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ESTIMATING TRENDS OF SEA-LEVEL FLUCTUATIONS FROM TIDE GAUGE DATA ANALYSIS ALONG BANGLADESH COAST

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ABSTRACT

The present study tries to determine the nature and magnitudes of relative sea-level to estimate present and future trends of mean sea-level (MSL) changes based on historical tide gauge data of Cox's Bazaar, Charchanga, Hiron Point, Khepupara and Sadarghat stations of Bangladesh. Annual PSMSL tide gauge dataset of Cox's Bazaar station shows 2.72 mm/year sea-level rise while CPA provided 'Metric' dataset of Sadarghat station demonstrate 3.93 mm/year sea-level rise along Chittagong coast. Accordingly, the sea-levels are supposed to be increased 10.54 cm, 24.11 cm and 37.69 cm than the 1988 MSL (213.70 cm) at Cox's Bazaar by the years 2050, 2100 and 2150, respectively. Moreover, based on long-term PSMSL tide dataset of Charchanga, Hiron Point and Khepupara stations, the estimated rise of sea-levels along the respective coasts are 8.15 mm/year, 3.56 mm/year and 18.66 mm/year, respectively. Finally, 7.4 mm/year average rate of sea-level rise has been calculated from all the studied datasets under present study. However, disregarding the exceptionally high rate (18.66 mm/year) at Khepupara station, determined average rate of sea-level rise along Bangladesh coast is 4.59 mm/year which seems to be consistent with the global average. Consequently, the predicted sea-levels along Bangladesh coast are approximately 22 cm, 45 cm and 68 cm above their average MSL (210.4 cm) in the years 2050, 2100 and 2150, respectively.

Key words: Sea-level fluctuation, Tide gauge data, Mean sea-level, Bangladesh coast.

INTRODUCTION

Bangladesh is a maritime country of approximately 1,47,570 square km. area which is situated between 20°34′ N and 26°38′ N latitudes and 88°01′ E and 92°41′ E Longitudes. Occupying the northern shore of the Bay of Bengal and except the hills of Chittagong and Chittagong Hill Tracts in the east, and the small part in the north, the terrain is mostly flat and constitutes about 23% of the total area (Hoque *et al.* 1999). About 50% of the landmasses are within 5m contour and the coastal zone is a very flat land within the contour of 3m and extends over a length of 710 km distance around the Bay of Bengal between India and Myanmar borders. This basic physiographic nature of the coastal area has made it a unique site for analyzing the effect of relative Sea Level Rise (SLR) related to Climate change. In fact, climate change is to be considered as the greatest environmental challenge facing the world today and the threat of sea level rise spans an enormous range of possible impacts from the relatively small and manageable to the catastrophic. Thus, Bangladesh, in particular the coastal belt, is at great risk from global climate change (WB 2000; SMRC 2000a, 2000b; MoEF 2002; and Agarwala *et al.* 2003) because of its very low elevation and exposure to various water related hazards. On the other hand, global climate change and consequent sea level fluctuation is a very common experience in the history of the land-sea interface through geological time scale. The evidence is clear that large changes in geo-environmental phenomena, including sea level changes, have resulted from climate change, especially as a consequence of glacial-interglacial cycles. For example, the period between 18,000 cal. yrs BP and 6,000 cal. yrs BP can be characterized by two phases of rapid sea-level rises (Fairbanks 1989) when most of the restoration of sea-level was controlled by melting of mid and high latitude ice-sheets (Jelgersma and Tooley 1995) due to the increase of global temperature. However, it is evident from Palaeo-climatic information that the earth's climate has experienced changes in the past on time scales ranging from several millions years to a few years which played a very significant role to shape and reshape the continental coasts, including the coastal belt of Bangladesh. Therefore, importance is there to develop a framework for the assessment of climate change induced sea level rise (SLR) and its impacts on land use suitability along the coastal region of Bangladesh. Hence, the present study concentrate on determining the nature and magnitudes of relative sea level to estimate present and future trends of mean sea-level (MSL) changes, mainly based on historical tide gauge data of selective stations along Bangladesh coast.

MATERIALS AND METHODS

Study Area

Present study area covers the coastal belt of Bangladesh which extends over a length of 710 km distance around the Bay of Bengal between India and Myanmar borders. This coast can be broadly divided into three distinct geo-morphological regions, viz. the eastern region, the western region and the central region. Based on past tide-gauge datasets of 5 selected stations (e.g., Cox's Bazaar, Sadarghat, Charchanga, Hiron Point and Khepupara) (Figure 1) from those three regions the attempt has taken under the present study to determine region wise as well as the overall trends of present and future sea-level fluctuations along Bangladesh coast.

