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# Trend of Sea-level-rise in West Bengal Coast

UTTAM KUMAR MANDAL[1*], DIBYENDU BIKAS NAYAK[1], ARPAN SAMUI[1], AMIT KUMAR JANA[1], SOURAV MULLICK[1], T.D. LAMA[1], A. K. BHARDWAJ[2], K. K. MAHANTA[1], S. MANDAL[1], S. RAUT[1], SUKANTA K. SARANGI[1] and D. BURMAN[1]

[1]ICAR-Central Soil Salinity Research Institute, Regional Research Station, Canning Town - 743 329, West Bengal

[2]ICAR-Central Soil Salinity Research Institute, Karnal – 132 001, Haryana

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**Coastal West Bengal, the low-lying landward extension of the continental shelf of the Bay of Bengal is one of the most vulnerable regions to climate change. Extreme climate –driven multifarious threats, including tidal gushes, deluge with sea water, permanent submergence of land, occurrence of salinity and water scarcity have taken a toll on food and environmental security of the region. The present article discusses sea-level–rise trends in the estuaries of West Bengal coast and compares it with other coastal region of India, based on estimates derived from tide-gauge data. The PSMSL (Permanent Service for Mean Sea Level) tide data have been analysed to detect the changes of sea level trend using Mann-Kendall non-parametric test and the magnitudes of such trends have been estimated using Sen's slope. The results affirmed that the rate of sea level changes for four stations, namely, Garden Reach, Diamond Harbour, Haldia and Gangra in West Bengal coast are found to be +7.48, +4.27, +3.24 and +2.06 mm yr$^{-1}$ whereas for the stations Mumbai and Cochin in west coast the rate of changes were +0.78 and +2.07 mm yr$^{-1}$ and for Chennai and Vishakhapatnam in east coast the rate of changes were +1.06 and +1.00 mm yr$^{-1}$. The rise in sea level in West Bengal coast was more during the last ten years (2005-2014) and it increased by 1.65% of long term average in the region. The information on rate of sea level would help in implementing defences against coastal flooding and salinity due to rising sea level.**

*(**Key words:** Sea level rise, Tide gauge, PSMSL, Global warming)*

Coastal ecosystems are important dynamic environments that are constantly reshaped and reformed. Relative sea/land level changes are fundamental to people living on the coast. The lands in West Bengal coast are degraded with low productivity due to soil and water salinity, waterlogging, drainage congestion, brackish underground water, besides the climatic constraints. The Sundarbans, the largest contiguous mangrove ecosystem in the world occupy the major part of West Bengal coast. Owing to the unique geographical location, the entire Sundarbans are under constant threat of powerful nor'westers, bay cyclones, tidal surges and constant changes of courses by the numerous distributaries of the river Ganges in the active part of the delta. A recent study of global deltas showed that the entire Bengal delta is sinking at a perilous rate due to sediment compaction from the removal of oil, gas and water from the inland delta's underlying sediments, the trapping of sediment in upstream reservoirs, flood plain engineering, and rising sea level (Syvitski *et al*., 2009). The Government of India mentioned in Parliament (based on studies conducted by Indian National Centre for Ocean Information Services, Hyderabad) that sea levels along the Indian coast are projected to rise by 3.5 inches to 34 inches by the end of the century due to global warming, posing a potent threat to the western coastline, including Mumbai, as well as to major deltas in east India (The Times of India, December 22, 2018). Based on global sea level data and modeling, Eriscson *et al*. (2006) have estimated that the sea level rise of the Bay of Bengal is the world's highest, at >10 mm yr$^{-1}$. Other studies have confirmed this trend, but with rates ranging from 4.0 mm yr$^{-1}$ in the western zone to 7.8 mm yr$^{-1}$ in the eastern zone (Alam and Ahmed, 2010; Han *et al*., 2010; SMRC, 2003; Unnikrishnan and Shankar, 2007). A 2007 report by UNESCO "Case Studies on Climate Change and World Heritage" has predicted 45 cm rise in sea level around Sundarbans likely by the end of the 21st century. The Intergovernmental Panel on Climate Change (IPCC) in its fourth assessment report presented similar observational evidence of climate change in the coastal regions and indicated the evidence of increased ocean temperature, changes in precipitation, corresponding upstream river discharge and rising sea level. This would lead to higher coastal flooding and increased salinity (Parry, 2007). Nandy and Bandyopadhyay (2010) estimated the trends of annual sea level records of four tidal observatories in the Hugli estuary - Sagar, Gangra, Haldia and Diamond Harbour of the Ganges-Brahmaputra delta from the records of Permanent Service for Mean

**Corresponding author*: E-mail: uttam_icar@yahoo.com

Sea Level (PSMSL). The rates of sea level changes for the stations were found to be-3.82, +0.89, +2.43 and 4.85 mm $yr^{-1}$ respectively. Data extracted from Holgate *et al.* (2013) and the Permanent Service for Mean Sea Level, also illustrates that relative sea-level rise varied from 4 mm $yr^{-1}$ (Hiron Point) to 19 mm $yr^{-1}$ (Khepupara) in Bangladesh part of *Sundarbans* (Brown and Nicholls, 2015).

