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Hydro-Meteorological Trends in Southwest Coastal Bangladesh: Perspectives of Climate Change and Human Interventions

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ABSTRACT

The southwest coastal region of Bangladesh, being under tidal influence and dependent on sweet water supplies from upstream, has a unique brackish water ecosystem. The region, having vast low-lying areas enclosed by man-made polders, is considered to be highly vulnerable to climate change induced hazards. In this study, linear trends in hydro-climatic variables, such as temperature, rainfall, sunshine, humidity, sweet water inflow and tidal water level in the region are assessed using secondary data and following both parametric and nonparametric statistical techniques. Correlation between the sweet water flow from the Gorai River, a major distributary of the Ganges River, and the salinity level in the Rupsa-Pasur River near Khulna, a southern metropolis, is also investigated. The results reveal that the temperature in the Khulna region is increasing at a significant rate, particularly in recent years. The number of extremely cold nights is decreasing and the heat index is increasing. The sunshine duration has a decreasing trend and the humidity has an increasing trend. Rainfall is increasing in terms of both magnitude and number of rainy days. However, the annual maximum rainfall and the number of days with high intensity rainfall have remained almost static. The annual maximum tidal high water level is increasing and the annual minimum low water level is decreasing at a rate of 7 - 18 mm and 4 - 8 mm per year, respectively. There is a negative correlation between the Gorai flow and the river water salinity around Khulna. Dredging of the Gorai during 1998-2001 resulted in an improvement of the salinity situation in the Khulna region. The variation in water salinity, tidal water level and sweet water flows in different time periods indicates that the human interventions through upstream diversion and coastal polders have contributed more in hydro-morphological changes in the southwest than the climate change. However, there are some evidences of climate change in the meteorological variables at Khulna.

Keywords: Trend; Hydro-Meteorology; Southwest Coastal Bangladesh; Salinity; Tidal Water Level; Human Interventions

1. Introduction

Bangladesh is a low-lying, deltaic country with sub-tropical monsoon climate. About 10% of the country is hardly 1 m above the mean sea level and one-third is under tidal excursions [1]. Most of the southern coastal areas (**Figure 1**) are within only 1 - 3 m of the mean sea level. The economy is predominantly agriculture based, and the poverty level is the highest in the area compared with other areas of Bangladesh. The Sundarbans, the world's largest mangrove forest and a Ramsar site, is located in the western part of the region. Khulna, the third largest city, with a population of about 1.5 million is also located in this region. The city has been identified as one of the 15 most climate change vulnerable cities of the world [2]. Cyclone, storm surge induced flooding, riverine coastal flooding, water logging, salinity intrusion and coastal erosion are the main climate and hydrologic hazards in the area. The cyclones "Sidr" in 2007 and "Aila" in 2009 caused widespread damage to property and havoc to people's livelihood. Commissioning of the Farakka Barrage on the Ganges River in India in 1975 has reduced the fresh water inflows to the region. Furthermore, construction of the coastal polders has gradually reduced the flood-plain storage areas for tidal waters from the Bay of Bengal. People have started migrating to the peri-urban and urban areas of Khulna as the opportu-

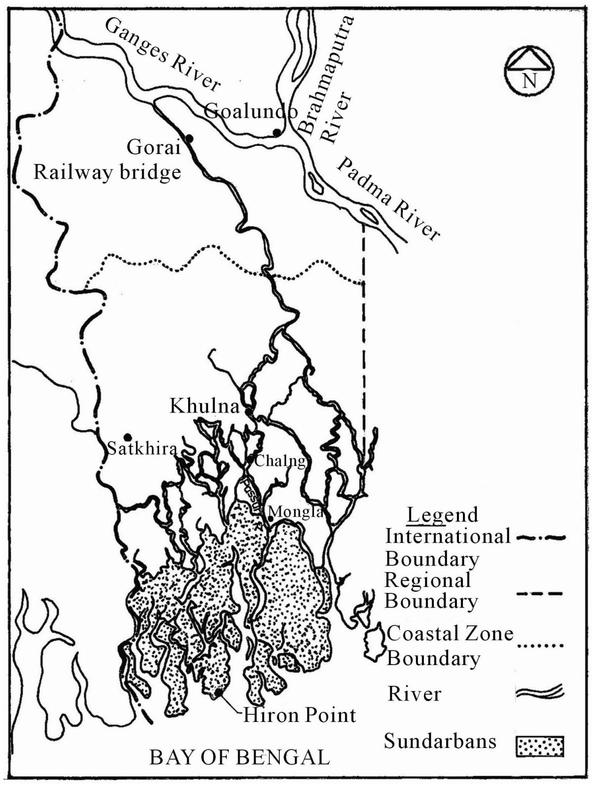

Figure 1. The southwest region of Bangladesh showing the coastal region, the Sundarbans, the Gorai River and the Rupsa-Pasur River.

nity for livelihood in rural areas have decreased due to climatic and hydrologic hazards.

