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Observation on Sedimentation with regard to Subsidence and Waterlogging in the Southwestern Part of Bangladesh

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Abstract

Ganges tidal deltaic plain in between the Gorai-Madhumati-Baleswar river system to the east and Kalindi-Ichamati-Raimangol river system to the west in the southwest of Bangladesh has been experiencing waterlogging problem since few decades. This problem has started in 1950s just after the construction of polders, became serious in 1980s and still a big environmental challenge in this region. Different initiatives have been taken by the government as well as the development partners keeping in mind that the main cause of waterlogging is excess sedimentation in the river beds compared to adjacent tidal flats.

Although visible cause of waterlogging is rapid siltation in the river beds, but other equally important invisible and unperceivable slow processes were not seriously considered during the construction of polders, rehabilitation of polders or any other activities to get rid of waterlogging problem. Unperceivable processes are related to climate, physico-chemical activities of sediments and tectonics of the area. Important specific physico- chemical processes are oxidation of peat/organic materials in the sediments, mineralization of organic matters, consolidation and shrinkage of sediments.

All the above processes are mostly related to the types of sediments and climate of the area. Most sensitive sediments are clay and organic materials. Severities of processes are related to percentage of sensitive materials, water content and temperature. Resultant of these processes is subsidence or height lost of the area. This height lost adds with the sea level rise and finally, waterlogged areas spread with time. In addition, subsidence rate of the area has been estimated from radio-carbon dating and correlated the subsidence and waterlogging of the area.

Keywords: Polder, waterlogging, subsidence, radio-carbon dating.

Introduction

The study area lies in the Ganges tidal floodplain and is broadly divided into non-saline floodplain and saline floodplain. These are again sub-divided into trans-

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transitional, mixed river, tidal and Sundarbans depending on the relief, soil and hydrological patterns of the area. In the generalized physiographic map of Bangladesh (ALAM *et al*. 1990[b], KHAN 1991, REIMANN 1993 and BRAMMER 2012), the study area has been mapped as a part of moribund (inactive) delta and tidal delta. Major physiographic divisions are mangrove swamp to the south, moribund delta to the north and tidal plain in between (ALAM *et al*. 1990[b]). Geographically the area falls within the Khulna, Bagerhat, Satkhira and Jashore districts excluding its Sundarbans part (Fig. 1).

