Dr. Meenakshi Chatterjee's contribution to the Sundarban Estuarine Programme

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Abstract:

Dr. Meenakshi Chatterjee was an associate professor of Dept. of Mathematics, Basanti Devi College, Kolkata and also a visiting faculty in the School of Oceanographic studies, Jadavpur university who worked on various interesting fields of applied mathematics. She played a crucial role in the research project funded by INCOIS, Ministry of Earth Sciences, Government of India under INDOMOD programme which was the first observational programme for systematic monitoring of tidal variations within Sundarban Estuarine system.Situated in the coastal state of West Bengal, the Sundarbans Estuarine System (SES) is India's largest monsoonal, macro-tidal delta-front estuarine system. It comprises the southernmost part of the Indian portion of the Ganga–Brahmaputra delta bordering the Bay of Bengal. The Sundarbans Estuarine Programme eastern (SEP), conducted during 18–21 March 2011 (the Equinoctial Spring Phase), was the first comprehensive observational programme undertaken for the systematic monitoring of the tides within the SES. The 30 observation stations, spread over more than 3600 km^2, covered the seven inner estuaries of the SES (the Saptamukhi, Thakuran, Matla, Bidya, Gomdi, Harinbhanga, and Raimangal) and represented a wide range of estuarine and environmental conditions. At all stations, tidal water levels (every 15 minutes), salinity, water and air temperatures (hourly) were measured over the six tidal cycles. This work may give an over view of her valuable contribution in our understanding of complex weather soil and tidal patterns in this very ecologically vulnerable and important deltaic plains.

Keywords:

Estuaries; Sundarbans; Tidal variations; Salinity, coastal state

Prologue :

A survey on the available literature reveals that most studies in SES are on river Hoogly.

Very little is known about the tides in the SES, how they amplify or decay as they propagate northwards along each estuarine channel, whether the patterns of amplification or decay are similar or different for each estuary. In order to answer these questions and know more about the tidal patterns in the SES estuaries, the Sundarbans Estuarine Programme (SEP) was undertaken during 18-21, March, 2011, and continued in intermittent spells till 2013. It was conducted as a part of the research project at SOS, Jadavpur University (Sanction No. F/INCOIS/INDOMOD-11-2007/2691 dated December 20, 2007) funded by INCOIS (Indian National Center for Ocean Information Services, Ministry of Earth Sciences (MoES), Government of India, under the INDOMOD programme. Dr Meenakshi Chatterjee as an Investigator for this project studied the variations of tidal water levels at 30 locations situated on various estuaries of the SES.

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The largest delta in the world, formed by the distributaries of the rivers Ganga and Brahmaputra (Seidensticker and Hai 1983; UNEP WCMC1987; Papa et al. 2010), is shared by Bangladesh and India (figure 1). On its west, the delta is bordered by river Hooghly (also Hooghly, Hugli) and on its east by river Meghna (figure 1). The Bay of Bengal forms the southern boundary of the delta, which includes in its southern fringes, the dense natural mangrove forests, the Sundarbans. The Indian part of the Sundarbans delta is about 40% of the total area. In this paper, we refer to this region lying between 21.25^0N–22.5^0N and 88.25^0E–89.5^0E as the Sundarbans Estuarine System (hereafter called SES). The SES is the largest monsoonal, macrotidal, delta-front, estuarine system in India and the most complex of the 100-odd estuaries that exist along the Indian coast. It's 9630 km^2 area is spread over the entire South 24 Parganas and the southern parts of the adjoining North 24 Parganas, the two southernmost districts of the state of West Bengal (figure 1).