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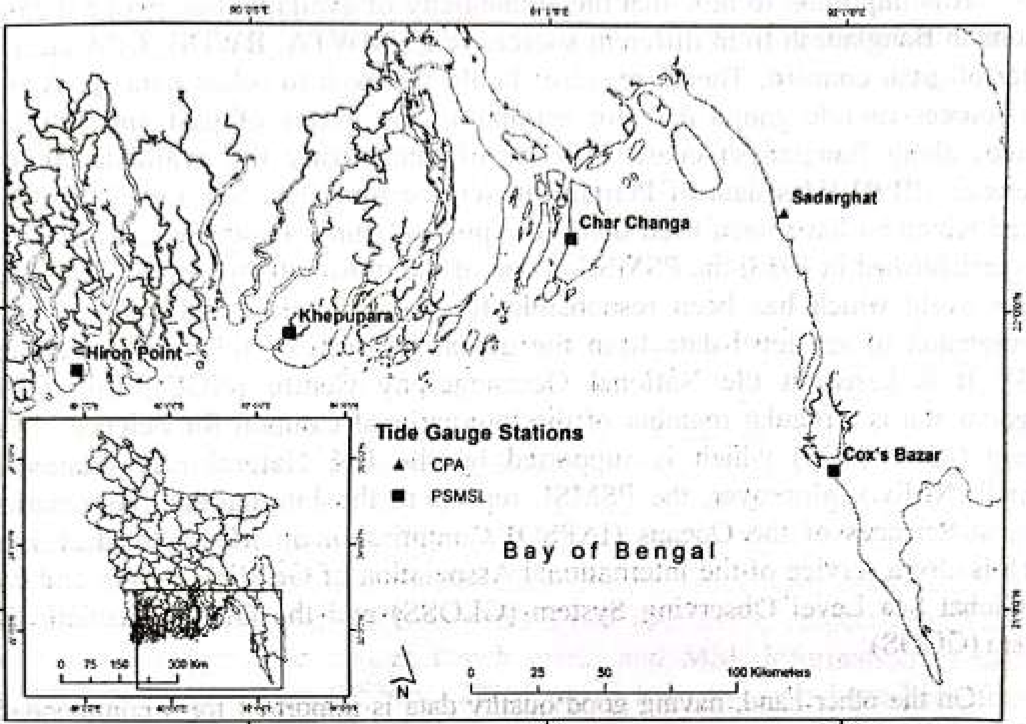


FIGURE 1: LOCATION OF THE STUDIED TIDE GAUGE STATIONS WITHIN THE STUDY AREA

Data and Methods

Major sources of available tide gauge data to determine coastal sea level change along Bangladesh coasts are the Bangladesh Water Development Board (BWDB), Bangladesh Inland Water Transport Authority (BIWTA), Chittagong Port Authority (CPA) and the Permanent Service for Mean Sea Level (PSMSL). Usually this type of data is termed 'Metric' data and can be used for different aspects of mean sea-level (MSL) analysis. However, 'Metric' data is to be upgraded by verifying monthly and annual MSL against the Tide Gauge Bench Mark (TGBM) of nearby land which is then termed as the 'Revised Local Reference' (RLR) data of the station. Thus, the data categorized as RLR are suitable for time-series analysis and can be used for the estimation of long term sea-level change (Woodworth 1991; Woodworth and Player 2003). Tide gauge data of Bangladesh is obtained by PSMSL from BIWTA which is then checked for further appraisal, including the conversion of the Metric data into RLR dataset. At present 'Metric' tide gauge data of Bangladesh is available for approximately 50 stations having a data range from 1 to 40 years, although data for only four stations (viz. Hiron Point, Khepupara, Charchanga and Cox's Bazaar) are processed to RLR level that are shown as PSMSL stations in Figure 1. In the present study the PSMSL provided RLR "tide gauge data" (Holgate *et al.* 2013; PSMSL 2015) of Cox's Bazaar, Charchanga, Hiron Point and Khepupara stations have been considered for detailed study while data from one CPA (Chittagong Port Authority) provided 'Metric' dataset of Sadarghat tide gauge station of Chittagong have been analyzed for comparison.

It is important to note that the authenticity of available tide gauge data of various stations in Bangladesh from different sources (e.g., BIWTA, BWDB, CPA etc.) is still the matter of great concern. Therefore, care should be taken to select data types and reliable data sources of tide gauge data for estimating the trends of past and future sea-level changes along Bangladesh coast. In view of that mostly the available Revised Local Reference (RLR) tides data of Permanent Service for Mean Sea Level (PSMSL) of the United Kingdom have been used under the present study. However, it is remarkable that being established in 1933, the PSMSL is one of the most authentic tide gauge data sources of the world which has been responsible for the collection, publication, analysis and interpretation of sea level data from the global network of tide gauges (Holgate *et al.* 2013). It is based at the National Oceanography Centre (NOC), Liverpool, United Kingdom and is a regular member of the International Council for Science - World Data System (ICSU-WDS) which is supported by the UK Natural Environment Research Council (NERC). Moreover, the PSMSL reports to the International Association for the Physical Sciences of the Oceans (IAPSO) Commission on Mean Sea Level and Tides which is also a service of the International Association of Geodesy (IAG), and works with the Global Sea Level Observing System (GLOSS) and the Global Geodetic Observing System (GGOS).