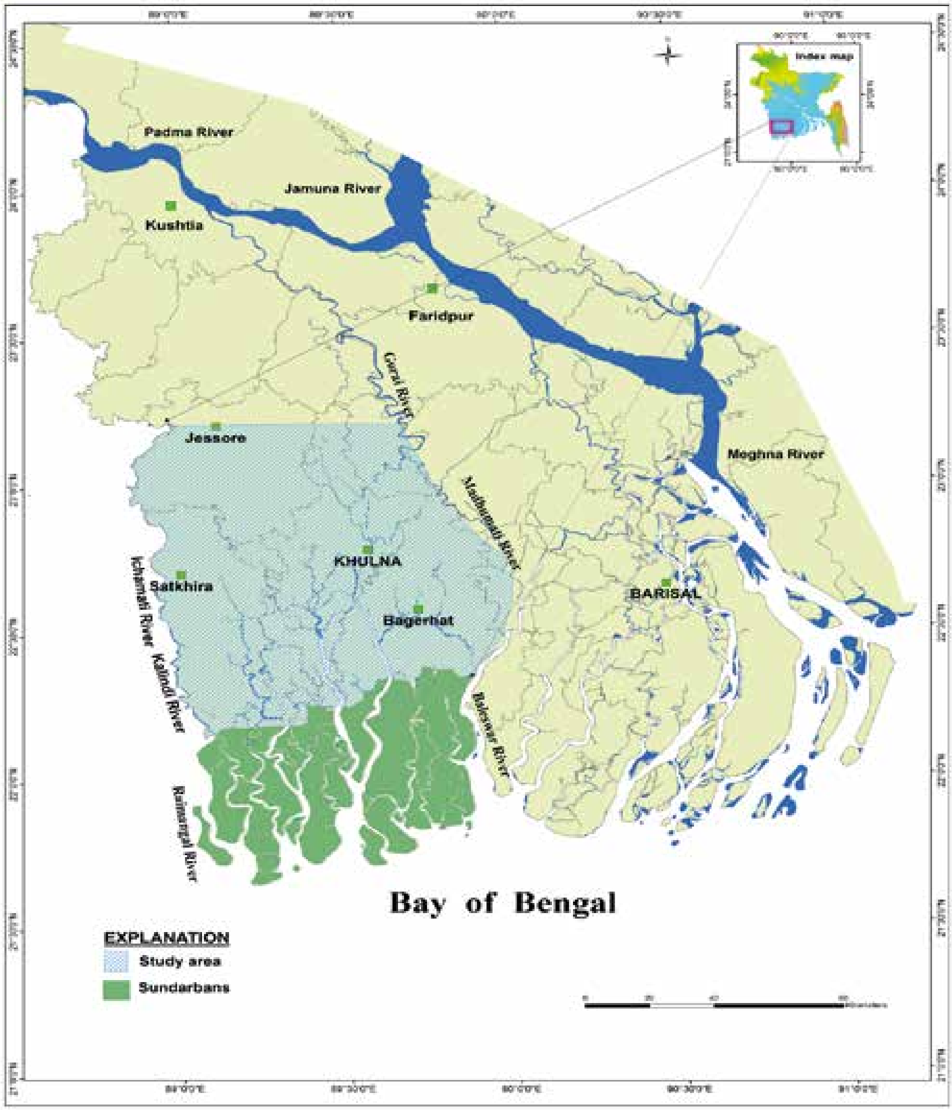

Fig.1. Location map of the study area.

The area suffers from crop failure due to saline water inundation and monsoon flooding is common in the area. Since the 17th century Zamindars/Landlords constructed temporarily low embankments and wooden sluice gates around the area to protect the arable land from flooding. These structures were normally existed eight months of the year and are locally known as "*Astomasi badh*". Thus they would get good harvest of paddy and different varieties of fish. After the abolition of Zaminders/Landlords system, the problems of land and water management became serious and crops failure occurred frequently due to irregular and insufficient maintenance of embankments and sluice gates of "*Astomasi badh*".

In the early 1950s, construction of permanent polders had been started to protect the crops from saline water inundation and thus to increase food production in the region (AFTABUZZAMAN 1990). Initially, the outcome of polders construction was remarkable, but unfortunately these were not sustainable. Due to interruption of natural land-building processes by the polders within three decades several thousand hectares of land became waterlogged and hundreds of kilometers of rivers became silted. In 2014, the waterlogged areas reached to about 50,100 hectares. Among 35 rivers, 4 rivers were completely silted, 11 rivers rapidly silting and the others have been silting at considerable rates.

Considering waterlogging is due to rapid siltation on river beds compared to adjacent tidal flats different initiatives have been taken by the government and development partners to dewater the area are structural like excavation and re-excavation of channels, construction of sluice gates, culverts, closures, embankments etc. However, in the process - the climate, physico-chemical processes, geology and tectonics of the area have not been considered properly. These are very slow activities difficult to perceive initially, but with time resultant is disastrous and difficult to repair. As a result, the outcome of all the initiatives has failed to fulfill the expectation of the affected people. Considering all these aspects the present study focuses on the qualitative interpretation of the slow processes and their eventual influence on the waterlogging problem.

Geology of the Area

The investigated area lies mostly in the Ganges tidal floodplain and partly in the Ganges river floodplain. The area is traversed by dense drainage network of the Ganges distributaries with very low local relief differences (within 1-3 m). North-south flowing rivers are the main drainage system in the area, along with a few rivers flowing east-west or northwest-southeast directions. These east-west flowing rivers, in many places are criss-crossed by north-south flowing rivers. Important rivers of the area from east to west - are Garai-Modhumati-Baleswar, Bhairab-Pusur, Bhadra-Ghengaril, Hari-Taker-Mukteswari, Sibsa, Kabodak (Kapatakshi), Betna, and Jamuna-Ichamati-Kalindi (Fig. 2).