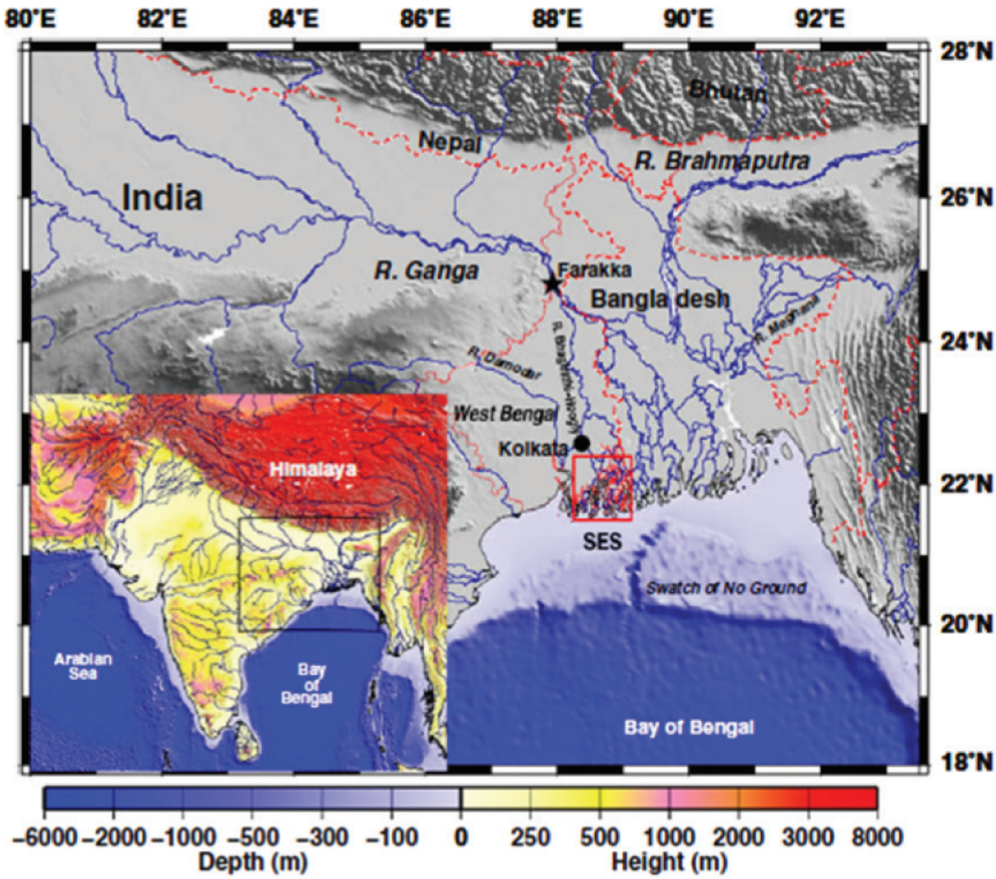

Figure 1. The Physical setting of the Ganga-Brahmaputra river system and the delta system. The inset shows topographic and bathymetric detail of the entire Indian subcontinent (the black marks the region plotted) with the major rivers (in blue), the Himalayas, the Arabian Sea and the Bay of Bengal. Topography and bathymetry data are from ETOPOI (Amante and Eakins 2009); the colour scale for both maps is at the bottom of the figure, In the larger map, only the ocean bathymetry is plotted to scale, with only a three-step grayscale shading being used to indicate the land topography. The Farakka Barrage is located on the Ganga, just upstream of the international border (red and white dashed curve) between India and Bangladesh. Note the 'Swatch of No Ground' in the Bay. The region shown in figure 2 is marked by the red box and consists of the South and North 24 Parganas districts in West Bengal within which the SES (Excluding river Hoogly) is located.