On the other hand, having good quality data is important for a commendable result. Therefore, the data quality of various tide gauge stations, used under the present study, has further been checked before analysis and errors in tidal data, particularly for the 'Metric' dataset, have been corrected manually. For example, in case of an overestimation of tidal level, erroneous data are removed from that dataset. Some impractical values, (viz., same figure for high and low tides) are removed from the dataset before obtaining a sea-level rise trend. Conversion of unit for any dataset was not required so that both the PSMSL and CPA data are provided in the form of mean sea-level (MSL) in millimeters (mm). Finally, mean yearly and, for selective stations, mean monthly water levels have been calculated and plotted in Excel for analysis. Ultimately, trends of mean sea level (MSL), and predicted sea levels until the middle of the next century (2150) have been calculated by linear regression.

RESULTS AND DISCUSSION

According to the present study the estimation of sea-level change along the eastern coast, calculated from 22 years (1979 - 2000) annual PSMSL tide-gauge dataset of Cox's Bazaar station, shows 2.72 mm/year sea-level rise (Figure 2). However, in a recent study sea-level change along the Cox's Bazaar coastal zone calculated by Sarwar (2013) shows a rise of 1.36 mm/year. Following the mentioned trend of sea-level change and associated regression equation the present study reveals that the predicted RLR sea-level along the Cox's Bazaar coast of Bangladesh is 7106.38 mm (Figure 3) in 2050. The study also calculates the potential RLR sea-levels of 7242.16 mm and 7377.94 mm for the years 2100 and 2150, respectively. Finally, using respective reference datum, bench mark, and mean sea level (1988) information of the prescribed revised local reference (RLR 1988) diagram of the station (Figure 4) by PSMSL (2015), the predicted mean sea levels along Cox's Bazaar Coast of Bangladesh have been calculated as 224.24 cm, 237.8 cm and 251.39 cm, above the allied Datum, for the years 2050, 2100 and 2150, respectively. Thus, the sea-levels of Bangladesh along the coast of Cox's Bazaar are supposed to be increased 10.54 cm, 24.11 cm and 37.69 cm than the 1988 MSL (213.70 cm above the Datum) by the years 2050, 2100 and 2150, respectively. According to this dataset the mean sea level of Cox's Bazaar coast in 2000 has been recorded 6981 mm which is 211.7 cm above the reference datum and 2 cm below 1988 MSL. Ultimately, at an interval of 50 years period, it has been found from the calculated sea levels that there is a very firm and continuous trend of sea level rise during 150 years period after the year 2000 along the Cox's Bazaar Coast (e.g., Eastern Coast) of Bangladesh (Figure 5).

On the other hand, sea-level rise along the central part of Bangladesh coast shows an extreme increasing trend. Based on 22 years (1979 - 2000) PSMSL annual dataset sea-level rise at the Charchanga station of Hatia Island is observed 8.15 mm/year which is significantly higher than that of Cox's Bazaar station. It has been found from the analysis of this dataset that at an increasing rate of 8.15 mm/year the predicted RLR sea-level along the Central Coast of Bangladesh is approximately 7418 mm in 2050. Accordingly, the potential RLR sea-levels along this coastal area of the country have been determined as about 7826 mm and 8234 mm for the years 2100 and 2150, respectively. However, following respective reference datum, bench mark, and MSL information of the RLR diagram of Charchanga station (PSMSL 2015), predicted sea-levels have been found as 2614.30 mm, 3021.99 mm, and 3429.69 mm above the datum for Bangladesh in 2050, 2100 and 2150, respectively. Eventually, on top of the RLR (1988) mean sea-level (MSL), the sea-levels along the central coast of Bangladesh are to be increased as 37.23 cm, 78 cm, and 118.77 cm in the years 2050, 2100 and 2150, respectively. These findings are also in a good agreement with the 5.73 mm/year sea-level rise calculated by Sarwar (2013) from 21 years tide gauge data of Charchanga station.