The *Sundarbans* delta was built by the hydrologic discharge of the Ganges-Brahmaputra (GB) river system. The GB river system having discharge which is second only to that of the Amazon River in magnitude, traditionally carried extremely large sediment loads (~109 t $yr^{-1}$) from different parts of the Himalayas and the upper parts of the Bengal delta (Goodbred and Kuehl, 2000) and is highly vulnerable to anthropogenic disturbance. The GB river system has undergone some drastic changes in the last century (Mikhailov and Dotsenko, 2007). Construction of dikes and polders along the upland river banks has changed the sedimentation process of the rivers. Large scale dike building in most rivers in the Bengal basin has been initiated in the 1960s. The most recent and one of the most significant anthropogenic disturbances of the Ganges occurred in 1975 when India completed a dam on the river in Farakka, West Bengal, that diverted certain amount of water from the Ganges about 425 km upstream of its confluence.

The literature on the trend of sea level variations of the West Bengal coast is inconsistence and there is a need to continuously monitor the change of sea level in the region. The consequence of climate change on sea level rise is of particular importance to coastal areas because of its impact is devastating. The area is disadvantaged by poverty, food insecurity, environmental vulnerability and limited livelihood opportunities (Sanchez-Triana *et al*., 2014). People can remember the devastation of cyclone *Aila* in West Bengal during 2009, super-cyclone in Orissa during 1999, as well as *Tsunami* in eastern coast during 2004 when thousands of hectares of fertile agricultural land and adjoining mangrove forests were turned into a vast wasteland due to ingress of saline sea water. The present study consists of the pattern of sea level change reflected in the tidal records of PSMSL pertaining to the stations along the Hugli estuary of West Bengal, as well as few stations of east and west coast of India for future adaptation decision on sea level rise in vulnerable coastal West Bengal.

## MATERIALS AND METHODS

The estuary of River Hugli in West Bengal was selected for the present study. Hugli is the western most distributary of the Ganga-Brahmaputra delta. The long-term sea-level data for the present study was sourced from permanent service for mean sea level (PSMSL, 2018) which collects, publish, analyse and interpret the sea level data from the global network of tide gauges.

### Tide gauges

Historically sea-level measurements were made using simple measuring poles or "tide staffs" until around 1830, when self-recording gauges with mechanical floats and stilling wells were introduced. Tidal poles and float gauges were the primary means of sea-level measurement for over 150 years and continue to operate at some locations today. While still part of modern-day tide gauge instrumentation, these technologies has since been superseded by pressure gauges, acoustic/ultrasonic gauges, and radar gauges. In recent years new technologies have developed allowing for real-time, remote tide information to be published online via a solar powered wireless connection to a tide sensor. At some places tide records cover centuries, for example in Amsterdam where data dating back to 1700 is available. In case of India, Mumbai tide gauge data started operating since 1878.

The oceans respond to the gravitational attraction of the Moon and the Sun, and the solar radiation, to produce the tides, which are normally the predominant signals in sea level records. The tides are easy to distinguish from other components of sea level variation (*e.g*. storm surges) because they have well defined periods, whereas other processes tend to occur at irregular intervals. To make accurate records, tide gauge at fixed stations measure water level over time. Gauges ignore variations caused by waves with periods shorter than minutes. These data are compared to the reference (or datum) level usually called mean sea level. Tide gauge sensors continuously record the height of the water level with respect to a height of reference surface close to the geoid. The geoid is the shape that the ocean surface would take under the influence of the gravity and rotation of Earth alone, in the absence of other influences such as winds and tides. In tide gauge, water enters the device by the bottom pipe (far end of the tube), and electronic sensors measure its height and send the data to a tiny computer.

There are fundamentally four types of measuring technology in tide gauge (IOC Manual, 2006).

**(a) A stilling well and float:** in which the filtering of the waves is done through the mechanical design of the well. The majority of historical sea level data were collected from float and stilling-well tide gauges with analogue charts, many of which are still in existence.

**(b) Pressure systems:** in which sub-surface pressure is monitored and converted to height based on knowledge of the water density and local acceleration due to gravity. Such systems have additional specific application to ocean circulation studies in which pressure differences are more relevant than height differences.