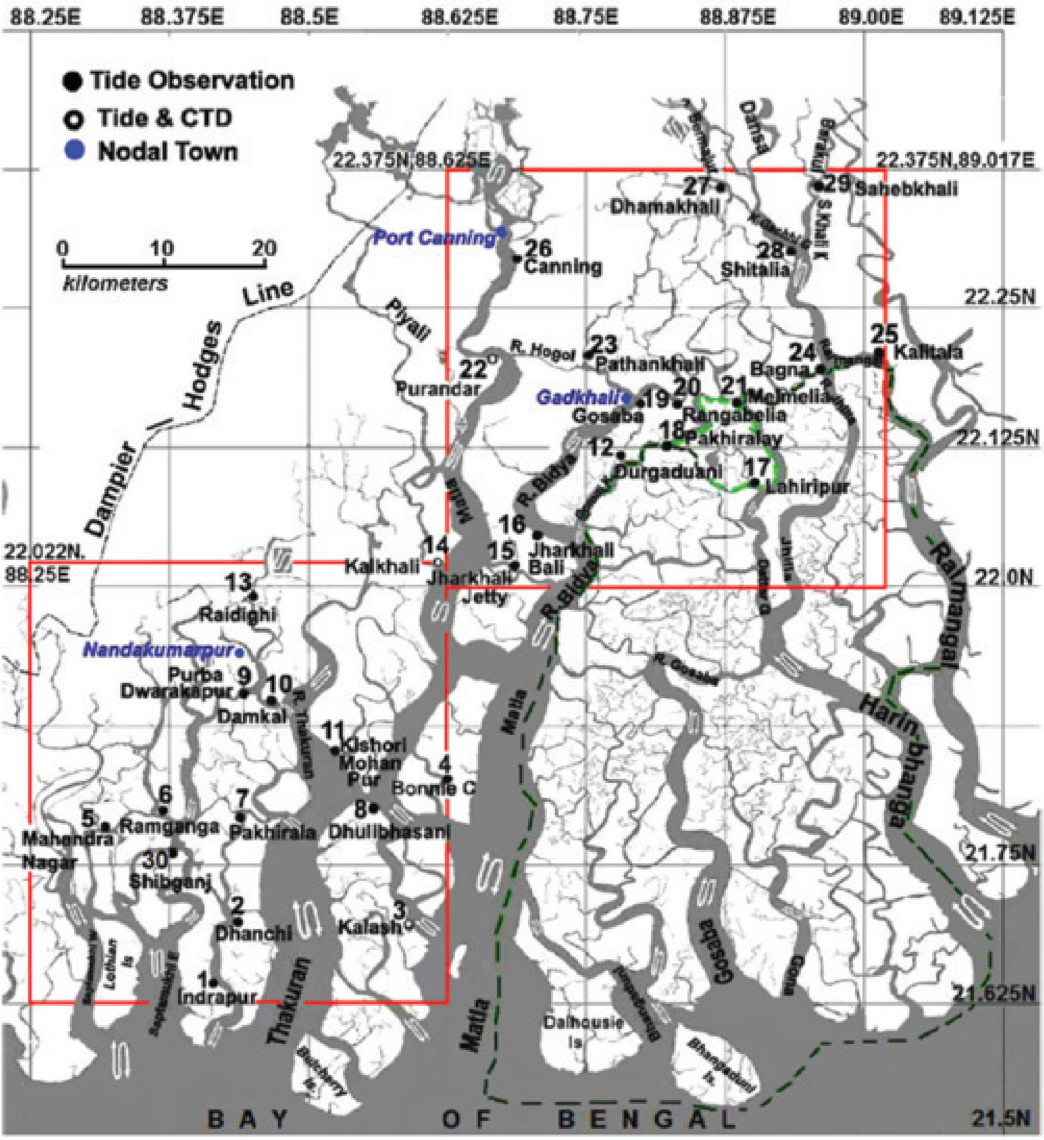

Figure 2. The Sundarbans Estuarine System (SES). Bordered in red is the area covered by the SEP. It consists of Sector 1 in the southwestern part and Sector 2 in the northeastern part. Names and numbers of the observation stations are shown. Dotted lines indicate the Sundarbans National Park and Tiger Reserve and the Buffer Zones (in green), and the Dampier–Hodges Line (in blue). The map was prepared by digitizing the 1967–1969 toposheets (1:50,000 scale) of the Survey of India. The symbols (an 'S' with arrows on either end) indicating the presence of the tide were filled in from these toposheets and the more recent map (1:250,000 scale; NATMO 2000) of the South 24 Parganas. This NATMO map was based on the SOI (1967–1969) toposheets, aerial photographs, IRS satellite imagery, and field surveys.

River Hooghly, the western most estuary of the SES, is the first deltaic offshoot of the Ganga. River Raimangal (figure 2) forms the eastern boundary of the SES. This trans-boundary river is a tributary of river Ichhamati, an easterly distributary of the Ganga situated in the North 24 Parganas. The northern limit of the Sundarbans and the SES is defined by the Dampier–Hodges Line (figure 2), an imaginary line that is based on a survey conducted during 1829–1832.The principal estuaries of the SES lying east of the Hoogly are the north–south flowing rivers: the Saptamukhi, Thakuran, Matla, Bidya, Gomdi (often called the Gomdi Khaal or the Gomor), Gosoaba, Gona, Harinbhanga and Raimangal (figure 2).Interconnecting these estuaries and forming the complex estuarine network are numerous west–east flowing channels, canals and creeks. Some of these interlinking channels are wide and strong enough to be considered as estuaries by themselves. Others, especially those east of the Matla, still remain unexplored and unnamed. All the principal estuaries in the SES (figure 2) are funnel-shaped and have very wide mouths. The Bidya and the Gomdi fall into the Matla around 21.917^{0}N, 88.667^{0}E and 22.069^{0}N, 88.747^{0}E, respectively. Widths converge rapidly northwards after short and wide southern stretches. Except in the vicinity of the sea face, the estuaries follow meandering courses with sharp bends. This meandering is most noticeable on the Matla, the longest estuary. At the sea face, the width of its mouth is greater than 26 km. It swings sharply to the west near its confluence with the Bidya (about 35 km due north of the seaface), after which the estuarine channel converges rapidly. At Port Canning (22.317^{0}N, 88.65^{0}E; figure 2), about 98 km north of the seaface, the width is less than 1 km. As one moves eastward from the Matla, the interconnections become so complicated that they are difficult to be identified as belonging to a particular estuary. Both the Hoogly and the Raimangal still carry the freshwater discharge of the Ganga into the Bay of Bengal throughout the year, with the lean period freshwater flow through the Hoogly augmented by the diversion of regulated amounts of the Gangetic main flow through the Farakka Barrage (figures 1 and 2).