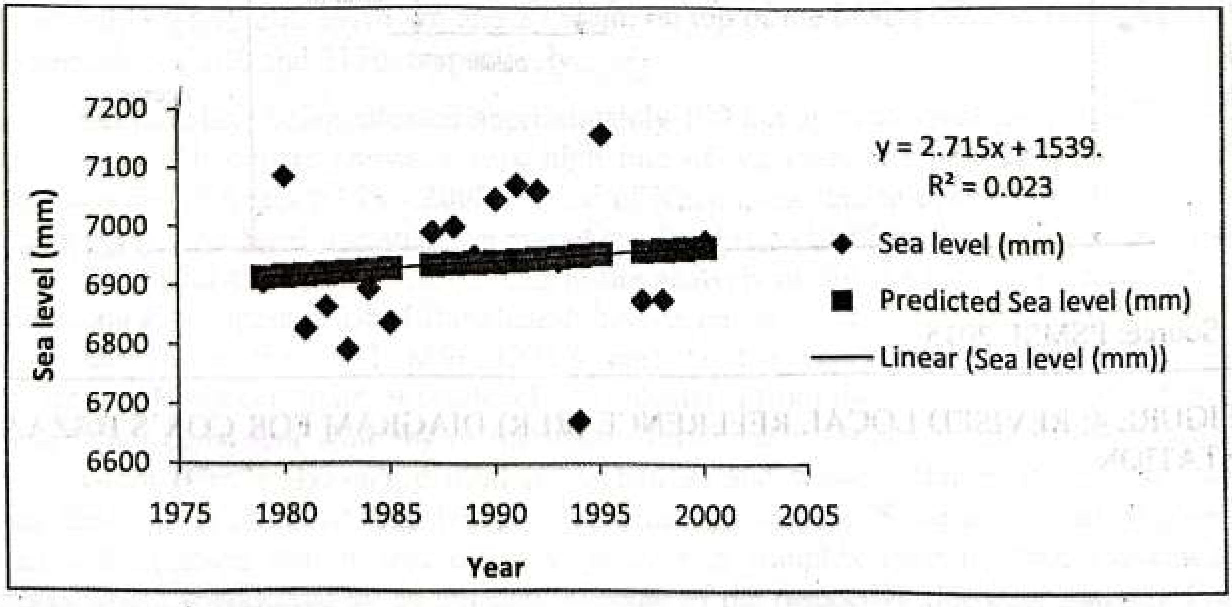


FIGURE 2: TRENDS OF SEA-LEVEL RISE BASED ON ANNUAL PSMSL TIDE GAUGE DATA OF COX'S BAZAAR STATION DURING 1979 - 2000.

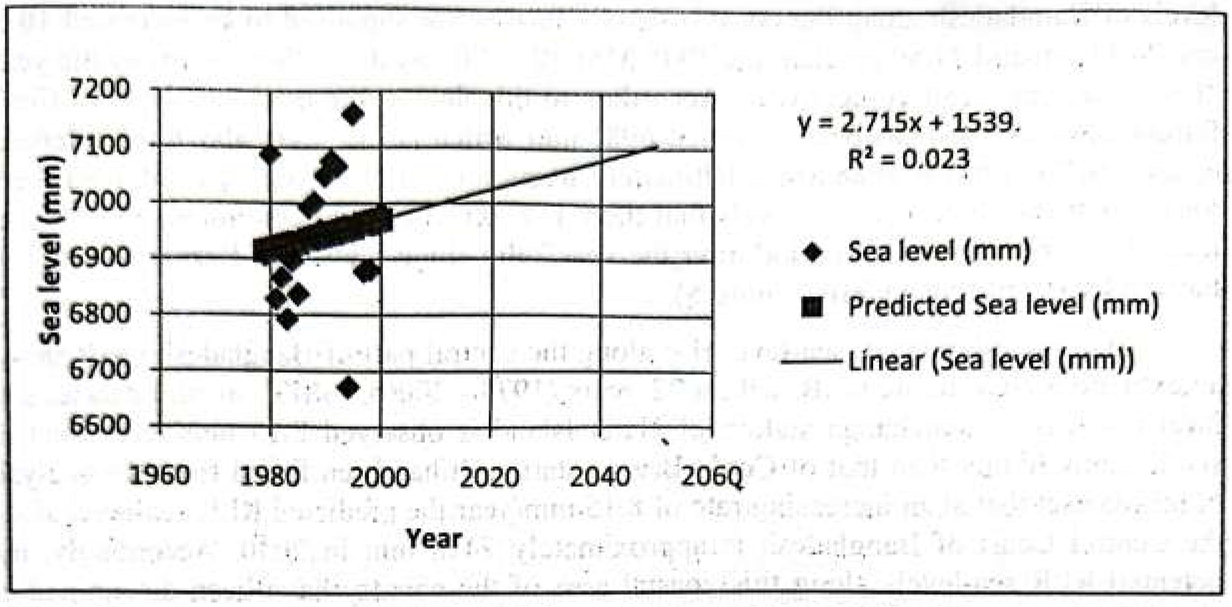
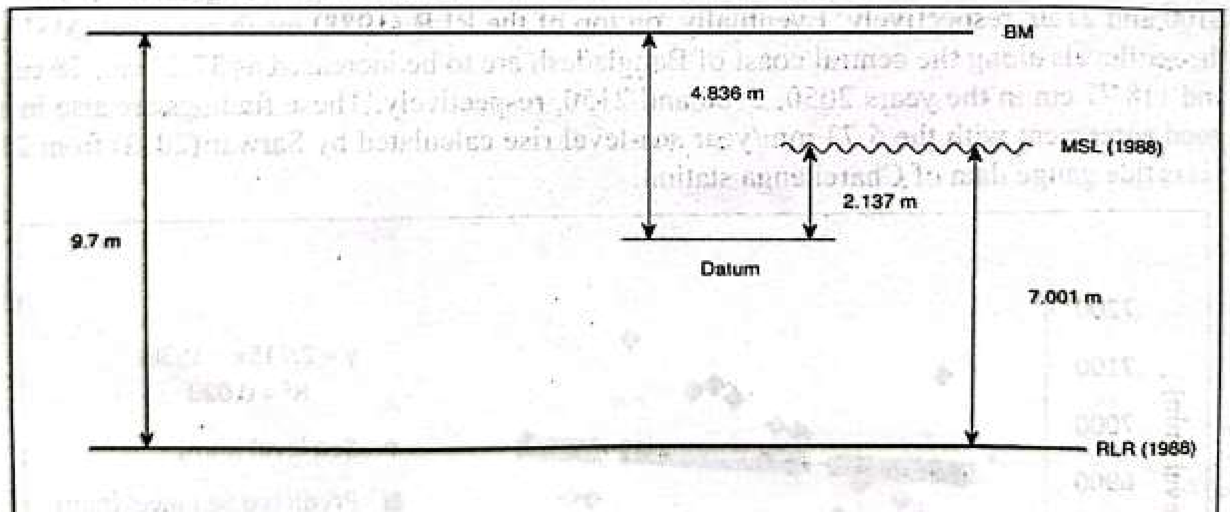