**(c) Acoustic systems:** in which the transit time of a sonic pulse is used to compute distance to the sea surface.

**(d) Radar systems:** similar to acoustic transmission, but using radar frequencies.

The measurements made by a tide gauge provide the relative movement of the sea level with respect to the land. Of course, neither land nor sea levels are constant over long periods of time. There are vertical movements of the land associated with a range of natural processes, such as co-seismic activity (earthquakes), in addition to glacial isostatic adjustment (post-glacial rebound) and plate tectonics and with a range of human activities (e.g. groundwater pumping). To understand sea level changes properly, the different sea level and land signals have to be decoupled. This is achieved by careful definition of the tide gauge datums (IOC Manual, 2006).

In India a real time network of tide gauges has been established by Survey of India (SOI) and National Institute of Ocean Technology (NIOT). The network comprises of 50 (36 by SOI and 14 by NIOT) state-of-the-art tide gauges transmitting real time data through satellite communication to Indian Nation Centre for Ocean Information (INCOIS) at Hyderabad, SOI at Dehradun and NIOT at Chennai simultaneously for processing and interpretation (www.surveyofindia.gov.in and www.incois.gov.in). Trend of sea level rise is assessed based on available data source of tide height. Out of 36 tide gauge stations under SOI, 30 stations are equipped with digital tide gauges co-located with GPS receiver to monitor sea level variation and crustal movement in real time data communication facilities. This tide data is also being mirrored to National Tsunami Warning Center, INCOIS, Hyderabad on real time for further analysis and issuance of alert/ warning in case of extreme events like tsunami and storm surges taking place in the region. The Survey of India, Dehradun is authorized to supply tide gauge data of India to PSMSL database.

## PSMSL

The PSMSL (PSMSL: www.psmsl.org) is the world's archive of tide-gauge records established in 1933, based in Liverpool at the National Oceanography Centre, UK. The database of the Permanent Service for Mean Sea Level (PSMSL) contains monthly and annual mean values of sea level from almost 2000 tide gauge stations located around 200 national authorities, responsible for sea level monitoring in the country around the world. The PSMSL tide gauge data are presented in two formats: 'metric' and 'revised local reference' (RLR) and are freely accessible. The later dataset is released after year-to-year checks are performed relative to a common datum and is fit for analysis of long-term changes in sea level.

The "Revised Local Reference" data set has a continuous history of benchmark surveys for each gauge, ensuring that sea level is measured relative to a known land-based datum. RLR datasets represent changes in relative sea level. At a particular station, they reflect all possible local and regional factors that may cause vertical land movements apart from the secular rise in the global sea level. These factors include glacial isostatic adjustments, tectonic movement, subsidence due to sediment compaction or groundwater extraction and rise in the water level due to infilling or constriction of estuaries. The RLR datum is arbitrarily taken as approximately 7 m below the mean sea level (MSL) to avoid negative values in gauge records. The PSMSL, RLR data were the source of all major works on long-term analysis and projection of global sea level from which the assessment reports of IPCC (Intergovernmental Panel on Climate Change) were prepared.

### Data availability

Although some authors mention that a 20 year record of mean annual data is adequate for computation of the rate of sea level change, a 50 year record is considered preferable for offsetting all local and short-term variations like effects of ENSO (*El-Nino* southern oscillation) and tropical storms (Nandy and Bandyopadhyay, 2011). Among the data of 27 Indian stations available at the PSMSL only nine stations (Chennai, Cochin, Mumbai, Visakhapatnam, Sagar, Tribeni, Haldia, Diamond Harbour, Garden Reach) have 40 or more years of usable RLR records. There are eight PSMSL sites in West Bengal and they all are located by the Hugli from its confluence near Sagar to 208 km upstream (Tribeni). Data from all of these stations are not usable for time series analysis, however four stations Sagar, Gangra, Haldia and Diamond Harbour are relatively free from the influence of upstream discharge and possess quality data of sufficient duration without unexplained datum shifts or anomalous values (spikes) are used for this study (Fig. 1, Table 1).

Garden Reach has 71 years tide data and it is the only station under INCOIS tide gauge database from West Bengal. Two stations Chennai and Visakhapatnam from east coast and Mumbai and Cochin from west coast which have long term database were also chosen for the study. Time series analyses were performed on these nine datasets to bring out the annual rates of changes in sea level in the coastal region.