All former distributaries of the Ganga, the inner estuaries of the SES lying between the Hooghly and the Raimangal are at present saline, tidal rivers. Geological changes during the 16th century caused the main flow of the Ganga to shift progressively eastward, resulting in the complete severance of these inner estuaries from the Gangetic freshwater flow at their upstream heads (UNEP WCMC 1987; Parua 2010). The estuarine character of the inner estuaries in the SES is now maintained by the semi-diurnal tides at their mouths and the freshwater received as local runoff. The major portion of the local runoff comes annually from the summer monsoon rainfall, ranging between 1500 and 2500 mm/year (Attri and Tyagi 2010) in this region and from the floods resulting from the freshwater accumulation in the upstream parts of the Ganga during the monsoons. Considerable precipitation is also received from the frequent pre-monsoon (March–June) and post-monsoon (October–February) depressions and cyclones that form and move in from the Bay of Bengal. Precipitation accompanying the frequently occurring pre-monsoon thunderstorms during March–May (known as Nor'westers or, locally, Kaal Baisakhi) is another source of fresh water runoff during the dry season (Attri and Tyagi 2010). It is possible that some amounts of vertical and lateral seepage of freshwater from underground aquifers may also occur. Several comprehensive reviews of the Sundarbans and its estuarine network are available in Seidensticker and Hai (1983), Sanyal (1983), UNEP WCMC (1987), De (1990), Banerjee (1998), Guha Bakshi et al. (1999), Mandal (2003), NGIA (2005) and Sarkar (2011). The brief overview of the region given below is based on these reviews.

The estuarine network has divided the terrain into 102 islands: 52 of these, covering an area of 5336 km^2, are currently inhabited by a population of over 4 million. Reclaimed from the forests since the 18th century, these islands are mostly situated in the northern 'stable' part of the Gangetic delta. Being only 0–3 m above the mean sea level, most settled areas are protected by embankments. The nodal towns (figure 2) situated in the northern parts of the SES, such as Raidighi (21.994°N, 88.447°E) which is also an observation station, Nandakumarpur (21.937°N, 88.218°E), Port Canning and Gadkhali (22.168°N, 88.788°E), are approximately 130–150 km away from the state capital Kolkata (22.57°N, 88.37°E), which lies to the northwest of the region (figure 1). Seventy percent of the terrain within the SES consists of water bodies, intertidal mudflats and creeks, saline swamps, sandy shoals, and dense, impenetrable forests. Inundation of these areas during high tide effectively increases the surface area of the estuarine channels. The submerged shoals, especially those at the mouth of the estuaries, change their orientations with every tidal cycle and are a hazard to navigation. The main estuaries and their network of naturally connected channels are mostly shallow, but navigable. They are heavily used for local transportation, tourism, and as economically viable shipping routes for the transport of goods between the ports of Kolkata (figures 1 and 2) and Haldia (22.017°N, 88.083°E; figure 2), to the northeastern states of India .

Within the SES, tidal influences underlie all the basic physical processes operating in the region. Indeed, the tides are so woven into the fabric of life in the Sundarbans that it is referred to as the Bhatir Desh or 'tidal country' (Beveridge 1897; Roy 1949b; Ghosh 2004; Chakrabarti 2009). This influence of the tides is more evident in the very dynamic 'active delta' in the relatively pristine southern part of the SES. Consisting of the 48 remaining islands, it occupies an area of 4264 km^2. Here, the still continuing process of delta-building manifests itself through erosion and accretion processes that operate continuously under the action of the semi-diurnal tides, high winds, wave action, shifting sediment loads, and other natural processes. The delicately balanced conditions existing in the numerous, unique and fragile ecosystems change almost daily under tidal influences. The SES forms the most important spawning zones and nursery for shrimps, prawns and a wide variety of fish and crustaceans, not only locally, but for the entire east coast of India. It also provides major pathways for nutrient recycling and acts as a natural filter for pollutants released from the human settlements and industrial belts in its northern reaches. Strict conservation measures initiated during the 1970s by the governments of India and West Bengal have resulted in the entire 'active' delta area being declared as protected Reserved Forests. Located in the southeastern sector of the SES is the Sundarbans National Park and Tiger Reserve (21.545°–21.929°N, 88.691°–89.103°E;

area 2585 km^2), with a core area of about 1330 km^2 (figure 2). It was declared a UNESCO World Heritage Site in 1987, while the entire SES was declared a Global Biosphere Reserve in 2001.