The study area is covered by alluvial and paludal deposits. Alluvial deposits are mangrove swamp deposits, tidal deltaic deposits and deltaic silt deposits. Paludal deposits consist of marsh clay and peat with wood fragments (Fig. 2) (ALAM *et al.*

1990[a]). Mangrove swamp deposits are mainly composed of silt and clay with high proportion of woody and organic rich materials. Sediments are dark grey to black in colour. Tidal deltaic sediments are mainly composed of clay, silty clay and silt. Occasionally, fine to very fine sands are found along the active and abandoned channels including crevasse splays. Sediments are light grey to greenish grey in colour. At places, when it is weathered the colour turns into yellowish grey. Vertically, sediment sequences are consisted of interlayering of clay, silty clay, peat, clayey peat and peaty clay. Marsh clay and peat deposits are paludal sediments deposited in a swampy environment. Sediments are composed of bluish grey marsh clay and brownish black to black peat. Alternation of clay and peat or clayey peat is common. At the centre of the marsh basin, peat is the thickest unit. Deltaic silt deposits are mainly composed of dusky yellow to yellow silt and silty clay. There is alternation of silty clay and clayey silt with fine to very fine sand.

Interpretation of sedimentary sequences indicates mostly central part of the investigated area surfaced by clay, clayey sand and clayey silt. Clay is mostly found

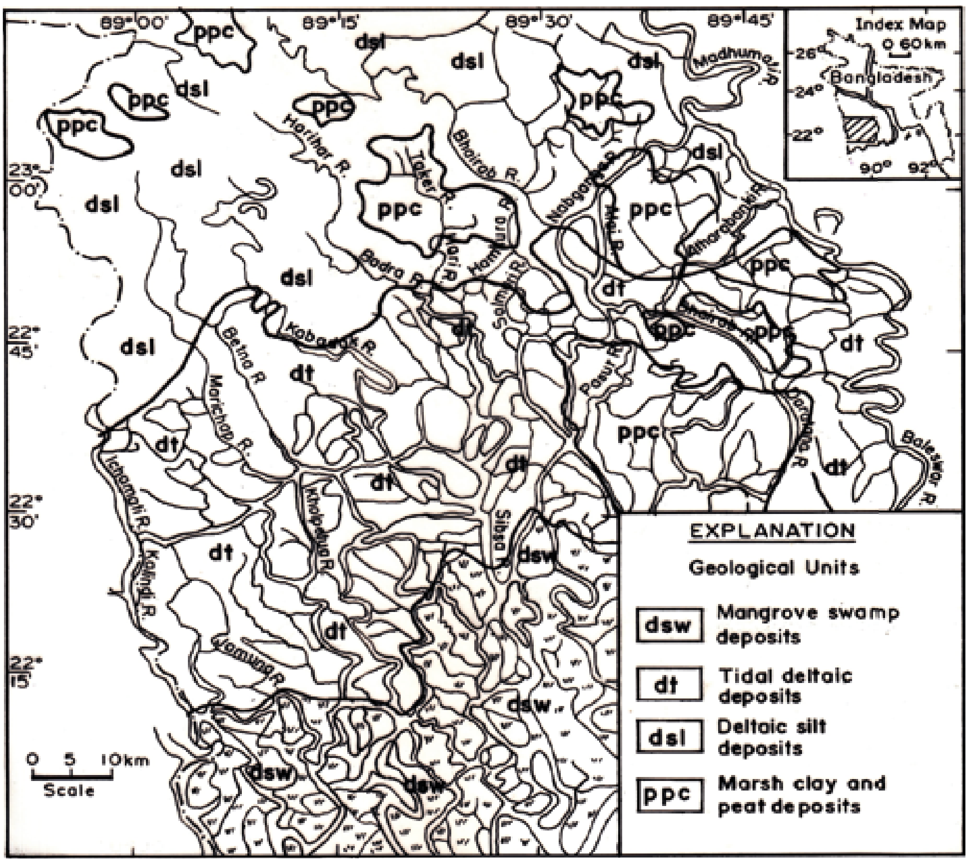

Fig. 2. Geological units of the study area (Modified after Alam *et al.* 1990[a]).

at the surface in the eastern part of the area. In most of the areas, surficial deposits are underlain by organic clay, clayey silt, silty sand and sand up to 10 m thick. In some areas sand continues up to 55-60 m and at places is interbedded with clay, clayey silt and clayey sand.

Khulna and Satkhira regions are mostly surfaced by clay and clayey silt. Clayey silt and clayey sand are exposed around Bagerhat district and organic clay/peat are overlain by sand and clayey sand in Jashore district. At depth, sand is dominant except, Bagerhat and Satkhira regions, where clayey silt and clay are interbedded with sand (Fig.3). Sediments near the surface like organic clay, clay and peat mostly took part in physico-chemical processes, e.g. oxidation, mineralization and compaction. Consequently, waterlogging and drainage congestion were firstly initiated in clay, organic clay and peat rich regions, and later spread-out in the adjacent areas.