### Methodology for trend analysis

A non-parametric Mann-Kendall (MK) is used for identifying trends in time-series data. A non-parametric test is taken into consideration over the parametric one since the distribution of the data is not known. The MK test checks the null hypothesis of no trend versus the alternative hypothesis of the existence of increasing or decreasing trend. Each data value is compared to all subsequent data values. The initial value of the MK statistic, $\tau$ (tau), is assumed to be 0 (*i.e.*, no trend). If a data value at a later time is higher than a data value of an earlier time, $\tau$ is incremented by 1. On the other hand, if the data value at a later time is lower than a data value sampled

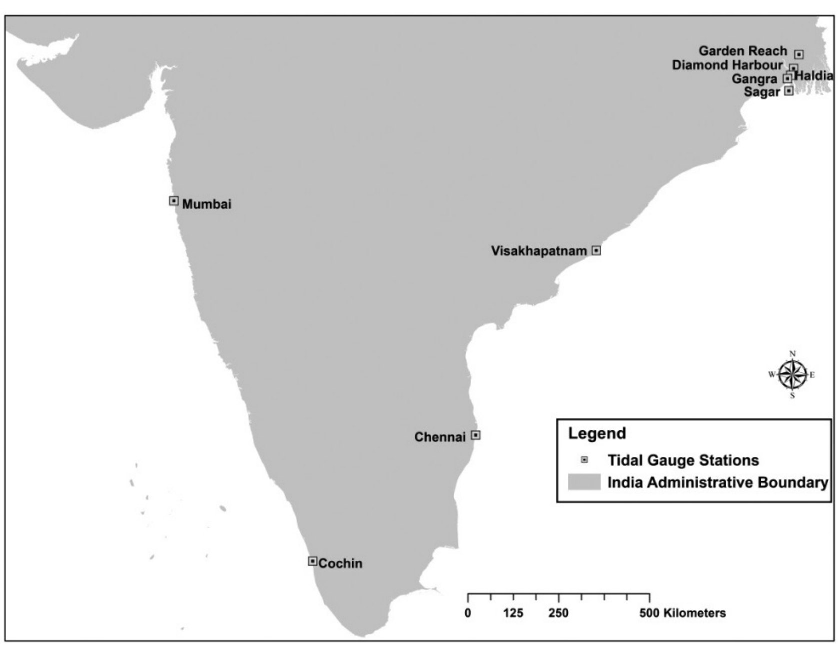



***Fig. 1.*** *Geographical location of tide gauges whose records were analysed in the present study*

***Table 1.*** *Data status of the PSMSL stations along the Hugli estuary, West Bengal and few stations in east and west coast of India (Data from PSMSL)*

| Station | Latitude and longitude | Distance from sea (km) | Periods covered in PSMSL RLR records | Available annual data (in years) | Usable annual data (in years ) | Remarks |
|---|---|---|---|---|---|---|
| Sagar (Saugor) | 21.65° N & 88.05° E | 0.0 | 1937-1987 (51 yr) | 48 | 48 | Data used in the present study |
| Dublet (Saugor) | 21.63° N & 88.13° E | 0.0 | 1882-1885 (4 yr) | 4 | 4 | Sample size too small for analysis |
| Gangra | 21.95° N & 88.07° E | 31.4 | 1974-2006 (33 yr) | 27 | 27 | Data used in the present study |
| Haldia | 21.95° N & 88.07° E | 43.4 | 1971-2006 (36 yr) | 34 | 33 | Data used in the present study |
| Diamond Harbour | 22.2° N & 88.17° E | 70.1 | 1948-2014 (67 yr) | 65 | 65 | Data used in the present study |
| Garden Reach | 22.55° N & 88.30° E | 142.1 | 1932-2014 (83 yr) | 71 | | Data integrity questionable due to unexplained post-1975 datum shift. Influenced by fluvial discharge, entire dataset flagged by PSMSL. The station is under INCOIS database and used for present study. |
| Kidderpore | 22.53° N & 88.33° E | 143.9 | 1882-1931 (50 yr) | 22 | 0 | Data integrity questionable due to unexplained post-1893 datum shift. Influenced by fluvial discharge, entire dataset flagged by PSMSL. |
| Tribeni | 22.98° N & 88.40° E | 204.8 | 1962-2006 (45 yr) | 44 | 0 | Data integrity questionable due to probable datum shift in mid 1970s. Influenced by fluvial discharge, |
| Mumbai | 18.92° N & 72.83° E | 0.0 | 1878-2010) (133 yr) | 118 | 118 | Data used in the present study |
| Cochin | 9.97° N & 76.27° E | 0.0 | (1939-2013) (75 yr) | 57 | 57 | Data used in the present study |
| Chennai | 13.10° N & 80.30° E | 0.0 | (1916-2012) (97 yr) | 48 | 48 | Data used in the present study |
| Visakhapatnam | 22.98° N & 88.40° E | 0.0 | (1937-2013) (77 yr) | 57 | 57 | Data used in the present study |

earlier, τ is decremented by 1. The net result of all such increments and decrements yields the final value of τ.

