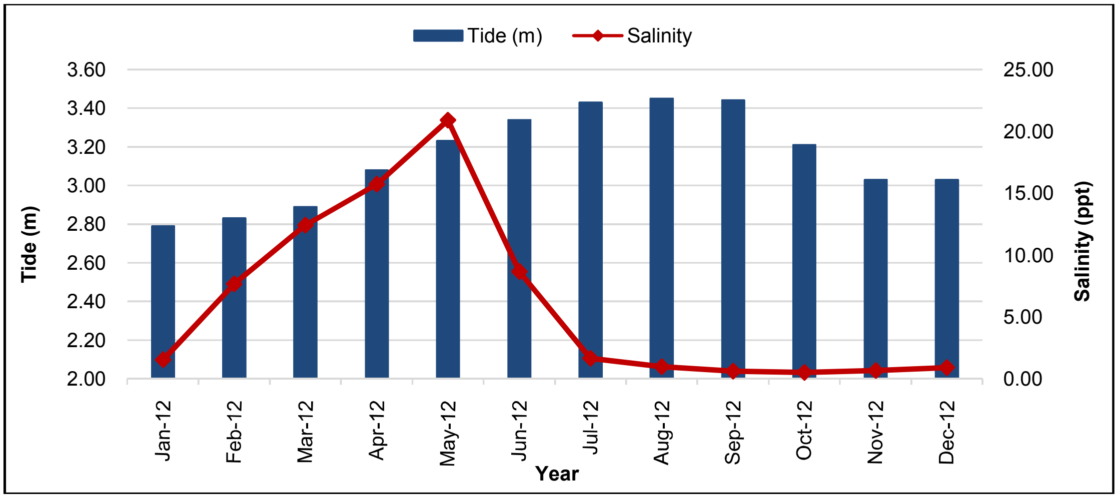


Fig. 3.2.2. Monthly maximum high tide versus salinity relationship (For the Year 2012)

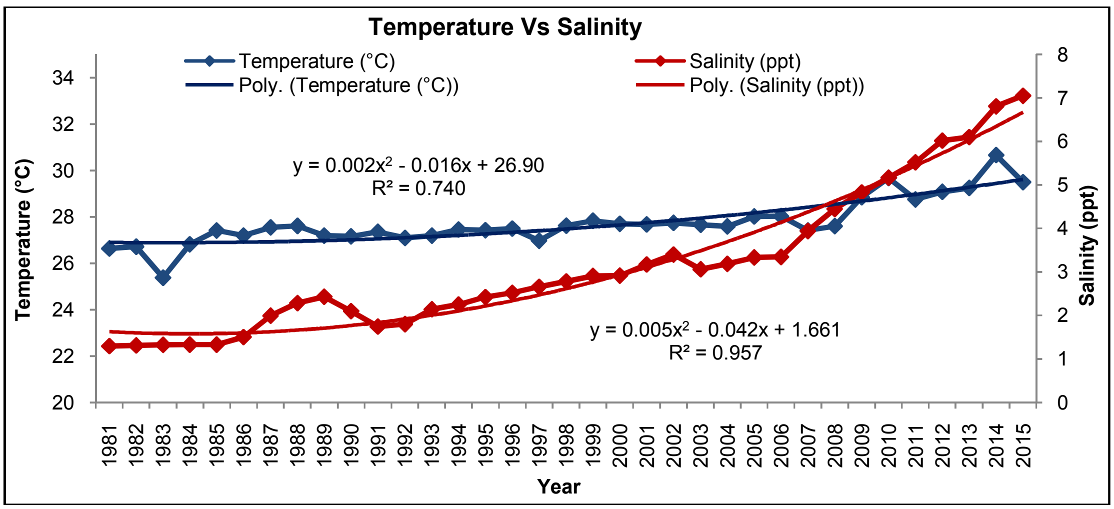


Fig. 3.3. Historical average temperature of Khulna versus salinity of the Passur River (From 1981 to 2015)

3.3 Temperature and Salinity

The above figure compares salinity with the temperature data. With a minimal fluctuation, the overall trend line of average temperature shows a thriving pattern. The quadratic equation $y=0.002x^2-0.016x+26.90$ (for temperature) shows the relationship between the temperature and time with an R^2 value of 0.678 which indicates that a moderately large amount of variation of y can be explained.