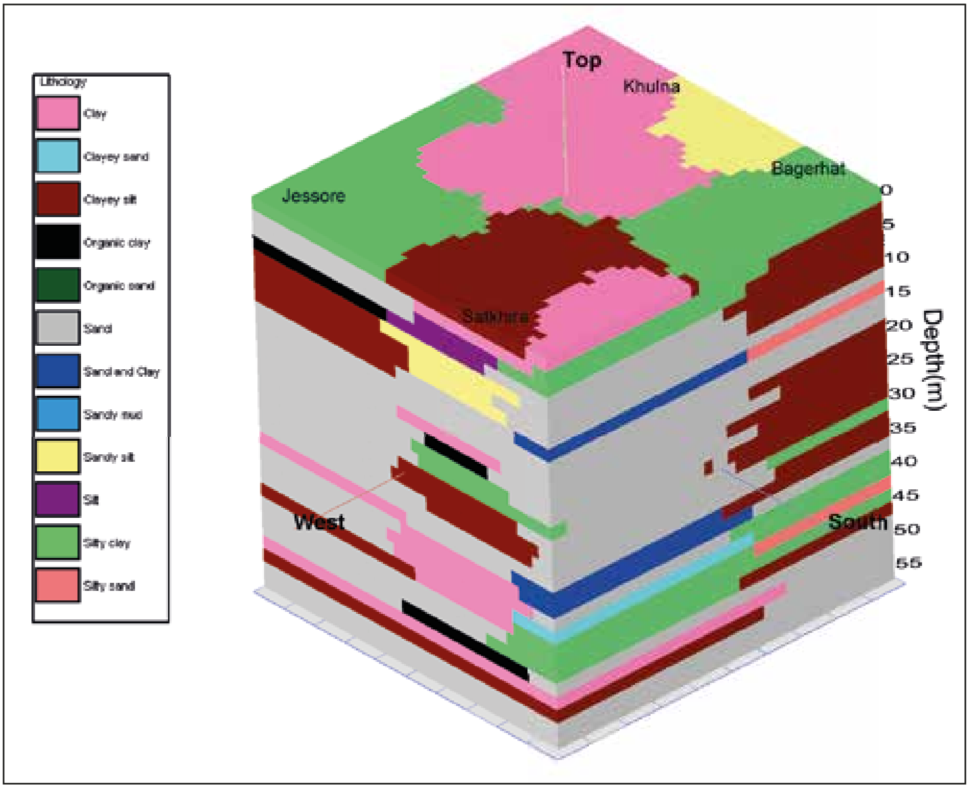

Fig. 3. Block diagram showing sedimentary sequences of the investigated area.

Tectonics of the Area

The Bengal Basin is located at the juncture of three interactive plates, namely Indian plate, Eurasian plate and the Burmese plate. The location, extension and tectonics of the Bengal Basin are constrained by the interaction of these plates. The Bengal Basin exposes a monotonous flat terrain sculpted with few relief features like Tertiary hills in the north and eastern parts; Pleistocene terrace areas in the northwestern and central part (MORGAN & MCINTYRE 1959 and BRAMMER 2012). The Bengal Basin can be classified into three distinct geotectonic provinces: (i) Stable Shelf or Geotectonic Province-1, (ii) Central Foredeep Basin or Geotectonic Province-2, and (iii) Folded Flank (CTFB) or Geotectonic Province-3 (HOSSAIN *et al*. 2019).

The investigated area is a part of the Faridpur Trough of the Central Foredeep in the southwest of the country. The Faridpur Trough is bounded by the Barisal Gravity High in the east and southeast. The Hinge Zone lies in the west and northwest. NE-SW trending Faridpur Trough is characterized by a general gravity low and may be underlain by transitional crust (HOSSAIN *et al*. 2019). The trough is tectonically less disturbed but may be subsiding.

Remnant of swamps and forest appear in the form of peat layers. Wood, trees and other vegetation are present within 30 m below ground surface provide evidences of large-scale subsidence caused possibly by structural down-warping and compaction of Recent sediments. Recent subsidence of the area has been estimated and deciphered by different authors (UMITSU 1993, KHAN & KUDRASS 1999, ALLISON *et al*. 2003, HANEBUTH *et al*. 2013 and REITZ *et al*. 2015).