$$\tau = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sign}(x_j - x_i)$$

The application of trend test is done to a time series $x_i$ that is ranked from i = 1, 2 …n-1 and $x_j$, which is ranked from j = i+1, 2 ….n. Each of the data points $x_i$ is taken as a reference point which is compared with the rest of the data points $x_j$ so that,

$$\mathrm{sign}\,(x_j - x_k) = 1 \text{ if } x_j - x_k > 0,$$
$$= 0 \text{ if } x_j - x_k = 0$$
$$= -1 \text{ if } x_j - x_k < 0$$

A high positive value of τ is an indicator of an increasing trend, and a low negative value indicates a decreasing trend. The p-value for the MK test indicates the absence or presence of any statistically significant trends. If the computed value of $p>p_{\alpha}$ the null hypothesis ($H_o$) is rejected at $\alpha$ level of significance in a two-sided test. In this analysis, the null hypothesis was tested at 95% confidence level.

The magnitude of the trend is predicted by the Sen's estimator (Sen, 1968). Here, the slope ($T_i$) of all data pairs is computed as

$$T_i = \frac{x_j - x_k}{j - k}$$

Where $x_j$ and $x_k$ are considered as data values at time j and k (j>k) correspondingly. The median of these N values of $T_i$ is represented as Sen's slope estimator of slope.

Sen's estimator is computed as $Q_{med}$ = T(N+1)/2 if N appears odd, and it is considered as $Q_{med}$ = [TN/2 +T (N+2)/2 ]/2 if N appears even. At the end, $Q_{med}$ is computed by a two sided test at 100(1-$\alpha$) % confidence interval and then a true slope can be obtained by the non-parametric test. Positive value of $Q_{med}$ indicates an upward or increasing trend and a negative value of $Q_{med}$ gives a downward or decreasing trend in the time series. We also calculated the slope of linear regression line for time series tide gauge data.

## RESULTS AND DISCUSSIONS

We could obtain hourly digital tide gauge database from 5[th] January, 2011 to 31[st] March, 2015 of Garden Reach station from INCOIS, Hyderabad. The diurnal variation of the water level of Garden Reach showed that tidal regime followed a semi-diurnal (2 cycles per day) pattern and there were two nearly equal high and low tides each day (Fig. 2). The tidal regime varies from place to place from diurnal (1 cycle per day), semi-diurnal and can be extended to ter-diurnal (third of a day period) tides and tides of even shorter period or mixed type (IOC Manual, 2006). In most regions of the world the tide is dominated by semi-diurnal components as we found in Garden Reach. The diurnal variation was compared for three seasons and the results showed that amplitude or tidal range between peak and trough of tide data was maximum during rainy season (July) followed by summer (April) and lowest during winter (December, Fig. 2).

The PSMSL monthly records indicate that there

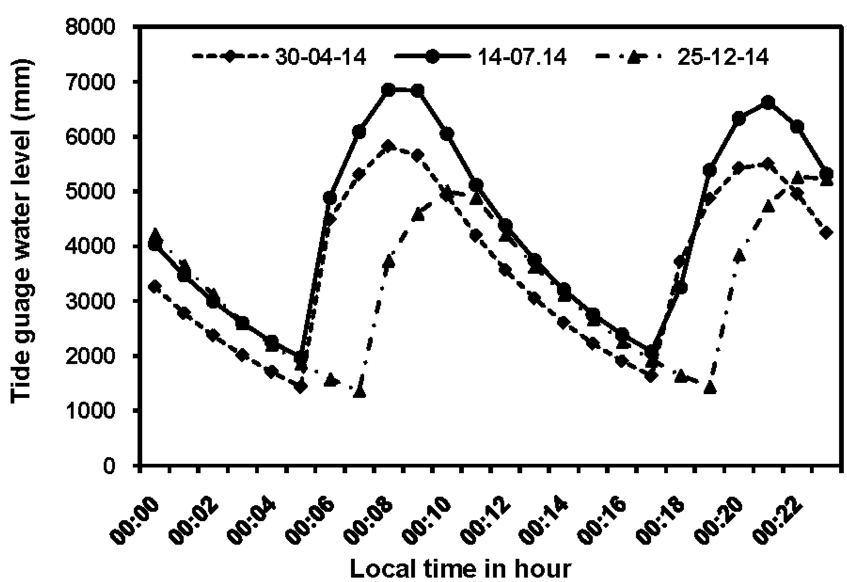



***Fig. 2.*** *Diurnal pattern of tide gauge water level in Garden Reach (Data provided by INCOIS, India)*

was marked intra-annual variation in tide gauge height (Fig. 3). August recorded maximum sea level in Hugli estuary whereas maximum value of sea level was observed in December in West coast and November in east coast of India. On the other hand minimum tide gauge height was recorded during February, September and March, respectively in Hugli estuary, west and east coast of India. The sea level varied by 582 to 1140 mm between February and August at Hugli estuary, whereas maximum and minimum sea level height varied by 117-177 mm in west coast and 200 to 427 mm in east coast. The sea level fluctuates throughout the year in Mumbai and shows three prominent peaks in March, June and December whereas Cochin is bimodal with smaller peak in June and the higher in December. Entire estuary showed unimodal pattern of monthly sea level fluctuations. Bimodal peak in November and June and in October and June was also found in Chennai and