The astounding biodiversity of the region is well known. It is all the more remarkable owing to its being the only habitat, at present, of several globally endangered species of flora and fauna, chief amongst which are the Sundari tree, which gives the Sundarbans its name, and the Royal Bengal Tiger. The strategic location of the Sundarbans at the head of the Bay of Bengal has also made it a natural protective barrier for the densely populated city of Kolkata to its north: the mangrove barriers are the first to absorb and reduce the direct impact of the cyclonic storms and accompanying surges moving in from the Bay of Bengal. Though they protect Kolkata from the impact of these surges, the Sundarbans themselves are vulnerable to them. This vulnerability was underscored when tidal surges of more than 2– 3 m height due to Cyclone Aila swept through the region on 25 May 2009, breaching more than 400 km of embankments and taking a huge toll: the entire Sundarbans biosphere reserve was inundated with 2–6 m of water for several days. Official estimates record 700 people dead and about 8000 missing. Dozens of tigers (out of the existing 256 or so), crocodiles and deer were swept away by the surge. In all, about 2.5 million people were affected by the cyclone and the damage caused was estimated at about Rs 1500 crores (about 550 million USD) (India Meteorological Department 2009; Wikipedia 2012). While it may be tough to protect infrastructure, an ability to predict the surge can help to save lives because the surge takes time to propagate through the long estuarine channels to reach the more thickly populated northern parts. Any progress in understanding and predicting the propagation of a storm surge through the SES is, however, contingent on the ability to predict the tide, making it critical to study the tides first, and Dr. Meenakshi Chatterjee made some seminal contribution in this field (Chatterjee et al.2013).

Some other researches in this area

Studies on tidal variations and its methods opens up promising research avenues on Sundarbans Estuarine systems not only in mathematics but also in other disciplines. The multi-disciplinary nature of the various research projects has been outlined in the following brief descriptions.

Impacts of Tidal variations in Short term variation of surface water properties in SES

"The effect of tidal amplitude was observed to be the important factor in determining the variability in most of the water quality parameters"(Nandy et al.2017). "The Sundarbans Estuarine System (SES) is a unique ecosystem, covered by mangrove vegetation which is very much tidally induced and all parts of the SES are propagated by the dominated semi-diurnal tide with an overall northward amplification" (Chatterjee et al. 2013).

Intra-monsoonal variation of zooplankton population in the Sundarbans Estuarine system

"The zooplankton dynamics in SES is mostly associated with environmental changes persuaded by unusual monsoon induced hydrological changes. In general, the unusual heavy rainfall and cloud burst conduced intense river discharge considerably affected hydrodynamics of SES, profoundly affecting the zooplankton community distribution and composition. Regarding larval composition, the present study depicts that water quality plays an important role in the seasonal sharing of copepod larvae as well as different meroplankton larvae. A long-term monitoring of zooplankton population is required in this ecologically important mangrove ecosystem, considering its role in ecosystem functioning and biodiversity conservation" (Nandy et al.2018).

Variation of salinity in the Sundarbans Estuarine System during the Equinoctial Spring tidal phase of March 2011

"The 30 observation stations, spread over more than 3600 km^2 , covered the seven inner estuaries of the SES: the Saptamukhi, Thakuran, Matla, Bidya, Gomdi, Harinbhanga, and Raimangal. At all stations or time-series locations (TSLs), the water level was measured every 15 min and water sample were collected every hour for estimating salinity. At 20 of the 30 TSLs, the salinity varied semi-diurnally, like the water level, and the maximum (minimum) salinity tended to occur at or around high (low) water. The temporal variation was more complex at the other 10 TSLs. Even at the TSLs at which a tidal stand exceeding 75 min was seen in the water level, the salinity oscillated with a semi-diurnal period. Thus, the salinity variation was unaffected by the stand of the tide that has been reported from the SES"(Chatterjee et al.2021).