According to the figure, it is obvious that a relation exists between local temperature and the salinity of the Passur River. In both cases, the positive intercept value indicates that both have been increased simultaneously. In 1981, salinity was 1.30 ppt and temperature was 26.64^{0}C and within the next 34 years, salinity and temperature were 7.05 ppt and 29.50^{0}C respectively. The regression results indicate that the change is collectively significant, F (2.32) = 182.043, p<0.05, R^2= 0.919.

Actually, rapid enhancement of the salinisation process is caused by climate change through sea level rise and increased evaporation from higher temperature. Evaporation starts increasing from February and attains its peak in May when maximum temperature is attained.

3.4 Rainfall and Salinity

Rainfall is considered to be a climatic factor which immensely controls the state of salinity. Historical rainfall analysis indicates that over the period rainfall pattern has changed both in magnitude and distribution, providing possible evidence of climate change which influences salinity. Moreover, it is proven that salinity occurs due to the lack of frequent rainfall and the degradation of river flow in the dry season, which is also dominated by rainfall runoff. However, both rainfall and evaporation affect the volume of salt, but they do not change the amount of salt.

The trend line of annual rainfall with a negative gradient implies a decreasing tendency. However, the rainfall in Khulna fluctuated significantly from 1981 to 2009, and from then it reduced steeply. The negative value of the slope indicates that the value of y decreases as the value of x increases. Here, the equation is -13.917x+1964.7 with an R^2 value 0.128 which indicates that a very few variations are possible to predict by the variation of x. Results of the Pearson correlation indicates that there is a significant negative association between salinity and rainfall, r (33) =-0.488, p<0.001.

The regression results indicate that the test is statistically significant, F (2.32) = 135.244, p <0.05, R^2= 0.894.

3.4.1 Monthly Rainfall and Salinity Relationship

The combination of line and bar graph illustrates an opposed relationship of salinity with local rainfall for 12 months. The Passur River is mainly fed by the local rainfall and spill from the Ganges. A simple relationship has developed from the figure of the annual rainfall versus salinity of the Passur River which pointed at a strong converse correlation between salinity and local rainfall. The analysis represents that a decrease in salinity of the Passur River was caused by the heavy rainfall. In the dry season when rainfall fluctuated between 0.3 mm and 80 mm, salinity was higher than 20 ppt and during the monsoon, with the increase in rainfall and rising river stages, salinity level dropped down sharply. As a result, in the wet period, the distribution of salinity near the shore area is generally lower than the lean period. In an average 75% to 80% of the annual rainfall occur during the monsoon period with steady rain whereas about 10% to 15 % of rainfall occur during both the summer and winter period.

The regression results indicate that the test is not statistically significant, F (2.9) = 1.795, p= 0.22, R^2= 0.285.

3.5 Sea Level and Salinity

From the Fig. 3.5, it is apparent that salinity has a direct and drastic relationship with sea level change. The height of the sea level at Hiron Point increased markedly since 1980. The straight line equation y= 4.288x-17.01 (for sea level) shows the relationship of sea level height with time where a coefficient of determination (R^2= 0.604) depicts a fairly decent model for the sea level values. The regression results indicate that the test is statistically significant, F (2.17) = 59.549, p <0.05, R^2= 0.875.

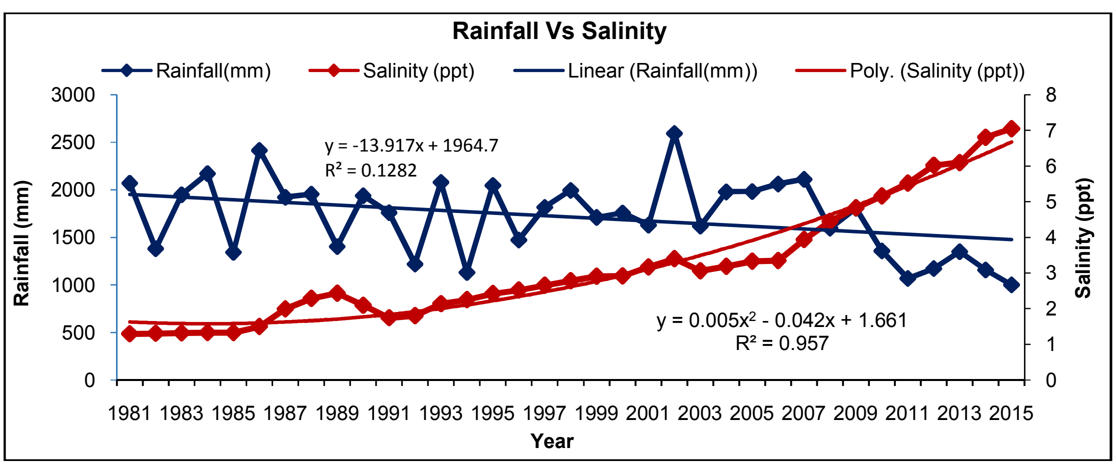


Fig. 3.4.1. Annual rainfall of Khulna versus salinity of the Passur River (From 1981 to 2015)