FIGURE 3: PREDICTED SEA-LEVEL RISE IN 2050 BASED ON ANNUAL PSMSL TIDE GAUGE DATA OF COX'S BAZAAR STATION DURING 1979 - 2000.



Source: PSMSL 2015

FIGURE 4: REVISED LOCAL REFERENCE (RLR) DIAGRAM FOR COX'S BAZAAR STATION

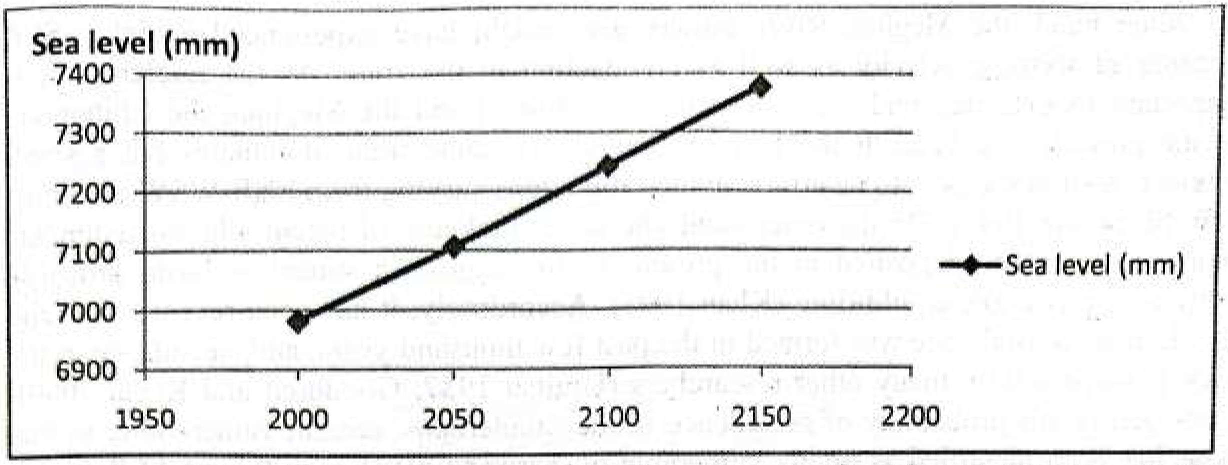


FIGURE 5: TRENDS OF SEA-LEVEL RISE DURING 150 YEARS PERIOD SINCE 2000 ALONG COX'S BAZAAR COAST OF BANGLADESH.