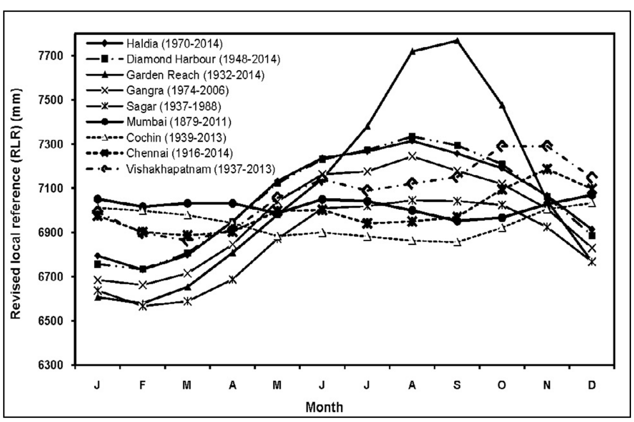



***Fig. 3.*** *Average monthly fluctuations of sea level at selected tidal stations (data from PSMSL).*

Visakhapatnam, respectively. The intra annual variation was higher in east coast than west coast may be because of variation of wind-forced coastal circulation and the salinity gradient between east and west coast of India (Shankar and Shetye, 2001).

The analysis of long period average tide data from five estuary stations in West Bengal coast established that the average annual tide water level in the region was 6850 to 7071 mm with a coefficient of variation between 0.57% to 2.56% (Table 2). The average annual tide water level in west coast was 6935 mm to 7017 mm and in east coast it was 6993 to 7076 mm. Among all the studied stations, the mean tide gauge height value was maximum in Visakhapatnam. The Mann-Kendall test affirmed significant positive trend of annual tide data in coastal region except in Sagar Island (Table 2). An anomalous feature of the records is that the Sagar observatory registered decrease in sea level an observation difficult to fit in the general scenario of increasing sea level in all stations. The Sen's slope indicated that the rate of sea level changes for four stations Diamond Harbour, Garden Reach, Haldia and Gangra in Hugli estuary are found to be +4.27, +7.48, +3.24 and 2.06 mm $yr^{-1}$ whereas for the stations Mumbai and Cochin in West coast the rate of changes were 0.78 and 2.07 mm $yr^{-1}$ and for Chennai and Vishakhapatnam in east coast the rate of changes were 1.06 and 1.00 mm $yr^{-1}$. Similar trend was also recorded by Unnikrishnan *et al*. (2015) and Nandy and Bandyopadhyay (2011). The estuary's sea level trends denote a positive relationship with the distance from the sea. As one moves northward from the mouth of the estuary at Sagar to its apex at Garden Reach, the rate of sea level change escalates at 0.097 mm per year per km (Fig. 4). A linear regression