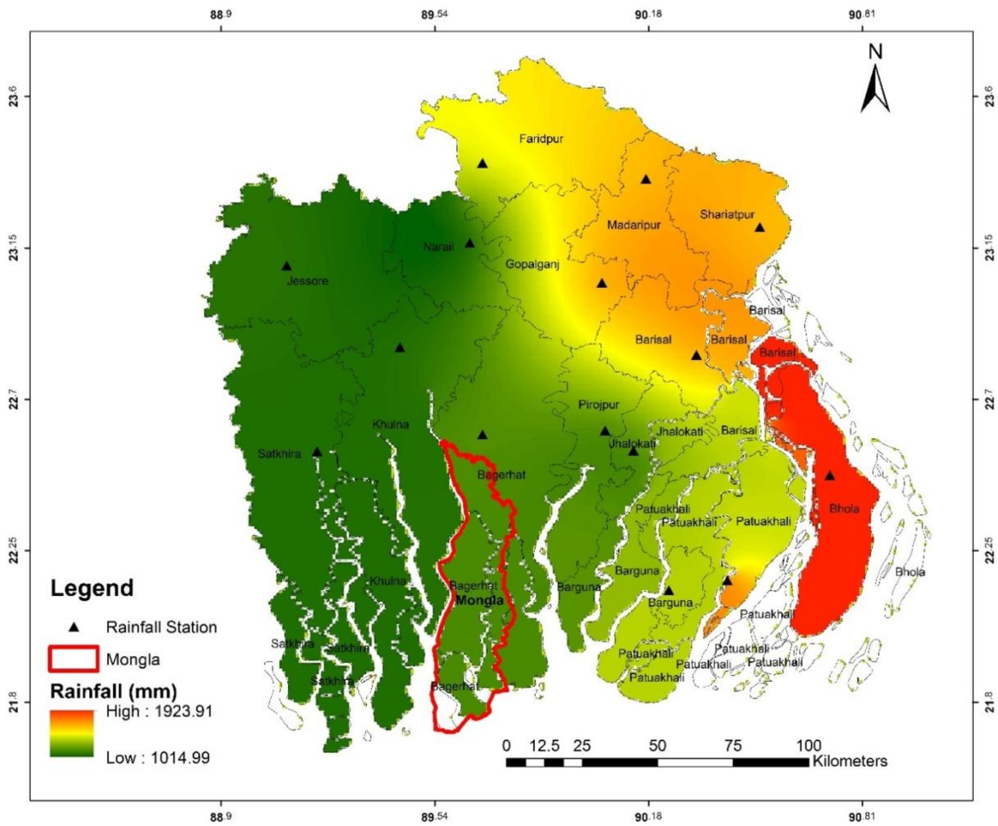


Fig. 3.4.2. Rainfall Distribution map for 2011-2012

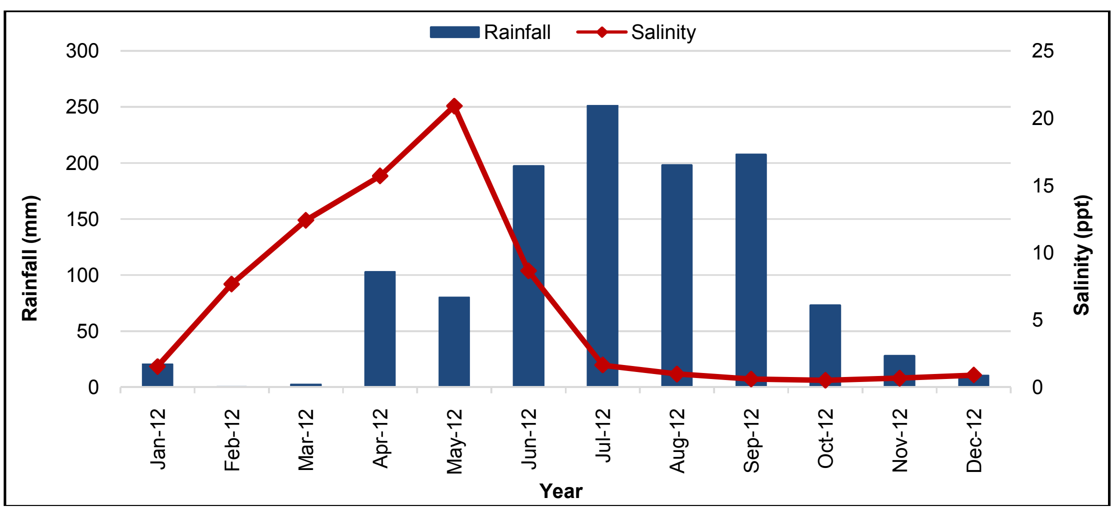


Fig. 3.4.3. Monthly Local Rainfall versus Salinity Relationship (For the Year 2012)