Methodology

Remote sensing techniques followed by field checks have been applied to study the geology, geomorphology and waterlogging of the area. Different types of satellite images, mostly hard copies have been used to map and check different units. LANDSAT images of different bands of 2014, 2001, 1993 and 1981 and SPOT images of 1989 have been used in geological and geomorphological mapping as well as to delineate the extent of waterlogging. Aerial photographs mostly black and white and limited coloured aerial photographs have also been used to study the areas of special interest. Supporting the remote-sensing data, topographic maps of different scales and years have also been used. Extensive hand augering up to 6 m together with boring up to 60 m were conducted to unveil the geology of the area. Samples were tested in the field to know primarily the texture, colour, plasticity and nature of organic contents. In the laboratory, mechanical analyses were done for sediment nomenclatures to prepare lithological logs and sedimentary sequence investigation. Radio-carbon dating of organic matters mostly from peat of different geomorphic units at different depths was done at the Federal Institute for Geosciences and Natural Resources, Hannover, Germany to understand the behavior of the sediments and the tentative rate of subsidence.

Climate Change and Sea Level Rise

Bangladesh lies in the tropical monsoon climatic zone, and is characterized by heavy seasonal rainfalls, high temperature and high humidity. The country is widely recognized as one of the most vulnerable to the adverse effects of climate change and sea-level rise. Most of the adverse effects of climate change will be in the form of extreme weather events, while water-related hazards such as flood and waterlogging are likely to be exacerbated.

Across Southeast Asia, temperature has been increasing at a rate of 0.14°C to 0.20°C per decade since the 1960s, coupled with a rising number of hot days and warm nights, and a decline in cooler weather (IPCC 2014). Tentative rate of sea-level rise along the coast of Bangladesh may range between 1 to 4.5 mm/yr between 1990 and 2100 (TITUS & NARAYANAN 1995). Present sea-level rise in the north Indian Ocean can be considered as 1.29 mm/yr (UNNIKRISHNAN & SHANKAR 2007). Considering the eustatic sea-level rise of 1.3 mm/yr and the average rate of subsidence 8 mm/yr (REITZ *et al.* 2015), it is assumed that inundation level in 2050 will at least about 30 cm.

Discussion

Bangladesh is a lower riparian country and the study area is even lower in elevation. The investigated area is a part of the Faridpur Trough of the Central Foredeep. The area comprises Mangrove swamp deposits, Tidal deltaic sediments, Marsh clay and peat deposits and Deltaic silt deposits (Fig. 2). The region is mostly surfaced by clay, clayey silt and clayey sand. At some places, the surface sediments are underlain by organic clay/peat (particularly around Jashore district) (Fig. 3). The area suffers from severe waterlogging problem since 1980s. Different structural type (excavation of silted channels, dewatering of waterlogged areas, construction of sluice gates, etc.) of initiatives has been taken to improve the waterlogging situation keeping in mind that the siltation on riverbeds is the main cause of waterlogging. Slow unperceivable processes related to climate, physico-chemical activities of sediments and tectonics of the area are ignored. Role of these slow unperceivable processes may have a huge impact on subsidence or height loss over cumulative time and the situation may be worse when the area is poldered. It is noteworthy that EGGLESMANN (1982) studied on peat polders and concluded that subsidence is greater in peat dominated areas compared to non-peat areas. The slow unperceivable processes are discussed below and followed by the result of present subsidence scenario in the area.

a) Role of slow unperceivable processes:

Important physico-chemical processes that influence subsidence due to volume reduction of sediments and in turn contribute to waterlogging problem are (i) oxidation of peat/organic materials (ii) shrinkage and consolidation of geological materials and (iii) mineralization of peat/organic materials (LUCAS 1982, VAN DAM & PETRA 2001). These processes are influenced by the depth of drainage (height of water-table/hydrology, notably moisture content of the area), character of the organic materials, the cropping system employed including irrigation, and the climate in particular the temperature regime.

WAKSMAN & STEVENS (1929) and WAKSMAN & PURVIS (1932) found different rates of decomposition in peats with different chemical compositions and containing different micro-flora and micro-organisms. Their observation suggests that peat were decomposed by 15% at 28°C in 18 months under optimum moisture conditions of 50%-80%. Above and below these moisture ranges, decomposition rates rapidly diminish. Organisms like bacteria are also responsible for decomposition of peat and are most active above 5°C. Soil microbial activity generally doubles for each 10°C increase in temperature (SCHOTHORST 1977). STEPHENS & STEWART (1976) worked on drainage depth and soil temperature to estimate subsidence of peat in different climates and concluded that higher the temperature higher is the subsidence rate. Therefore, in the peaty region of tropics like Bangladesh where temperature remains in the range of 25°C-30°C, oxidation is important in lowering the surface level i.e. subsidence.