Moreover, the sea-level rise from 21 years (1983 - 2003) annual PSMSL dataset of Hiron Point station of the western coast of Bangladesh has been observed as 3.56 mm/year which is in a very good agreement with 3.38 mm/year sea-level rise determined by Sarwar (2013) for the same station. The study reveals that following a rate of 3.56 mm/year rising trend the RLR sea-levels at the Hiron Point station of the western coast will attain 7260.45 mm in 2050. The study also determines 7438.35 mm and 7616.25 mm sea levels along the Hiron Point coast of Bangladesh in the years 2100 and 2150, respectively. Thus, based on various information of the respective RLR diagram (PSMSL 2015) for the Hiron Point station, sea-levels above the Chart Datum (CD) for this station have been calculated as 2044.45 mm, 2222.35 mm and 2400.25 mm in 2050, 2100 and 2150, respectively. Finally, the predicted sea-levels at Hiron Point station of the western coast of Bangladesh have been determined as 21.95 cm, 39.74 cm and 57.5 cm, on top of the MSL (182.5 cm) of 1986, in the years 2050, 2100 and 2150, respectively.

Remarkably, being situated approximately 100 km apart towards the east of Hiron Point station, Khepupara shows a very high rate of sea level rise. Annual PSMSL tide gauge data for 23 years (1979 - 2000) period of Khepupara station demonstrate a trend of 18.66 mm/year sea-level rise alike the rate of sea-level rise (14.84 mm/year) determined by Sarwar (2013) for this station. According to the analysis of this dataset the predicted sea-levels along Khepupara coast of Bangladesh have been estimated 113.6 cm, 206.91 cm and 300.21 cm above the 1991 MSL (225.6 cm), in the years 2050, 2100 and 2150, respectively. However, trend of sea-level rise calculated from the tide-gauge dataset of this station is not consistent with any of the trends developed from others tide gauge datasets along eastern (Cox's Bazaar), central (Charchanga) and western (Hiron Point) coast of Bangladesh. It is assumed that being located in between the Sunderbans and Meghna estuary, Khepupara station area might experience a complex isostatic land movement process which is reflected by an unusual outcome of the respective tide data analysis. For example, sediment deposition in the central coast is dominated by silt but that in the Sunderbans is of mud or mangrove. This might results in apparently higher sea-level rise across Sunderbans, due to possible greater compaction, than that on the central coast. On the other hand, the Meghna River estuary area might have experienced a higher SLR because of tectonic activity as well as compaction in the zone. As the reference, it is important to note that under the floodplains of Surma and the Meghna, the Chittagong Strike prevails and beneath the Bay of Bengal, the same trend dominates but a small number of strikes appear to be erratic in their directions varying from ENE-WSW to almost NW-SE (Khan 1991). On the other hand, the large thickness of recent alluvial sediments being continuously deposited in the present basin suggests a subsiding basin probably maintaining isostatic equilibrium (Khan 1991). Accordingly, it has been revealed that the Sunderbans coastal zone was formed in the past few thousand years, and subsidence in the area is suspected by many other researchers (Umitsu 1987, Goodbred and Kuehl 2000). Considering this probability of subsidence in the Sunderbans, coastal vulnerability in this zone has been identified as highly vulnerable by Sarwar (2013) even though SLR in this area has been found quite normal by himself.

Additionally, in order to substantiate the outcomes of PSMSL mean sea-level datasets, particularly of the Cox's Bazaar station, the CPA (Chittagong Port Authority) provided annual tide gauge data of Sadarghat station, Chittagong have been analysed. For this purpose, trend of mean sea-level change of the region has been determined using tide gauge data of the period between 1995 and 2012. Based on this dataset, trend of sea-level rise along Chittagong coast of Bangladesh has been calculated as 3.93 mm/year (Figure 6) which is in a very good agreement with the trend (3.72 mm/year) of the monthly mean PSMSL sea-level data of Cox's Bazaar station determined under the present study. But based on a 16 years (1986 - 2001) BIWTA tide gauge dataset of Sadarghat station Sarwar (2013) found a sea-level fall of 11.75 mm/year which is completely contradictory with the outcome under current study. Of course, Sarwar (2013) himself calculated a relatively more reliable sea-level changing trend (6.1 mm/year rise) along Chittagong coastal zone on the basis of 29 years (1976 - 2005) BIWTA tide gauge dataset of Outfall Karnafulli station, located only 15 km inward from the Sadarghat station in the river Karnafulli. On the other hand, the eastern coastal zone of Bangladesh is treated as an active zone where uplifting is observed by Khan *et al.* (2005), though a fall in sea level by 11.75 mm/year seems to be very unusual with respect to any of the others nearby stations along Chittagong coast. However, based on the CPA tide gauge dataset of Sadarghat station, the present study reveals that following an increasing trend of 3.93 mm/year sea level rise, the relative sea-level along the Chittagong coast of Bangladesh might reach up to 2394 mm, 2590 mm and 2786 mm above Indian Spring Low water (ISLW) Chart Datum (CD), in the years 2050 (Figure 7), 2100 and 2150, respectively. Accordingly, the predicted sea-levels along the Sadarghat coast of Chittagong have been computed 13.1 cm, 32.7 cm and 52.3 cm higher than the sea-level of the year 2000 (226.3 cm above ISLW) in the years 2050, 2100 and 2150, respectively.