The most manifested effect of climate change is increasing saltwater intrusion that possesses a great threat for the coastal people by diminishing freshwater availability. Exacerbation of salinity depends on the distance from its location to the seashore. As the sea level increases, saline water starts to penetrate in coastal rivers being drained by tidal flow. Sea level rise in Bangladesh has been estimated to be higher than global sea level rise [14]. From the coastline, salt water is evident to have traversed more than 100 km towards the inland along tributary channels during the dry season and the current seawater pace will increase it more upward. Nearly 18% of the total land area in Bangladesh would engulf with just a 1m rise in sea level [14].

3.6 Ganges Discharge and Salinity

The southwestern region has been strongly invaded by the reduced flows of the Ganges because rivers of this area originated largely from this mighty river. The average flow of the Ganges at Hardinge Bridge (inside Bangladesh) in the pre-Farakka period was 11,690 m^3/sec (Fig. 3.6.1). The minimum flow takes place in March to May and currently, with the drainage failure, it gets down to a few hundred m^3/s. This exhibits some irregular flow direction which has given rise to the level of river salinity in the coastal belt of Bangladesh. This figure shows how average salinity at the south-west region of Bangladesh started to increase based on upstream diversion. The absence of freshwater force approves the salinity to encroach farther inland.

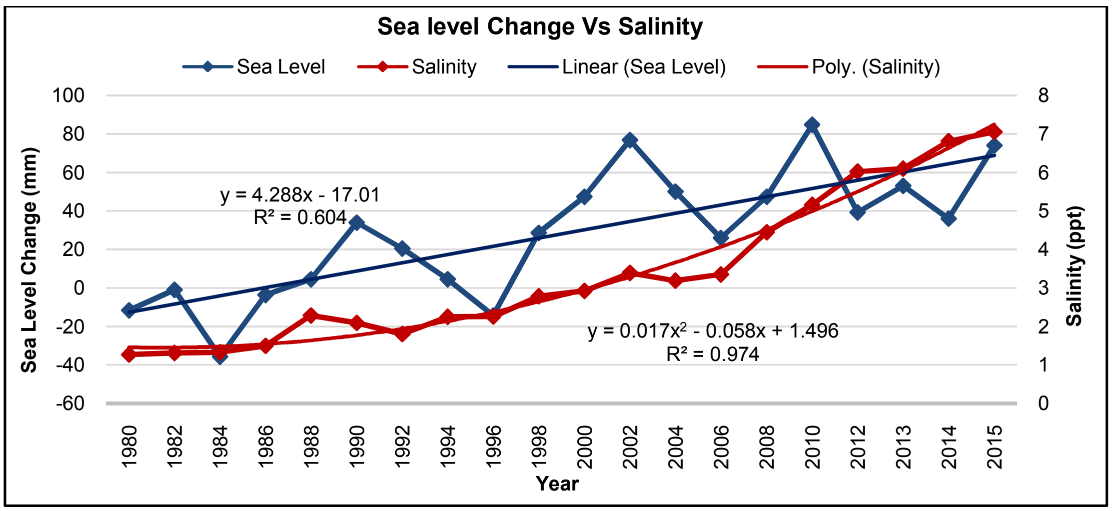


Fig. 3.5. Sea level change at Hiron Point versus salinity of the Passur River (From 1980 to 2015)