Sea level is projected to rise between the present (1980-1999) and the end of this century (2090-2099) by 35 cm (23 - 47 cm) in the A1B scenario [3]. However, the distribution will not be uniform due to ocean density and circulation changes. The rise along the Bangladesh coast could be 0 - 5 cm more than the global average. Existing literature indicate that the spatial coverage and temporal duration of salinity would increase due to this sea level rise. The 5 ppt isohaline could move about 9 km farther inland during the dry season due to a sea level rise of 32 cm [4]. The inundated area could also increase by about 11% due to the rise of sea level by 88 cm. About 84% of the Sundarbans could be deeply flooded under such scenario and the mere sustenance of the Sundarbans could be at risk. Thus, any change in climate induced by global warming and dimming could further aggravate the already fragile agro-ecosystem of the region and worsen the poverty situation.

Though there have been a few studies on the impacts of climate change on coastal areas using scenario-based model studies [4-6], no study has been conducted on existing trends of hydro-climatic variables in the coastal region, particularly in and around Khulna. This study investigated the long-term trends in temperature, rainfall, sunshine, humidity and tidal water level in the Khulna region using secondary data. Correlation between the Gorai flow and the salinity in the Rupsa water is also investigated. The role of human interventions, both within and outside the country, on sweet water inflow and the river water quality is also assessed. The variation in tidal water level around Khulna in relation to sea level rise and human interventions is also explored.

2. Methodology and Data

In this study, the linear, monotonic trend in a variable was investigated mostly at annual, seasonal and monthly time scales. The Intergovernmental Panel on Climate Change [3] used this technique while investigating the long- and short-term trends in observed climatic and hydrologic variables. The method is based on fitting a straight line to a set of time series data so that the sum of squared errors becomes the least. This is the most widely used technique in trend analysis and is most robust in case of normally distributed data and in absence of too many outliers. However, where the distribution of the variable is not Gaussian and there are many outliers in the data set, the linear but non-parametric technique may be more appropriate to investigate the trend. This latter technique [7] is based on the ordering of a set of data and has no distributional assumption. Both the parametric and nonparametric techniques were used to assess trends in different hydro-climatic variables due to their relative strengths and weaknesses. The statistical significance levels of the parametric and nonparametric trends were studied by employing the t-test and the Mann-Kendall test, respectively. The Statistical Package for the Social Sciences (SPSS) software was used in this purpose.

The linear correlation between two variables was studied by computing Pearson's correlation coefficient, which has a parametric distributional assumption. Kendall's tau and Spearman's rho having no distributional assumption were also computed in appropriate cases to see if there is a significant difference in direction and strength of the relationship between the parametric and non-parametric techniques.

The data for this study were carefully examined before using for trend and correlation analyses. Any daily data with negative value (except for the tidal water level) and absurd value was treated as missing using a computer program. The daily data were then sorted in a chronological order with the missing dates identified. From the daily values, 10-day values were calculated for each month and year and for each data set, provided that daily values for at least one day is available for a 10-day period. The reason for calculating the 10-day value before the monthly, seasonal and annual values was that, if the latter values were calculated directly from the daily values with some criteria, such as 80% non-missing days, they might not be representative. Monthly values were calculated from the 10-day values, and the seasonal and annual values from the monthly values. It is noted that the third 10-day period in a month consists of 10, 11, 8 or 9 days depending on the month and year. For rainfall data, missing values during the dry months, when there is little or no rainfall, were filled in with rainfall from the nearest location. No attempt was made to fill in the rainfall data of missing days during the wet months, when rainfall is highly variable both in space and time.

Temperature, rainfall, sunshine and humidity data were collected from the Bangladesh Meteorological Department (BMD) and river discharge, bathymetry and water quality data from the Bangladesh Water Development Board (BWDB). The tidal water level data were collected from the Bangladesh Inland Water Transport Authority (BIWTA).