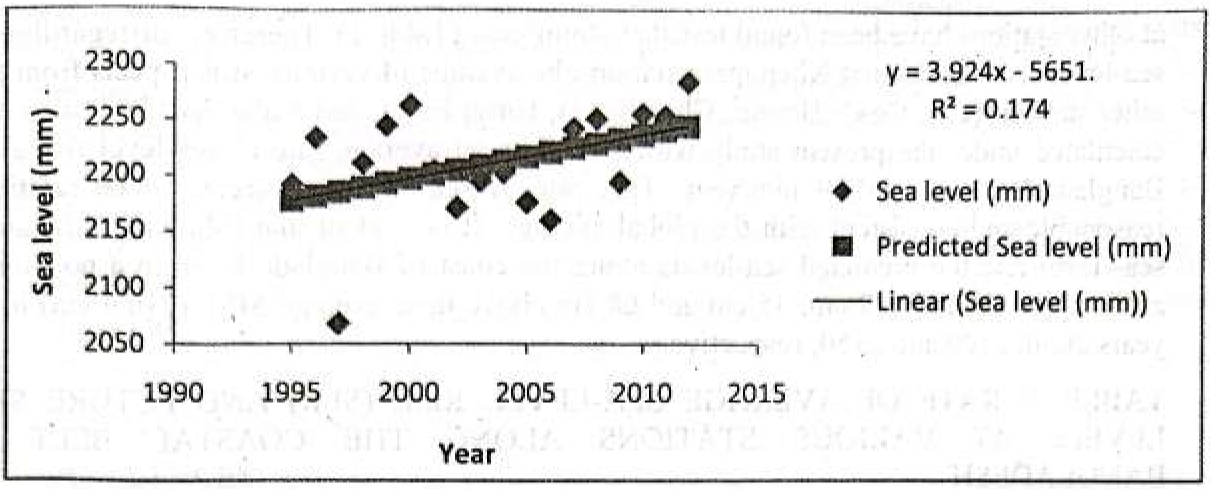


FIGURE 6: TRENDS OF ANNUAL SEA-LEVEL RISE BASED ON CPA TIDE GAUGE DATA OF SADARGHAT STATION, CHITTAGONG DURING 1995-2012.

Finally, the average trends of recent sea-level change and predicted sea-levels for 150 years period after the year 2000 have been calculated (Table 1) from the outcomes of four RLR tide gauge datasets (viz., Cox's Bazaar, Charchanga, Hironpoint and Khepupara stations) and one 'Metric' dataset (viz., Sadarghat station). It is evident that the value of average MSL determined from these tide datasets is 213.44 cm while the average of recorded sea-levels in 2000 for those stations has been found as 219.32 cm. Thus, the average rate of sea-level rise along the coast of Bangladesh has been calculated as 7.4 mm/year while average values of predicted sea levels have been found 40.32 cm, 77.33 cm and 114.33 cm, above their respective MSLs, in the years 2050, 2100 and 2150, respectively (Table 1).