Discussion

The observed variations of tidal water levels at 30 locations situated on various estuaries of the Sundarbans Estuarine System (SES) have been presented and discussed in Dr. Chatterjeis paper (Chatterjee et al.2013). It is for the first time that such data, consisting of continuous measurements of tidal elevations at 15-minute intervals over a 72-hour period, have been reported from this region. The observation stations, located on all the principal estuaries within the SES covered a wide range of conditions such as estuarine cross-sections, meanders, depths, and confluences with west–east channels. The pattern of amplification was, nevertheless, complex because the SES consists of not only the south–north-flowing main channels, but also fairly big west–east-oriented channels connecting them. Likewise, the tidal range was also low at M4 (Bonnie Camp), which too was located in a connecting channel. In general, however, the tidal range increased from mouth to head, that is, the tidal wave amplified northwards. A simple explanation for this amplification can be given as follows.

Channel geometry and frictional dissipation are the most important factors that determine the amplification or decay of a tidal wave as it progresses headwards along an estuarine channel. All the major estuaries in the SES are funnel-shaped; with widths decreasing rapidly headwards (northwards) from their mouths (section 1), i.e., they are convergent channels. This type of estuarine geometry has a 'funneling effect', which tends to amplify the tide as it propagates towards the head of the channel. Frictional dissipation on the other hand, tends to decrease this amplification. The northward amplification of the semi-diurnal tide observed in general in the SES channels therefore implies that, on an average, the geometric effect dominates over frictional dissipation in the SES. Apart from this dominance of geometric effect over frictional dissipation, another likely cause of the amplification is the non-availability of adequate spill areas on either bank of the estuarine channels and the consequent inability of the heavily silt laden tide to dissipate itself completely. This condition exists mostly in the northern parts of the SES, where premature reclamation of land for human settlement and construction of protective embankments has gone on extensively and steadily since the mid-19th century. This has resulted in a progressive rise in the tidal levels over the years owing to raising of the channel beds by deposition of the tidal silt (Majumdar 1942). This so-called 'Heaping Up of the Tides' is observed to be most pronounced near Port Canning, situated on the narrowest part of the Matla and one of the earliest areas to be settled (Majumdar 1942). Observed Highest High-Water Levels (HHWL) rose from 1.884 m in 1865 to 3.849 m in 1930 (Majumdar 1942). In the present study, the HHWL observed at Canning was 7.08 m, a near doubling from 1930. This increase in HHWL can be attributed to the blockage of most of the spill area of the Matla, known as the Salt Lake Marshes, which once extended northwest from Port Canning right up to the east of the city of Kolkata. Reclaimed and settled under the huge population pressure faced by West Bengal following India's independence, the Salt Lake Marshes have been completely built up and at present form the part of Greater Kolkata known as Salt Lake City. The observations show that the semi-diurnal (M2) amplitude roughly doubled from mouth to head, but there was no such amplification of the diurnal band. The amplification was maximum for the 4-hourly (M6) and 6-hourly (M4) tidal constituents which amplified by a factor of about 4–5. Other constituents were weaker. In most of the locations in the SES, the tide was found to be a superposition of the M4 and M6 bands on the dominant semi-diurnal M2 band. Nonlinear effects, for example, the interaction of the semidiurnal tide with the bottom of the channel (nonlinear friction), can lead to the generation of the higher harmonic bands such as the M4 and M6, which amplify as the tide progresses headward along the channels. Depending on the amplitude and the phase of a harmonic, such a superposition leads to the tidal asymmetries. The flood-dominant and ebb-dominant duration asymmetries observed at the SES locations are the best known examples of such tidal asymmetries. The shortest time of rise (strongest flow current) recorded was 4 hours at B20 (Rangabelia) during LW3–HW4 (LW stands for Low water and HW stands for High Water) at M26 (Canning) during LW4– HW5. At some stations during some tidal cycles, however, the flow dominance gave way to ebb dominance. The shortest duration of fall (strongest ebb current) was 5 hours 15 minutes at S30 (Shibganj) during HW1–LW1. Well-known causes of ebb dominance in tidal estuaries are the presence of upstream freshwater and tidal flats. Tidal flats exist extensively throughout the SES, but the transient nature of the change over to ebb-dominance from flow-dominance observed at only a few stations on the Saptamukhi over single tidal cycles suggest that the presence of freshwater is the most likely cause of this transition. The possible source of freshwater in the western channels may be the inflow from the Hoogly via connecting west–east channels during the periodic discharge of freshwater at Farakka. In the east, the Raimangal receives freshwater from Ganga via Ichhamati. This duration asymmetry has practical consequences. The flow dominance implies strong flow tidal currents and the inward transport of sediment from the mouth of the estuaries, which has an impact on estuarine morphology (Speer 1984; Dronkers 1986; Friedrichs and Aubrey 1988; Speer et al. 1991). The tidal duration asymmetry is significantly affected in the SES by the tidal stand that was observed at most stations. Water Level (WL) changes imperceptibly during a stand, but this slow change is distinct from the slow change of 30 minutes (three successive observations) that normally occurs near the crest and trough of a sinusoidal curve We provide an objective definition of a stand: a station has a stand if the change in WL between successive measurements is within ±0.01 m for the normalized WL curve for that station over four or more measurement intervals. If the stand duration thus estimated is 30 minutes, WL changes slowly for a total of 60 minutes around the HW or LW level. HW stands were common in the SES 9a & 9b, but LW stands also occurred at a few stations during some tidal cycles. The duration of the HW stand was found to vary from 15 to 150 minutes. Longer stands are observed at the north eastern stations. Only a few stations did not exhibit a HW stand; notable among these stations are Canning (M26), which had the highest tidal range and B16 (Jharkhali Bali). At B16, the normalized water-level differences between consecutive observations near the HW/LW peaks were consistently found to exceed the prescribed threshold of ±0.01 m, implying higher rates of rise and fall of the WL near HW and LW. While it is possible that the tidal stand observed in most of the SES locations represents another type of asymmetry of the tide, the observations show that flow-dominant tidal duration asymmetries exist over most tidal cycles at all the SES locations, but tidal stands, particularly the LW stands, may or may not exist at a location. An extreme case is the vanishing of tidal asymmetries at some of the locations over some tidal cycles: S1 and M8 (tidal cycle 1), GH21 (tidal cycles 3 and 5), and R25 (tidal cycles 1 and 3).