3. Trends in Observed Temperature, Frequency of Hot Days and Cold Nights, Warm and Cool Spells, and Heat Index

The day-time maximum and night-time minimum temperatures on a daily time scale at Khulna were available for a period of 63 years (1948-2010). Monthly and seasonal time series were created from the daily values as mentioned above. Graphical plots of the time series indicated that the temperature at Khulna started rising faster since 1980. So, in addition to the long-term trends, the trends in temperature for the period of 1980-2010 were estimated. The results (**Table 1**) indicate that the average maximum temperatures in the pre-monsoon (March-May) and monsoon (June-September) seasons, and the average minimum temperatures in the pre-monsoon, post-monsoon (October-November) and winter (December-February) seasons are increasing at faster rates in recent times than anticipated either from long-term observed trends reported in [8] or climate model projections reported in [9-11]. The average maximum temperature during the monsoon season is rising at 0.037˚C per year and the average minimum temperature during the winter season is rising at a staggering rate of 0.047˚C per year. The change in direction of trend in the winter season for both maximum and minimum temperatures and that in the pre-monsoon season for minimum temperature may indicate a non-monotonic pattern in air temperature variation in those seasons. It is to be noted that the use of nonparametric technique resulted in similar values of the above trends and significance levels.

The mean monthly maximum temperature has an increasing trend in all months except for December-March, which is the winter season in Bangladesh (**Table 2**). The monthly trends also have become stronger in recent years for all the months except for October. The trend in January is negative even in recent years. The trends in mean monthly minimum temperatures also have become stronger in recent years (**Table 2**). The trends are found to be positive for all the months in recent years. Furthermore, their statistical significance has also increased. The mean minimum temperature in different months of the dry season (November-May) is found to be increasing at a very high rate. An increase in green house gases and small particulate matters in the atmosphere and more prevalence of cloud and fog during this season could be the possible reasons for the night temperature rise. It thus appears that the use of the recent temperature data, rather than the long-term data, depicts a better picture of cli-

Table 1. Trend (˚C/year) in seasonal temperatures at Khulna.

Season	Trend in maximum temperature for the period of		Trend in minimum temperature for the period of	
	1948-2010	1980-2010	1948-2010	1980-2010
Winter	−0.018***	0.022	−0.018***	0.047***
Pre-monsoon	0	0.034**	−0.001	0.045***
Monsoon	0.019***	0.037***	0.003	0.013*
Post-monsoon	0.021***	0.027**	0.006	0.042***

Note: ***, ** and * indicate that the trends are significant at 99%, 95% and 90% level of confidence, respectively.

Table 2. Trend (˚C/year) in monthly temperatures at Khulna.

Month	Trend in maximum temperature for the period of		Trend in minimum temperature for the period of	
	1948-2010	1980-2010	1948-2010	1980-2010
Jan	−0.028***	−0.013	−0.032***	0.025
Feb	−0.016	0.046*	−0.013	0.067***
Mar	−0.013	0.014	−0.003	0.048*
Apr	0.001	0.028	0.008	0.051**
May	0.010	0.059***	−0.008	0.037**
Jun	0.020***	0.039**	0.001	0.013
Jul	0.022***	0.033***	0.007**	0.018*
Aug	0.023***	0.043***	0.005	0.012
Sep	0.013**	0.035***	−0.001	0.010
Oct	0.023***	0.021	0.002	0.020
Nov	0.018***	0.034**	0.008	0.064***
Dec	−0.006	0.024	−0.009	0.066***

Note: ***, ** and * indicate that the trends are significant at 99%, 95% and 90% level of confidence, respectively.

mate change scenario. In case of minimum temperature, the average of the monthly trends of a season is generally higher than the corresponding seasonal trend indicating that the intra-year variability in night-time minimum temperature has also increased. The trend in April for maximum temperature is found to be lower and that in minimum temperature higher with the nonparametric technique.

The annual minimum temperature time series indicated that there is no overall trend in the long-term series. However, there is a strong increasing trend in the recent data series (0.05˚C and 0.1˚C per year for the periods of 1980-2010 and 1983-2010, respectively). The magnitudes of these trends remained similar even with a nonparametric method. The annual maximum temperature has no significant trend in both long-term and recent time series. The number of extremely cold nights having temperature less than or equal to 9.7˚C, which corresponds to the 10th percentile of the daily minimum temperature in the month of January, was found to be decreasing. However, the number of extremely hot days having temperature greater than or equal to 37.2˚C, which corresponds to the 90th percentile of the daily maximum temperature in the month of April, was found not to be changing significantly. The upper and lower ten percentiles were taken as indicators of extremely hot days and cold nights following some past studies [12,13]. The longest durations of consecutive hot days and cold nights exhibited trends more or less similar to the above trends.