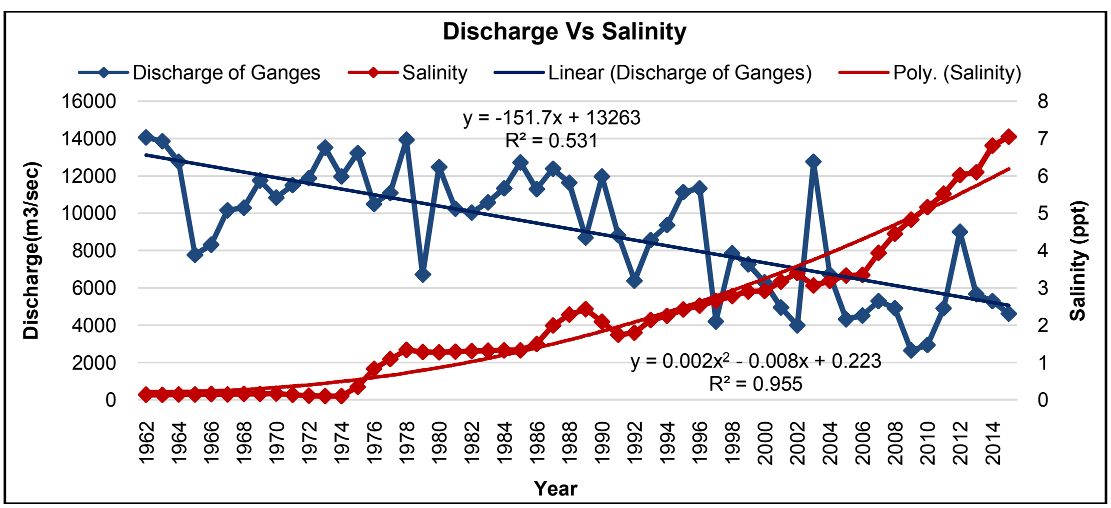


Fig. 3.6.1. Average discharge of the Ganges at Hardinge bridge versus salinity of the Passur River (From 1962 to 2015)

The above figure demonstrates a comparison between the amount of freshwater discharge from the Ganges River and the salinity of the Passur River. Here, the straight line equation y=-151.7x+13263 (for discharge) evidently shows the relationship between the dependent and the independent variables where the negative value of slope indicates that the discharge is declining as the time has passed. The value of R^2 (0.531) for discharge was moderate, so more than half of the variation of y can be interpreted by this linear relationship.

It can be seen that the apparent variations in the river salinity are linked with the alterations in river flow volume. In previous years, salinity concentration was normal of the rivers that receive a freshwater input, but currently, this flow dropped down at a dreadful rate. The regression results indicate that the test is collectively significant, F (2.51) = 208.089, p <0.05, R^2= 0. 891. So, the salinity of the Passur River is strongly correlated to the discharge, and it fluctuates based on the freshwater availability.

3.6.1 Monthly Discharge of Ganges and Salinity Relationship

The monthly distribution of salinity and discharge has shown how discharge conflicted with salinity throughout 2012. As the salinity level in the Passur River is greatly influenced by the upstream river discharge, mainly the Ganges River, they both maintain a strong relationship. It can be seen that in the first month of 2012, the salinity level stood at 1.54 ppt then it started to rise almost linearly to reach about 20.9 ppt in May. The upward trend suddenly broke and fell dramatically over the next two months until 0.98 ppt. The number plateaued between 0.61 and 0.91 ppt from September to December. To sum up, it is well observed that when the flow of fresh water was ceased, the salinity of the Passur River at Mongla was high and from June, discharge increased as a result salinity levels were at the minimum because freshwater forced the saline water to back the ocean.

Here, The regression results indicate that the model is not statistically significant, F (2.9)= 2.946,
p =0.10, R^2= 0.396.

3.7 Future Projections: Up to the year 2050

Future Projections of Salinity of the Passur River, Temperature and Sea Level Rise in Southwest Coastal Area for 2050:

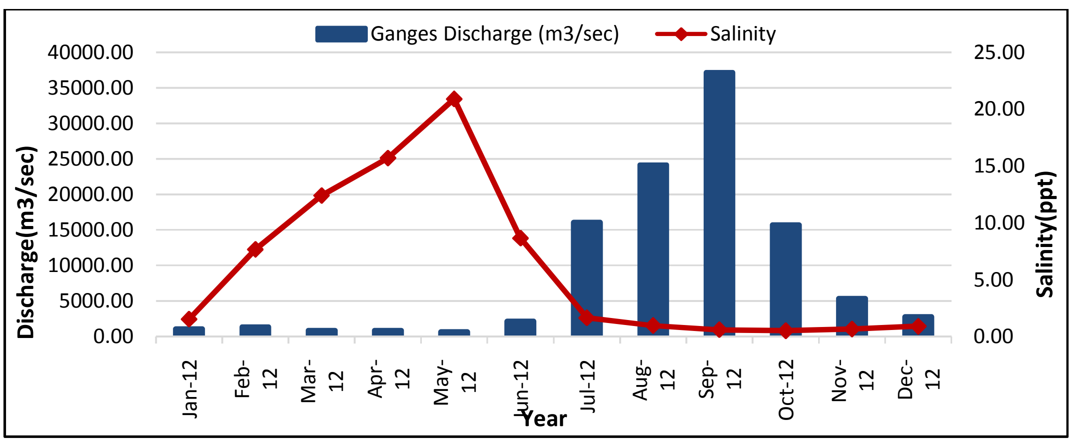


Fig. 3.6.2. Monthly Ganges discharge versus salinity relationship (For the Year 2012)