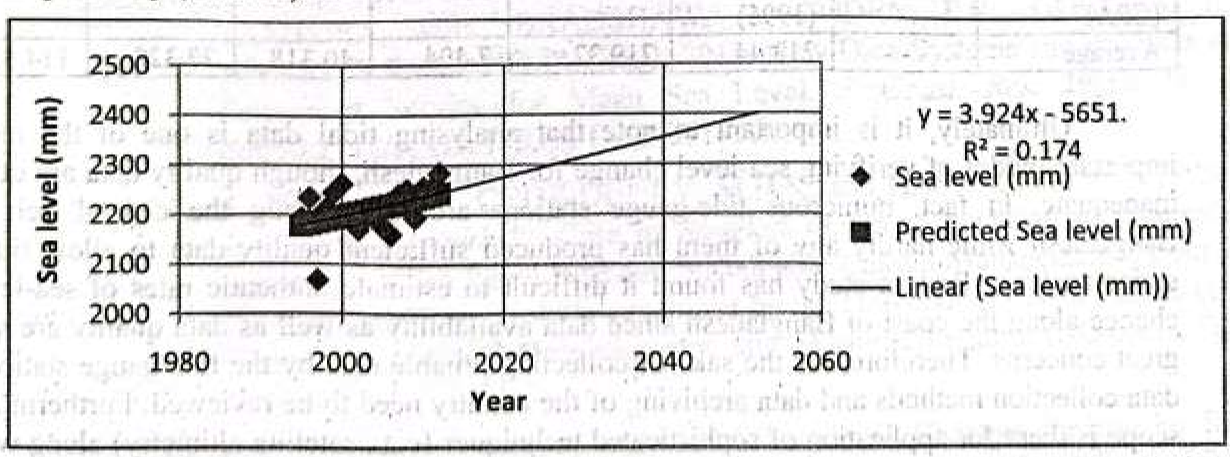


FIGURE 7: PREDICTED SEA-LEVEL RISE IN 2050 BASED ON THE CPA TIDE GAUGE DATA OF SADARGHAT STATION, CHITTAGONG DURING 1995-2012

On the other hand, having a general rising pattern, differences are there among estimated sea-level rises along various parts of the coast at local scale. Particularly, results obtained by analysing tide-gauge data of Khepupara station has shown a higher rate of 18.66 mm/year SLR while except Charchanga station (about 8 mm/year) the rates of SLR at other stations have been found less than 4mm/year (Table 1). Therefore, disregarding the sea-level rise obtained at Khepupara station, the average of various SLR aspects from four other stations (e.g., Cox's Bazaar, Charchanga, Hiron Point, and Sadarghat) have also been calculated under the present study which exhibits an average rate of sea-level rise along Bangladesh coast as 4.59 mm/year. This rate of sea-level rise seems to be relatively reasonable and consistent with the global average. It is evident that following this rate of sea- level rise the predicted sea-levels along the coast of Bangladesh are in a position to attain approximately 22 cm, 45 cm and 68 cm above their average MSL (210.4 cm) in the years 2050, 2100 and 2150, respectively.

TABLE 1: RATE OF AVERAGE SEA-LEVEL RISE (SLR) AND FUTURE SEA-LEVELS AT VARIOUS STATIONS ALONG THE COASTAL BELT OF BANGLADESH

Name of Stations	Datum	MSL (cm)	Recorded sea-level (cm) in 2000	Rate of SLR (mm/ year)	Predicted sea-levels (cm) above respective MSL		
					2050	2100	2150
Cox's Bazaar (PSMSL)	BIWTA (CD)	213.7 (1988)	211.7	2.72	10.54	24.11	37.69
Charchanga (PSMSL)	BIWTA (CD)	224.2 (1988)	217.6	8.15	37.23	78	118.77
Hiron Point (PSMSL)	BIWTA (CD)	182.5 (1986)	193.9	3.56	21.95	39.74	57.50
Khepupara (PSMSL)	BIWTA (CD)	225.6 (1991)	247.1	18.66	113.61	206.91	300.21
Sadarghat (CPA)	ISLWL	221.2 (1995)	226.3	3.93	18.26	37.88	57.5
Average	-----	213.44	219.32	7.404	40.318	77.328	114.33

Ultimately, it is important to note that analysing tidal data is one of the most important modes of verifying sea-level change for Bangladesh, though quality data are quite inadequate. In fact, numerous tide-gauge stations are there along the coastal belt of Bangladesh while hardly any of them has produced sufficient quality data to allow time-series analysis. Present study has found it difficult to estimate authentic rates of sea-level change along the coast of Bangladesh since data availability as well as data quality are still great concerns. Therefore, for the sake of collecting reliable data by the tide-gauge stations, data collection methods and data archiving of the country need to be reviewed. Furthermore, scope is there for application of sophisticated techniques (e.g., satellite altimetry) along with the conversion of metric data of various stations to RLR category in order to supplement the scanty tidal records. However, tide-gauge data of four stations (viz. Cox's Bazaar, Charchanga, Khepupara and Hiron Point) recorded in the RLR list of PSMSL database are the most authentic data sources to estimate sea-level rise along the coastal zones of Bangladesh. Consequently, under the present study mainly the data of these four stations along with CPA provided metric type dataset of Sadarghat station, have been examined with a view to understand the trends of sea-level change along the eastern coast (e.g., Chittagong - Cox's Bazaar coast) with reference to other coastal areas (e.g., central and western coasts) of the country. Since a very firm and continuous rising trend of sea-level has been observed, it is the matter of great concern that huge area of coastal Bangladesh is in a position to be captured by the sea within the next century. Therefore, importance is there to conduct very detailed and micro-scale researches to devise appropriate inundation scenarios mainly based on the surface configuration along eastern, central and western coast of Bangladesh. Finally, vulnerability assessment is essential to know the thread of coastal inundation in recent future with reference to the distress and extends of the sea-water injections to the coastal agricultural lands of the country in particular.

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