The long-term temperature data indicated an increasing trend (significant at 99% level of confidence) in the diurnal temperature range-the difference between the daily maximum and minimum temperatures-during the months of May to October. However, such trends have become non-significant and deceasing in recent years. The mean monthly diurnal temperature range has non-significant decreasing trend in long-term data and significant (99% level) decreasing trend in recent data during the months of December-April. Thus, the decreasing trend in diurnal range is becoming stronger with the passage of time.

The analysis of heat index, which is a measure of perceived temperature in human body [14-16], indicates that the probabilities of occurrences of heat stress in a day with apparent temperature greater than or equal to 27˚C are 66, 95, 97, 97, 98, 98, 97 and 87 percent in the months of March-October, respectively. The heat index was found to be increasing in all these months. The increasing trends also have become higher in recent years. The trends for August-September are significant at 99% level of confidence and that for May, July and October at 95% level of confidence. The trend in June is significant at 80% level of confidence. Thus, the rising temperature, coupled with a rising humidity, is causing serious discomfort to the people of Khulna.

4. Trends in Observed Sunshine and Humidity

The bright sunshine duration data at Khulna were available for a period of 27 years (1984-2010). The average durations of sunshine in the winter, pre-monsoon, monsoon and post-monsoon seasons were found to be about 7.7, 8.0, 4.9 and 7.4 hours a day, respectively. There is a decreasing trend in seasonal sunshine durations, except for the monsoon season. The decreasing trend in the winter season is about 0.6 hours a day per decade, which is equivalent to a decrease of 7.8% in average sunshine duration in a decade. The post-monsoon season has a decreasing trend of 0.4 hours a day per decade, which is equivalent to a decrease of 4.9% in average sunshine duration in a decade. The winter and post-monsoon trends are statistically significant at 99% and 95% level of confidence, respectively. The pre-monsoon season has a non-significant decreasing trend of 0.2 hours a day per decade (1.6% a decade). The monsoon season, in contrast, has a non-significant increasing trend of 0.2 hours a day per decade (4.0% a decade). Both the magnitudes and significance levels of the above trends in the seasonal sunshine durations remained similar with the nonparametric technique. In a monthly scale, the sunshine duration has a decreasing trend for all months, except for June, July and August. The trends in December and January of the winter season are statistically significant at 99% and 95% level of confidence, respectively. The trend in October of the post-monsoon season is significant at 95% level of confidence. The trends in other months are not significant at 90% level of confidence. The trend in sunshine duration found in this study is more or less consistent with the findings of [17-20] for Bangladesh.

The data on relative humidity at Khulna were available for a period of 63 years (1948-2010). The relative humidity at Khulna has increasing trends of 2.3%, 1.3% and 0.3% per decade in the winter, post-monsoon and pre-monsoon seasons, respectively (**Table 3**). In contrast, the monsoon season has a decreasing trend of 0.4% per decade. The trends in the winter and post-monsoon seasons are significant at a level of confidence of 99%. The decreasing trend at the monsoon season is significant at a lower level of confidence (90%). The trend of the pre-monsoon season is not significant. The use of nonparametric technique resulted in similar values of seasonal trends except for the monsoon season for which the confidence level of the decreasing trend increased to 95%. In a monthly scale, the highest rate of increase is found in the month of January in the middle of winter and then the rate gradually falls till the month of June, the beginning

Table 3. Trend (%/decade) in relative humidity at Khulna.

Season	Trend	Month	Trend
Winter	2.3***	Dec	2.2***
		Jan	2.8***
		Feb	2.0***
Pre-monsoon	0.3	Mar	1.1
		Apr	0.1
		May	−0.2
Monsoon	−0.4*	Jun	−0.7***
		Jul	−0.5**
		Aug	−0.4
		Sep	0.1
Post-monsoon	1.2***	Oct	0.7*
		Nov	1.8***

Note: ***, ** and * indicate that the trends are significant at 99%, 95% and 90% level of confidence, respectively.

of the monsoon and thereafter the rate increases gradually till January. The months of May-August show decreasing trends in humidity. The trend in relative humidity found in this study is more or less consistent with the findings of [18,20,21] for Bangladesh. The increasing humidity trends of the winter, post-monsoon and pre-monsoon seasons are consistent with the decreasing sunshine trends in these seasons. Furthermore, the decreasing humidity trend of the monsoon season is consistent with the increasing sunshine duration trend in this season.