3.7.1 Projection for salinity

Coefficients[a]						
Model		**Unstandardized coefficients**		**Standardized coefficients**	**t**	**Sig.**
		B	**Std. error**	**Beta**		
1	(Constant)	-221.627	10.941		-20.256	.000
	year	.113	.006	.943	20.457	.000

a. Dependent Variable: Salinity (ppt)

Here, y-intercept is -221.627 and slope is .113. From the regression analysis, estimated salinity for 2050 is 10.023 ppt.

Prediction equation is based on a correlation where salinity and time are strongly correlated, r=0.943.

The future (2050) salinity of the Passur River at Mongla will increase above 10 ppt that is mesohaline or highly saline, whereas present (2015) salinity is 7.05 ppt (moderately saline).

3.7.2 Projection for temperature

Coefficients[a]						
Model		Unstandardized coefficients		Standardized coefficients	t	Sig.
		B	Std. error	Beta		
1	(Constant)	-131.863	19.120		-6.897	.000
	Year	.080	.010	.824	8.348	.000

a. Dependent Variable: Temperature (°C)

Here, y-intercept is -131.863 and slope is .080. From the regression analysis, the estimated temperature for 2050 is 32.14°C

Prediction equation is based on correlation where temperature and time are strongly correlated, r=0.824.

The future (2050) temperature of Khulna will increase to 32.14 ^{0}C where present (2015) temperature is 29.5°C.

3.7.3 Projection for sea level

Coefficients[a]						
Model		Unstandardized coefficients		Standardized coefficients	t	Sig.
		B	Std. error	Beta		
1	(Constant)	-4460.673	839.793		-5.312	.000
	Year	2.246	.420	.783	5.345	.000

a. Dependent Variable: Sea Level

Here, y-intercept is -4460.673 and slope is 2.246. By using simple linear regression, the estimated sea level rise for 2050 is 143.627 mm.

Prediction equation is based on correlation where sea level rise and time are strongly correlated, r=0.783.

The future (2050) sea level rise at Hiron Point may reach approximately 143.627 mm where present (2015) sea level rise is 74.00 mm.

Table 3.7. Comparison of future projection (2050) of salinity, temperature and sea level with the baseline and present (2015) scenario

Future Projection for 2050								
Salinity (ppt)			Temperature (°C)			Sea level (mm)		
Base 1962	Present 2015	Future 2050	Base 1981	Present 2015	Future 2050	Base 1980	Present 2015	Future 2050
0.14	7.05	10.023	26.64	29.50	32.14	-11.61	74.00	143.627

In general, some points are clear from the observation that salinity is constantly increasing in coastal rivers because this area is less elevated from the sea level, scarcity of freshwater discharge have seriously affected on a monthly basis by upstream river flow, rainfall and tidal effect. The reduction in the mean monthly discharge of the Passur River is a result of deliberate withdrawal of the Ganges water at Farakka and the environmental impact of this downcast flow is very serious regarding increased salt-water intrusion in the coastal area which has significant adverse effects on the agriculture and fisheries, infrastructure, forestry, industry, human health and drinking water sectors.

Overall, the findings have reported that the climate change phenomenon will cause considerable changes in river salinity in the southwest region of Bangladesh especially during the dry season (November to May) by 2050. According to IWM, for domestic purposes, the salinity of water should be within 1 ppt and for crop production 4 ppt. But now the river salinity is far beyond that. As a result, the requirement of fresh drinking water has become a serious issue for the people of coastal areas.

The key visualisation of this study is that the combination of climate change and reduction in freshwater inflow from the upstream will convert the present freshwater zones into saline zones and lower saline zones into more saline zones. Both environmental and anthropogenic factors are accountable for thriving sea water. However, the outcome of the diminishing freshwater flow will be greater than the impact of climate change on the south-western portion.