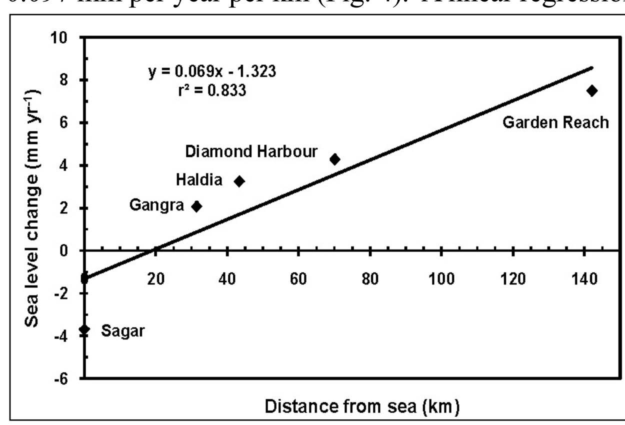
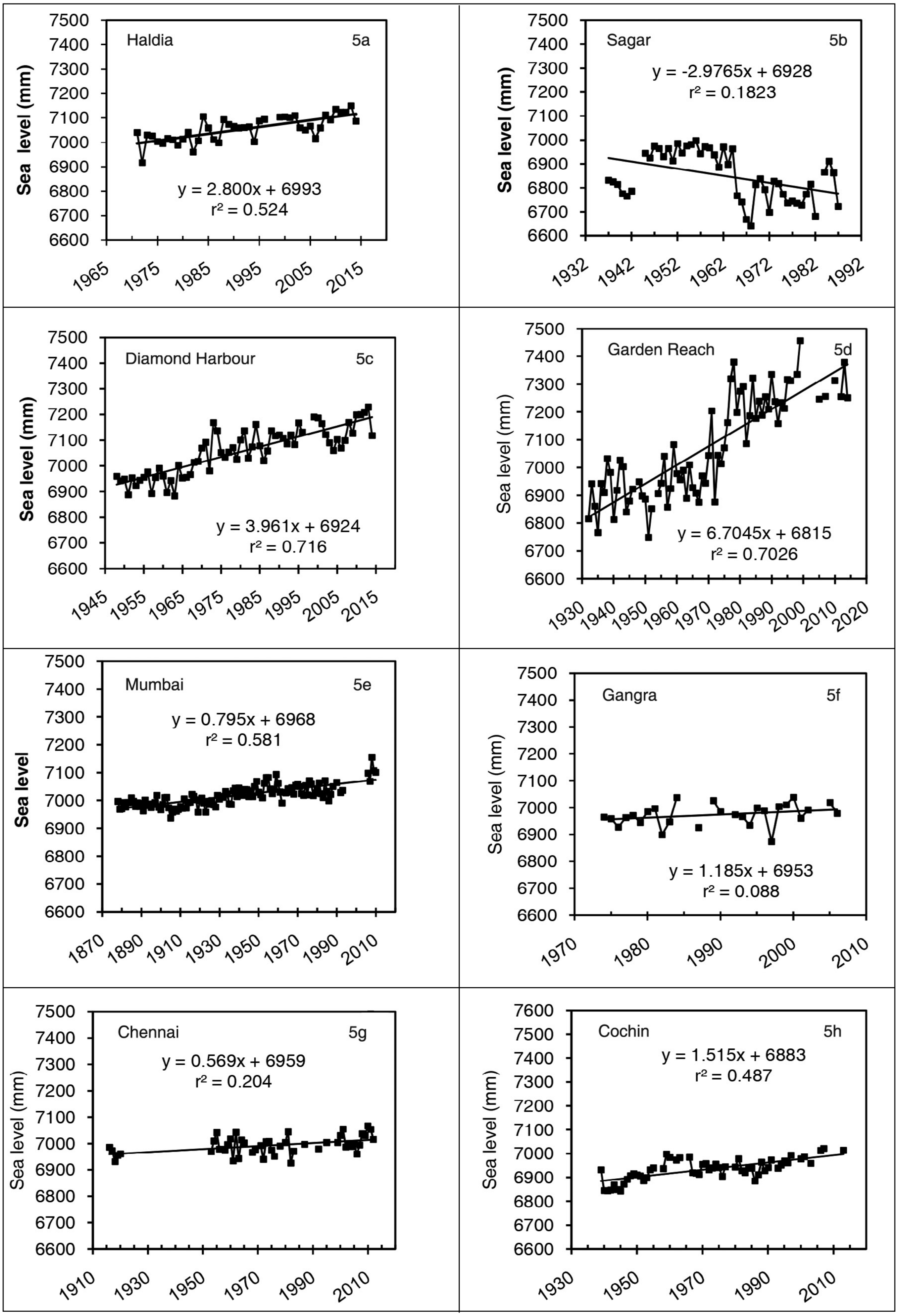



***Fig. 4.*** *Relation between landward distance and rate of sea level change at tidal observatories of the Hugli estuary around Sundarbans*

equation was also developed for time series data for all the stations (Fig. 5). The slope of the regression line in most of the stations was comparatively less than Sen's slope in non-parametric test (Table 2).

To understand the decadal behaviour of sea level means values were compared with the decadal means (Fig. 6). The station Sagar was not considered for decadal change as no recent database is available. It was observed that in the last decades of available data the sea level increased by 117 mm from average sea level in estuary of West Bengal coast, whereas in other stations of east coast it was 22-52 mm and in West coast it was 82 to 90 mm.