There are two likely reasons of increasing trend of humidity-one due to increases in temperature and the other due to increases in wetness of land surface. Though the temperature has an increasing trend in the country, the combined effect of temperature, sunshine and humidity on potential evapotranspiration is found to be negative, rather than positive [17,21]. Since the irrigated area in the country has witnessed a phenomenal increase over the last three decades, particularly in the dry season (November-May), which also coincides with the periods of higher increases in humidity and decreases in sunshine, it is most likely that the irrigation development (along with the shrimp aquaculture in coastal region) for rice cultivation using standing water on firms has contributed largely to the increase in humidity in Bangladesh.

5. Trends in Rainfall

The analysis of rainfall data for a period of 63 years (1948-2010) at Khulna indicates that the rainfalls have increasing trends of 8 mm, 31 mm, 9 mm and 6 mm per decade during the winter, monsoon, post-monsoon and pre-monsoon seasons, respectively. The trend in the winter season is significant at 95% level of confidence and that in the monsoon season is significant at 80% level of confidence. However, the trends in the pre- and post-monsoon seasons are not significant at 80% level of confidence. Similar trends were found in seasonal rainfalls for Khulna using a non-parametric technique with a shorter data-set (1958-2007) [23]. Among the monsoon months, June has a non-significant negative trend of 6 mm a decade, July has a non-significant positive trend of 5 mm a decade, August has a positive trend of 14 mm a decade being significant at 80% level of confidence, and September has a positive trend of 7 mm a decade being significant at 90% level of confidence. Thus, the monsoon is found to be strengthening towards the end of the season. The annual total rainfall is found to be increasing at 53 mm a decade which is significant at 95% level of confidence.

The number of rainy days in a year is found to be increasing at 0.8 days per annum, which is significant at 99% level of confidence (**Figure 2**). The numbers of rainy days during the wet (June-October) and dry (November-May) seasons show increasing trends of 0.6 days and 0.2 days a year, respectively. Both these trends are significant at 99% level of confidence. The nonparametric technique also results similar trends, both in magnitudes and significance levels. The maximum number of consecutive rainy days in a year is found to be increasing at 99% level of confidence. The maximum number of consecutive non-rainy days in a year is found to be decreasing at 99% level of confidence. The nonparametric technique results slightly lower decreasing trend than the parametric technique in case of consecutive non-rainy days.

The maximum rainfalls in one day (**Figure 3**), in consecutive 3 days, and in consecutive 7 days, though increasing, are not statistically significant. Also, the numbers of days with rainfall of more than 50 mm and 100

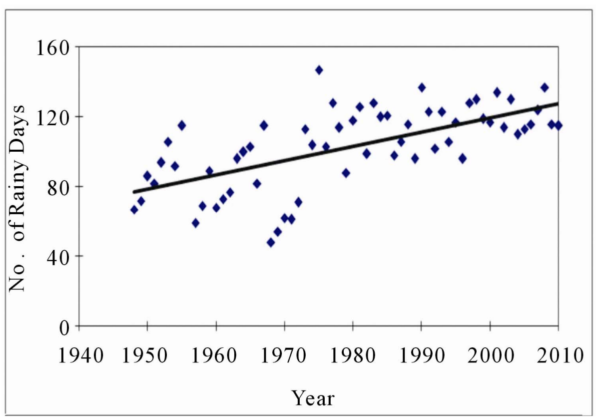

Figure 2. Trend in the number of rainy days at Khulna.

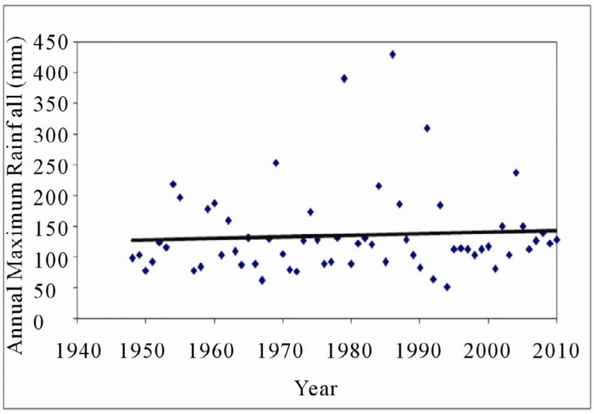

Figure 3. Trend in the annual maximum rainfall at Khulna.