Although the tide in such cases is symmetric, in that the duration is the same for rise and fall, HW tidal stands of considerable duration exist during these cycles at these locations Another exception is B16 (Jharkhali Bali) which does not have a HW (LW) stand, except during the first (third) tidal cycle, but has significant flow-dominant asymmetry for all tidal cycles. These exceptions imply a need to distinguish the tidal stand from the tidal asymmetry: while they may have much in common, the observations suggest that they are distinct phenomena. The engineering implications of a tidal stand are obvious. If the ebb currents are strong, then there is possibility of scouring near the jetty piers during a LW stand. It is the more common HW stand, however, that is probably a more serious threat. Stations like Bagna (R24) commonly have HW stands of duration 75 minutes or more; a 75-minute stand implies that the WL changes slowly around the HW mark over 1 hour and 45 minutes instead of the usual 30 minutes (for a pure M2 tide). This ‘wall of water’ develops twice a day at several stations in the SES, increasing the chance of a surge due to a storm coinciding with the high tide. A long stand also leads to a jump in the rate of change of WL, even if for a short duration .An example of the possible impact of the stand is the repeated destruction of the Forest Department jetty at Bagna, leading to the abandonment of any further attempts at constructing a permanent jetty there. This problem has generally been attributed to the tidal range at Bagna being higher than at other locations. As the data show, however, the range at Bagna is actually lower than the range at several other stations .We conjecture that it is the long HW stands that make Bagna and other neighboring stations on the Raimangal more prone to destruction by surges. Storm surges have periods ranging from a few hours to a day. It is likely that a surge whose period is around 4–6 hours will amplify considerably as it propagates inland, just as do the M4 and M6 tides with the same periodicities. Such a surge would have a higher potential for destruction. The ubiquity of stands in the SES and the considerable variation in its duration makes the SES an interesting laboratory for studying this tidal phenomenon, which, apart from being poorly understood, possibly has a significant influence on the life of the inhabitants of this tidal country. The SES, with its remarkable geometry of interconnected channels and the tidal stand, presents a challenge for estuarine modelling(Chatterjee et al.2013).

Acknowledgements

Here the author presented briefly Dr. Meenakshi Chatterjee's contributions in Sundarban Estuarine Programme and also a very short discussion on researches after this programme The author gratefully acknowledges Dr. Sumana Chatterjee (Depatment of Chemistry, Basanti Devi College) for her valuable suggestion and encouragement to take the initiatives to do this work She also extend her thanks to all the teaching faculties of Mathematics Deparment (Basanti Devi College) Dr. Gour Chandra Mandal, Dr. Maitreyee Panja for their support.