Current and future climate change data on sea level


Haldia
5a
y = 2.800x + 6993
r² = 0.524
Sea level (mm)
Sagar
5b
y = -2.9765x + 6928
r² = 0.1823
Sea level (mm)
Diamond Harbour
5c
y = 3.961x + 6924
r² = 0.716
Sea level (mm)
Garden Reach
5d
y = 6.7045x + 6815
r² = 0.7026
Sea level (mm)
Mumbai
5e
y = 0.795x + 6968
r² = 0.581
Sea level
Gangra
5f
y = 1.185x + 6953
r² = 0.088
Sea level (mm)
Chennai
5g
y = 0.569x + 6959
r² = 0.204
Sea level (mm)
Cochin
5h
y = 1.515x + 6883
r² = 0.487
Sea level (mm)

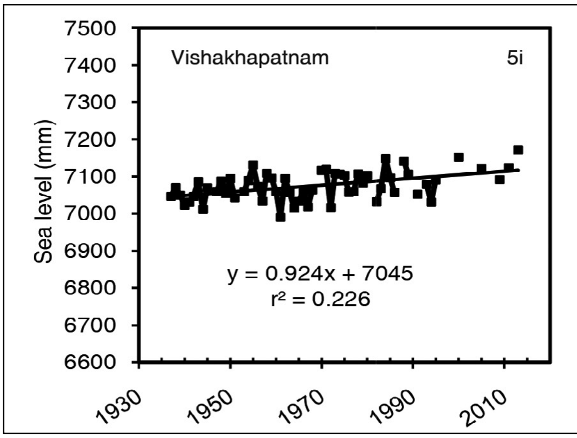



*Fig. 5.* *Changes in annual sea level at tidal stations*

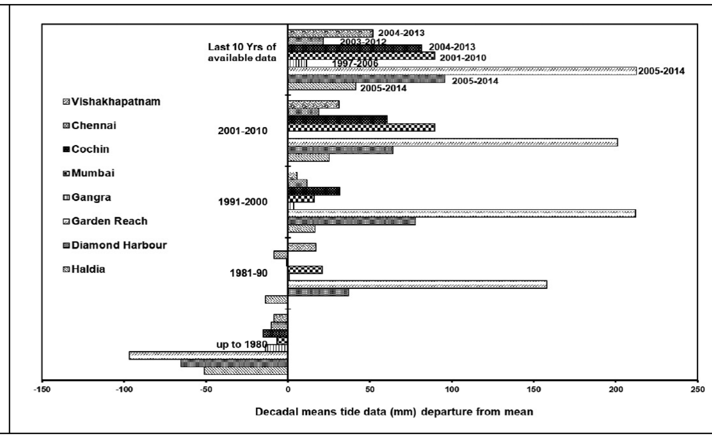



*Fig. 6.* *Decadal means of tide gauge data departure from annual mean of selected tidal stations*

***Table 2.*** *Trend analysis of long period tide gauge data at Hugli estuary West Bengal along with East and West coast of India*

| Station | Minimum | Maximum | Mean | C.V. | Kendall's tau | P-value | Sen's slope | Slope of linear regression line |
|---|---|---|---|---|---|---|---|---|
| Haldia | 6918 (1972) | 7150 (2013) | 7055.69 | 0.72 | 0.530 | < 0.0001 | 3.24 | 2.80 |
| Diamond Harbour | 6883 (1963) | 7230 (2013) | 7056.98 | 1.30 | 0.659 | < 0.0001 | 4.27 | 3.96 |
| Garden Reach | 6750 (1951) | 7457 (1999) | 7071.58 | 2.56 | 0.614 | < 0.0001 | 7.48 | 6.70 |
| Gangra | 6874 (1997) | 7039 (2000) | 6973.19 | 0.57 | 0.277 | 0.049 | 2.06 | 1.19 |
| Sagar | 6641 (1968) | 6998 (1956) | 6850.06 | 1.48 | -0.319 | 0.0016 | -3.69 | -2.98 |
| Mumbai | 6937 (1905) | 7156 (2008) | 7016.91 | 0.53 | 0.563 | < 0.0001 | 0.78 | 0.80 |
| Cochin | 6843 (1945) | 7022 (2007) | 6934.70 | 0.64 | 0.521 | < 0.0001 | 2.07 | 1.52 |
| Chennai | 6926 (1982) | 7067 (2010) | 6993.10 | 0.49 | 0.292 | 0.004 | 1.06 | 0.57 |
| Visakhapatnam | 6990 (1961) | 7172 (2013) | 7075.81 | 0.56 | 0.286 | 0.002 | 1.00 | 0.92 |

rise is set to have a number of impacts, particularly on coastal systems. Such impacts include increased coastal erosion, higher storm-surge flooding, inhibition of primary production processes, more extensive coastal inundation, changes in surface water quality and groundwater characteristics, increased loss of property and coastal habitats, increased flood risk and potential loss of life, loss of nonmonetary cultural resources and values, impacts on agriculture and aquaculture through decline in soil and water quality, and loss of tourism, recreation, and transportation functions.

Owing to the great diversity of coastal environments, and differences in the resilience and adaptive capacity of ecosystems, the projected relative sea level impacts will be highly variable in time and space. River deltas and small island states are particularly vulnerable to sea-level rise. As the coastal areas of West Bengal have large population growth, that puts in more people at risk from sea level rise.

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