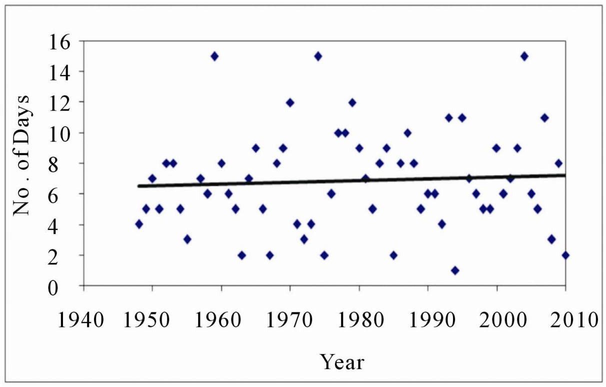

Figure 4. Trend in the annual number of days with rainfall of more than 50 mm at Khulna.

mm, though show increasing trends, are not statistically significant (**Figure 4**). Similar trends in rainfalls were also found for Satkhira, which is another meteorological station in the southwest coastal region. From the above analyses, it thus appears that there are some evidences of increase in rainfall in the southwest coastal Bangladesh. The increasing trend in rainfall results primarily from the increasing number of rainy days. The trend in rainfall intensity, though increasing, is not statistically significant. Nevertheless, climate model results indicate an increase in the frequency of extreme rainfall events of shorter duration (6 hours) at Khulna in future [23]. The rainfall trend is found to be consistent in general with the sunshine and humidity trends at Khulna and Satkhira.

6. Trend in Tidal Water Level

The analysis of tidal water levels of the Rupsa-Pasur River at Khulna for a period of 74 years (1937-2010) indicates that the annual maximum high tidal water levels are increasing at a rate of 18 mm per year and the annual minimum low tidal water levels are decreasing at a rate of 8 mm per year (**Figures 5** and **6**). Both these trends were found to be statistically significant at a confidence level of 99%. The BWDB gage station at Khulna is located at a distance of 125 km inland from the sea coast. To see the trend in tidal water levels near the sea, data for BIWTA station at Hiron Point, which is only 11 km inland from the coast line, for a period of 33 years (1977-2010) were also analyzed. The trend in annual maximum water level was found to increasing at a rate of 7 mm per annum and that in minimum water level to be decreasing at 4 mm per annum. The increasing trend is significant at 80% level of confidence and the decreasing trend at 90% level of confidence. It thus clearly appears that the extremes in tidal water levels are more prominent in inland areas compared to those near the sea.

The possible reasons for the decreasing trends in annual minimum water levels at both Khulna and Hiron-

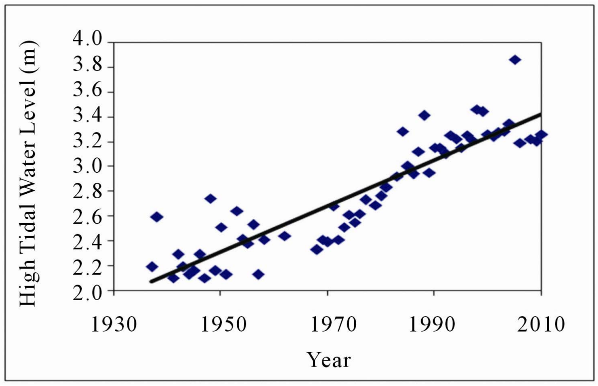

Figure 5. Trend in annual maximum high tidal water levels.

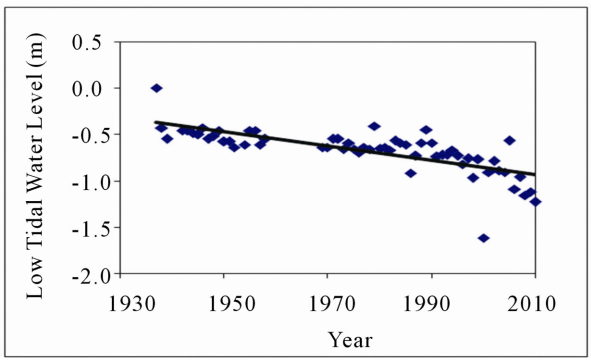

Figure 6. Trend in annual minimum low tidal water levels.