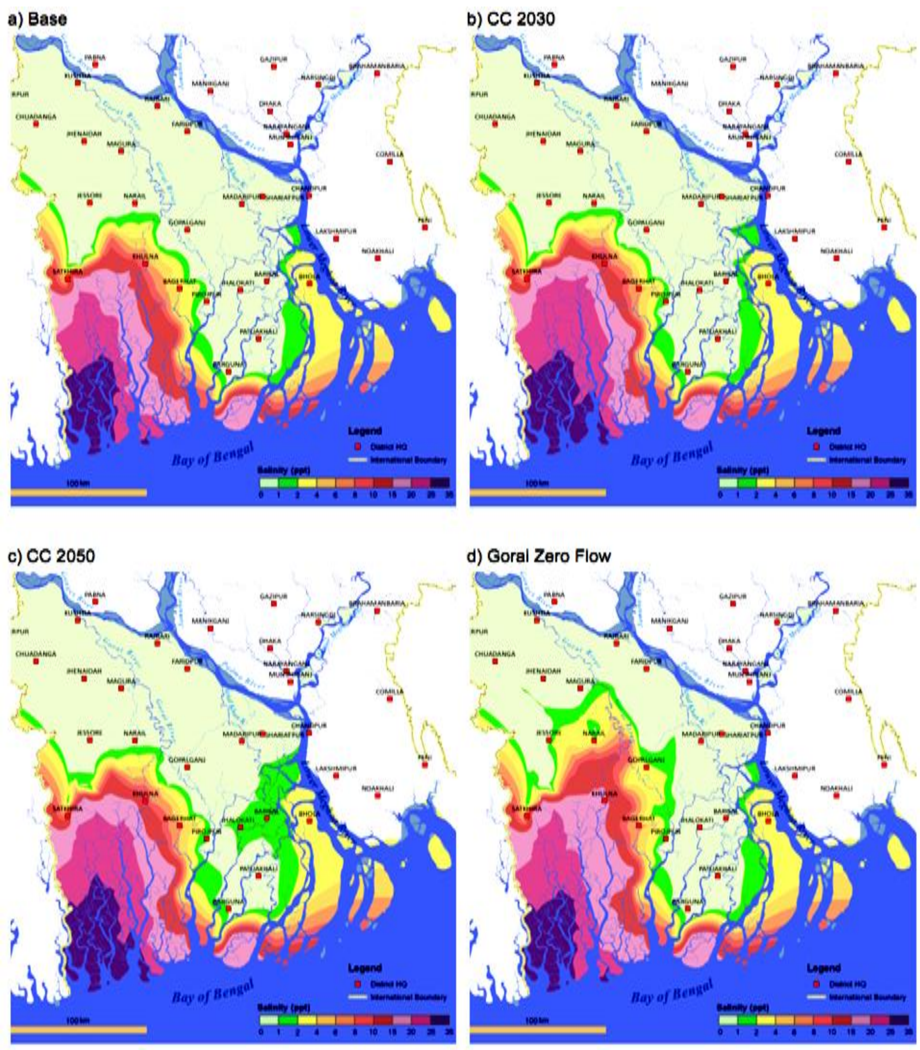


Fig. 3.7. Future projection of salinity in the Southern Area [19]
(Baseline Year 2000)

4. CONCLUSION

The country has already been facing several natural disasters which are seriously affecting the ecosystems and the socio-economic schemes in the coastal area. For example, cyclones are the common phenomena that are increasing due to climate change because their origination relied on sea surface temperature. Bangladesh faced the devastating cyclone storms in 1970, 1991, 2007, 2009 and in 2016 which have created enormous economic and social deprivation for the rapidly flourishing population in the coastal area and make the woodland, its inhabitants and natural resources more fragile for further destruction [20]. However, cyclones are considered as another cause for increased salinity. The intensity and duration of cyclones have been redoubled which conduces landslide and occur tremendous amount of salt water to intrude landward through estuaries. This significant volume of salinity has the deadliest effect on the livelihood and socio-economic life of the people living in Mongla. They have taken agriculture as the source of improving their lifestyle, but now they are experiencing an extreme deficiency in crop yield. In Mongla Upazila, Aman crop area fell 30 per cent to 14,925 acres in 2008 from 21,350 acres in 1996, according to Bangladesh Bureau of Statistics [21]. With the sea level rise, Bangladesh is going to lose a huge portion of its grazing field which will put down the rice and wheat production by 10% and 30% by the year 2050 [14]. Besides making harvesting difficult, high salinity hampers livestock and milk production, trees and plants, create food insecurity, contaminate water and agricultural lands, damage valuable resources, ecosystem and biodiversity. Coastal people are dependent on natural resources for their subsistence, and these damages exaggerate unemployment problem, impoverishment, lack of literacy and malnutrition. All these crisis eventually impose great health risk for human. Respiratory problems are prominent together with waterborne diseases due to declining vegetation in this area. Moreover, pregnant women and children are the worst sufferer. Collection of drinking water is a burden for them and it has major influences on the socioeconomic status of local people. Salinisation declines soil fertility, that's why farmers have converted their livelihood from crop cultivation to shrimp cultivation, a rapidly developing profitable business. Though salinity is suitable for shrimp farming, it is a serious threat to the diversity of freshwater fish. Shrimp cultivation increases salinity in ponds as it retains saline water in freshwater bodies. The Passur River was ecologically balanced, hygienic and rich in marine habitat. Being influenced by sea water, some inland freshwater species are likely to be disappearing gradually. Also, the freshwater fishing area is decreasing with the increasing sea level which leads to serious damage to the fisheries sector of Bangladesh. Besides this, increased water temperature is not convenient for many species, for instance, oxygen becomes insoluble, and fish physiology is severely affected by high temperature.