References

1. Attri S D and Tyagi Ajit 2010 Climate Profile of India; Met. Monograph No. Environment Meteorology – 01/2010. India Meteorological Department, Ministry of Earth Sciences, Government of India, 129p.
2. Banerjee A 1998 Environment, population and human settlement of Sundarban Delta; Concept Publishing, 424p.
3. Beveridge H 1897 Akbarnama Vol I; Translation of the original work by A Fazl (in Persian), Asiatic Society of Bengal,Calcutta.
4. Chakrabarti R 2009 Local people and the global tiger: An environmental history of the sundarbans; Global Environment n3 72–95, https://www.globalenvironment.it
5. Chatterjee M, Shankar D, Sen G K, Sanyal P, Sundar D,Michael G S,Chatterjee A, Amol P, Mukherjee D, Suprit K, Mukherjee A, Vijith V, Chatterjee S, Basu A , Das M, Chakraborti S, Kalla A, Misra S K, Mukhopadhyay S, Mandal G and Sarkar K 2013 Tidal variations in the Sundarbans Estuarine System, India; J.Earth. Syst. Sci. 122 899–933, https://doi.org/10.1007/s12040-013-0314-y.
6. Chatterjee M; Shankar D; Vijith V; Sen G K; Sundar D; Michael G S; Amol P; Chatterjee A; Sanyal P; Chatterjee S; Basu A; Chakraborty S; Mishra S K; Suprit K; Mukherjee D; Mukherjee

A; Mukhopadhyay S; Mondal G; Kalla A; Das M 2021 Variation of Salinity in the Sundarbans Estuarine System during the Equinoctial Spring tidal phase of March 2011; J. Earth Syst. Sci (2021) 130-150 https://doi.org/10.1007/s12040-021-01636-9

7. De R. N 1990 The Sundarbans; Oxford University Press, Delhi, 49p.
8. Dronkers J 1986 Tidal asymmetry and estuarine morphology; Netherlands J. Sea Res. 20(2/3) 117–131.
9. Ghosh Amitava 2004 The Hungry Tide; Ravi Dayal Publisher, Delhi, 433p; Achintyarup Roy 2009 Bhatir Desh, Bengali translation, Ananda Publishers, 377p.
10. Guha Bakshi D N, Sanyal P and Naskar K R (eds) 1999 Sundarban Mangals; Naya Prokash, Kolkata, 771p. (ISBN 81-85421-55-2).
11. India Meteorological Department 2009 Severe Cyclonic Storm, AILA: A Preliminary Report; Regional Specialized Meteorological Centre–Tropical Cyclones, New Delhi, 26p.
12. Majumdar S C 1942 Rivers of the Bengal Delta; Calcutta University Readership Lectures, Calcutta University, 124p.
13. Mandal A K 2003 The Sundarbans of India: A development analysis; Indus Publishing, 260p, ISBN 8173871434.
14. Nandy T, Mandal S, Deb S, Ghosh M, Nath T, Chatterjee M 2017 Short-term variations in the surface water properties in the Sundarban Estuarine system, India; Springer, Switzerland, https://doi.org/10.1007/s40899-017-0139-y
15. Nandy T, Mandal S, Chatterjee M 2018 Intra-Monsoonal variation of Zooplankt on in the Sundarbans Estuarine system, India; Springer, Switzerl and, https://doi.org/10.1007/s10661-018-6969-8
16. National Geospatial Intelligence Agency 2005 Prostar sailing directions, India and Bay of Bengal en route; Publication 173. Revised and corrected through NTM 33/05 (13August 2005), 8th edn.
17. Roy H K 1949a Some potamological aspects of the river Hooghly in relation to Calcutta water supply; Science and Culture {\bf14} 320.
18. Sarkar K L 2011 Sundarbaner Itihaas (in Bengali); Rupkatha Prakashan, 184p.
19. Seidensticker J and Hai M A 1983 The Sundarbans Wildlife Management Plan. Conservation in the Bangladesh Coastal Zone. IUCN, Gland, 120p.
20. Speer P E and Aubrey D G 1985 A study of non-lineartidal propagation in shallow inlet/ estuarine systems, part II – Theory; Estuarine Coast. Shelf Sci. 21 207–224.
21. Speer P E, Aubrey D G and Friedrichs C T 1991 Nonlinear hydrodynamics of shallow tidal inlet/bay systems; In:Tidal Hydrodynamics (ed.) Parker B B (New York: JohnWiley), pp. 321–329.
22. Chatterjee M; Shankar D;Vijith V; Sen G K; Sundar D; Michael GS;Amol P; Chatterjee A;Sanyal P;Chatterjee S;Basu A; Chakraborty S; Mishra SK; Suprit K; Mukherjee D;Mukherjee A;Mukhopadhyay S; Mondal G;Kalla A;Das M 2021 Variation of Salinity in the Sundarbans Estuarine System during the Equinoctial Spring tidal phase of March2011;J.Earth Syst.Sci(2021)130-150 https://doi.org/10.1007/s12040-021-01636-9