point could be the reduction in the sweet water flow from upstream areas or the reduction in storage areas of saline tidal water or both. The increasing trends in annual maximum water levels could result either from silting up of the rivers, reduction in flood tide propagation areas, or a rise in the sea level, or a combination of these factors. However, if sea level rise had any effect on the observed trends, the effect had been much lower than that of anthropogenic interventions as the high and low tidal levels have significant opposite trends. The rising trend in the high tidal water level can be explained by a sea level rise phenomenon but not the falling trend in the low tidal water level. About 40 polders with 1566 km of embankments and 282 drainage sluices, encompassing an area of 411 thousand hectares, were constructed in Khulna-Jessore region under the coastal embankment project during 1960s and 1970s with the financial assistance from USAID. The time series data on flood control, drainage and irrigation coverage reveals that the coverage has increased to 477116 ha in 1993 from 0 ha in 1956 in Khulna district. The embankments thus constructed denied the entry of the tidal waters into the polders. As a result, the heavy loads of silt, carried by the tides, settled on the river beds, which gradually rose above the levels of the lands within the polders and closed the exits of the sluices. Simultaneously, subsidence continued within the polders without having compensating silt deposits. These led to severe drainage congestion in the coastal areas, particularly in polders 24, 27 and 28, during 1990s. These coastal polders and the Farakka barrage had contributed to the gradual siltation of the coastal rivers and are the principal factors contributing to the tidal water level extremes. The comparison of the multi-year bathymetries of the Rupsa-Pasur River (not shown) also supported the above arguments.

7. Variation in the Gorai River Flow

The Gorai River is the principal distributary of the Ganges River at its right bank inside Bangladesh. Its flow is the major source of fresh water for the southwest Bangladesh during the dry season to check saline water intrusion from the Bay of Bengal, to prevent siltation in the regional rivers, to maintain navigational depth, to sustain the mangrove ecosystem of the Sundarbans and to provide irrigation water for agriculture. However, due to diversion of the water from the Ganges River with a barrage at Farakka inside India since 1975, the dry season flow of the Gorai River has reduced significantly. For instance, the annual minimum flow time series (**Figure 7**) indicates that such flow reduced to almost nil in 1976 immediately after commissioning of the barrage. However, it was not until 1981 when the effect of the withdrawal became very prominent. The average lowest flow was about 110 m^3/s till 1980 and it came down to only about 10 m^3/s during the period of 1981-1998. The off-take of the Gorai was silted up due to reduction in inflow from the Ganges. Towards the end of the latter period in 1996, Bangladesh and India signed a treaty to share the Ganges flow. The treaty became effective in January 1997 and established the circumstances for restoration of the Gorai flow. A 20-km reach of the river from its off-take was dredged after the monsoon season of 1998 and maintenance dredging was continued for another two years. The three-year dredging removed about 18.5 million m^3 of sediment from the river [24]. This resulted in an increase of the annual minimum flow to about 45 m^3/s during the years of 1999-2008. It thus appears that the dredging of the river could restore only about 42% of the natural minimum flow and even that was on a temporary basis. The minimum flow in the last three years became almost nil. The disruption to the natural flow regime of the Ganges in the upstream with the Farakka barrage has caused significant adverse effect on the flow regime and morphology of the Gorai.

8. Correlation between Salinity and the Gorai Flow

The Rupsa-Pasur still has connection to the Gorai River and receives the sweet water supplies. The Gorai flow pushes away the saline water front in the Rupsa-Pasur near Khulna [25]. The analysis of river water salinity (EC) near Khulna using a data set of 34 years (1975-2008) shows a higher salinity during high (flood) tide compared to that during low (ebb) tide. There is a negative correlation between the Gorai flow and electrical conductivity (EC) in both the tidal cycles. The correlations are statistically significant at 95% confidence levels during the months of February to May. The highest correlation coefficient in the high tidal cycle was found to be −0.68 in the month of March and that in the low tidal cycle was −0.64 in the month of April, both the correlations being statistically significant at 99% level of confidence. Thus, when the Gorai flow was high, the river water salinity in Khulna was low. This inference is also supported by the difference in EC values between the pre- and post-dredging situations (**Figure 8**). The EC values became lower due to the dredging of the Gorai after the monsoon season of 1998.

9. Conclusions

Both mean maximum and minimum temperatures at seasonal and monthly time scales show in general in-

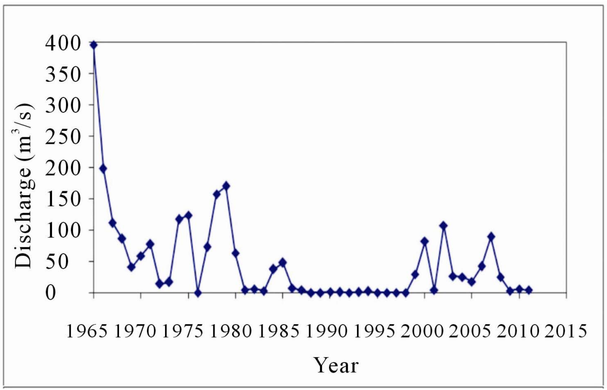

Figure 7. Time series plot of annual lowest flow of the Gorai River at Gorai Railway Bridge.