To diminish their adverse impact, both adaptation and mitigation are needed to be considered as a solution. Adaptation requires minimising the negative impacts and hazards caused by sea level rise in living organisms, including human life, property and the environment. To cope with this problem people have to understand the changes in detail. For this, it is utmost necessary to regulate salinity trespass and monitor salinity levels along the coastal belt of Bangladesh. However, using proper embankments and coastal polders can resist the sea water to mix with pond and river water, thus protect freshwater species; implementation of policies like long-term land management approaches, re-excavation of canals, streams, and rivers can be the potential measure of adaptation; promoting public awareness programs among the people as an individual human being are highly appreciable that can make people realise the advantages of sustainable livelihood; food conservation and using rainwater harvesting method are significantly important for the farmers as well as to halt converting agricultural lands into shrimp cultivation lands which play a vital role to restrain the negative outcome of salinity intrusion; finally, to protect coastal people from disasters like cyclone, appropriate arrangement like construction of cyclone shelters and cyclone-resistant building can be taken. Other useful moves are to provide suitable training courses on proper scientific and technical skills, give an effective idea about the value of plants, health risk and hazards caused by global warming.

On the other hand, mitigation involves global endeavour where the main focus is to impede climate change and sea level rise by emission control. To combat with this problem, certain global exertions have been taken to discretion from the United Nations Framework Convention on Climate Change (UNFCCC) in 1992 to Kyoto Protocol in 1997 and Paris Agreement in 2015 where the main motivewas to strengthen the worldwide unity to lower the greenhouse gas emission, especially for the industrial countries. Neglecting this problem will prolong the chance of global warming and eventually the sea level rise, so all the countries should come forward to find a solution. Although Bangladesh ejects an insignificant amount of greenhouse gasses (<0.40%), the problems cannot be overlooked and instant steps should be taken to eliminate its emission. Bangladesh cannot afford enough technological appliances owing to its financial condition. In this situation, the government must seek help from the international organisations because it is a global problem, not local.

Bangladesh has a total of 230 rivers of which 54 rivers have originated in India and 3 from Myanmar. Among these trans-boundary rivers, The Ganges, the Brahmaputra and the Meghna are the major rivers which have a great impact on the habitat, morphology of the river bed, aquatic biodiversity, pollution control, flood control, nutrient and sediment load and also on the socio-economic environment of Bangladesh. In this situation, proper management projects for assignation and distribution of water from the Ganges including other common rivers should be considered by the Water Resources Ministers. It has always been rigorous for Bangladesh as the upstream states do not pay any attention because they are not the sufferers but to establish the rights of citizens, consultation with international judicial specialists is must who invoke for sustainable water arrangement and legitimate water allocation.

The study shows that more saline water intrusion will likely to occur during the dry season with the increased sea level rise by the year 2050. If the outflow of exaggerated gases were to keep in a static position, yet it is not likely to control sea level rise properly beyond 2100. With the continuation of SLR, the consequences of extended submersion will accelerate the salinity concentration around coastal areas. Now people should come forward to take some necessary steps such as, emphasise on salinity issues in International Forum; more investigation should be done in order to invent salt-resistant crop strains; identification of the plants that can grow in salty soil; storage of additional rainwater for irrigation purposes; development worldwide awareness about the damage caused by salinity as sea-level is rising; implementation of standard coastal embankments; the activities like deforestation and carbon emission should be discouraged and finally the upland freshwater flow must be increased.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history/26879