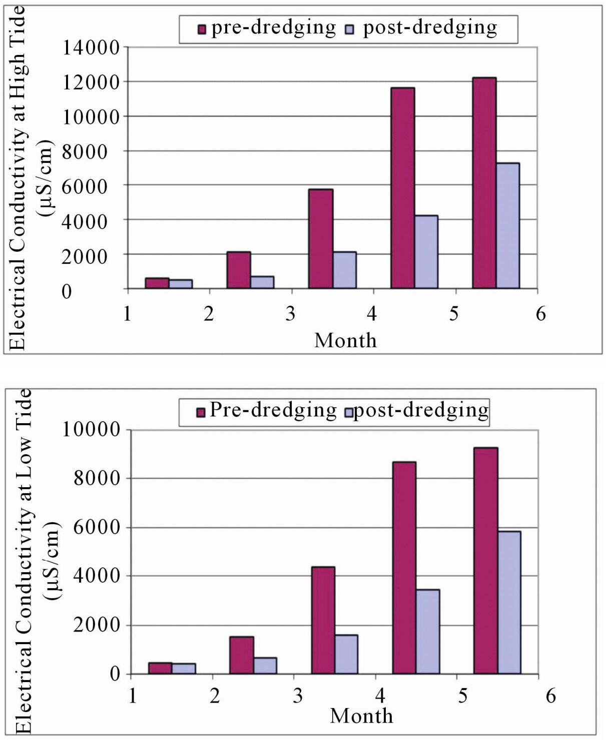

Figure 8. Comparison of Electrical Conductivity (EC) of the Rupsa-Pasur River at Khulna between the pre- and post-dredging situations.

creasing trends at southwest coastal Bangladesh. Among the four seasons, the monsoon season has the highest rising trend of 0.037˚C per year in the mean maximum temperature and the winter season has the highest rising-trend of 0.047˚C per year in the mean minimum temperature. At monthly scale, the mean maximum temperature has the highest trend in May and the mean minimum temperature in February of 0.059˚C and 0.067˚C per year, respectively. The annual minimum temperature has an increasing trend but the annual maximum temperature has no overall trend. The numbers of extreme hot days and cold days per annum and the longest durations of such days have trends similar to the trends in annual maximum and minimum temperatures. The heat index shows an increasing trend which is adding discomfort to the lives of the people of Khulna. The mean seasonal sunshine duration is found to be decreasing except for the monsoon. The rates of decrease are 7.8%, 4.9% and 1.6% per decade in the winter, post-monsoon and pre-monsoon, respectively. Consistent with the sunshine trends are the mean seasonal humidity trends in an opposite direction of change. The rainfalls have increasing trends of 8 mm, 31 mm, 9 mm and 6 mm per decade during the winter, monsoon, post-monsoon and pre-monsoon seasons, respectively. However, the trends are significant only for the winter season at 95% level of confidence and for the monsoon season at 80% level of confidence. There are some evidences that the monsoon is strengthening towards the end of the season. The number of rainy days in a year and the maximum number of consecutive rainy days are found to be increasing in the southwest coastal region. The meteorological variables thus provide some indication of climate change in the southwest Khulna region.

The analysis of the tidal water levels of the Rupsa-Pasur River indicates that the annual maximum high tidal water levels are increasing at a rate of 7 - 18 mm per year and the annual minimum low tidal water levels are decreasing at a rate of 4 - 8 mm per year depending on the locations. The coastal polders and the Farakka barrage in India are found to have contributed to the gradual siltation of the coastal rivers and hence to the tidal water level extremes. The analysis of the lowest flow of the Gorai River indicates that the disruption to the natural flow regime of the Ganges in the upstream with the Farakka barrage has caused significant adverse effect on the flow regime and morphology of the Gorai. The lowest flow has now ceased to almost nil. The river salinity at Khulna has also good correlation with the Gorai flow during the months of February-May. The dredging of the Gorai during 1998-2001 contributed positively towards restoration of the sweet water flow to the southwest region and to check the level of salinity near Khulna.

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