During the decomposition of soil organic matters (SOM), organic nutrients contained in organic matter (e.g., organic phosphorus, nitrogen, and sulfur) are converted to inorganic forms that are available for plant uptake. This conversion is known as mineralization. Drainage of peat soils for agriculture can lead to large carbon losses due to oxidation of peat. The rate of carbon losses mainly in the form of CO_2 and CH_4 due to mineralization of SOM is related to peat subsidence of the area (SCHIPPER & MCLEOD 2002). SCHIPPER & MCLEOD (2002) studied the subsidence rates and mineralization in peat soils and found peat subsidence rates averaged 3.4 cm/yr (95% confidence interval of 3.2 to 3.5 cm/yr) and total carbon losses due to mineralization averaged 3.7 t $ha^{-1}yr^{-1}$ (95% confidence interval of 2.5 to 5.0 t $ha^{-1}yr^{-1}$). Also estimated on average, 37% of the subsidence was due to losses of organic matter caused by mineralization, with the remainder (63%) attributed to consolidation.

Areas having peat deposits subside after drainage, not only because of oxidation of organic matters and mineralization but also due to shrinkage and consolidation of materials. The main causes of shrinkage and consolidation are physical and mechanical processes. Above the phreatic surface important physical process is withdrawal of moisture from the surface layers by evapotranspiration may cause high moisture tensions in the root zone resulting in a decrease in volume of those layers. When the groundwater level is lowered, the mechanical force like buoyant of water is lost in the upper layers. The deeper layers then have to bear an increased weight of $1g/cm^2$ per cm of drawdown of the groundwater table (SCHOTHORST 1977). This causes mechanical compression by the soil layers below the phreatic surface.

Consolidation is commonly divided into a primary phase and a secular phase. The former is largely a function of the rate of water escapes from and through the peat mass. This can be very high in the initial phase of drainage because of the high permeability of raw peat. When permeability decreases as a result of consolidation the primary hydrodynamic phase becomes almost constant. On the other hand, secular consolidation continues long after the primary phase has stopped to play its initial important role and may in the end account for half the total loss in volume (SCHOTHORST 1977).

b) Influence on subsidence and waterlogging:

Till 1950s there was a balance between sedimentation and subsidence in the study area. After 1950s due to construction of embankments along the rivers the rate of sedimentation ceased on tidal flats and the sediments of the tidal flats experienced oxidation, mineralization, compaction as well as shrinkage along with tectonic subsidence. As a result, riverbeds became higher and tidal flats gradually became relatively lower. The rate of subsidence and morphology of coastal low land in southwestern Bangladesh influenced by poldering are shown in Fig. 4. Here, the stable land surfaces are indicated by the straight line; and the riverbeds and the tidal flats are indicated by wavy lines where crests mark the silted riverbeds and adjacent troughs show the tidal flats. In southwest coastal low land, the average tidal range is about 3 m (Hiron Point/Pasur river) maximum tidal fluctuation is about ~4 m (WILSON *et al.* 2017). Normally, tidal flats were between 1-3 m above the sea level, but due to construction of polders parts of the tidal flats are now below the sea level and permanently waterlogged.

Subsidence of the area reported earlier by MORGAN & MCINTYRE (1959). Calculation of subsidence rates from radio-carbon-dated organic materials mainly from Sundarbans mangrove without coastal embankments shows between 1.3-7.1 mm/year (ALLISON *et al.* 2009). Dating of exposed 300-year-old salt kilns on the eastern coast of the Sundarbans about 35 km west of Kuakata area suggests a subsidence rate of 5.2±1.1 mm/year (HANEBUTH *et al.* 2013). KHAN & KUDRASS (1999) observed from C^{14} dating that the rate of subsidence is about 1.5-2 mm/year near the middle-western part of the delta, while it is 5.0-5.5 mm/year near the southeastern part. Calculation from UMITSU (1993), the tentative subsidence rate in the deltaic part of Bangladesh is about 3 mm/year. Recent studies show the Ganges - Brahmaputra

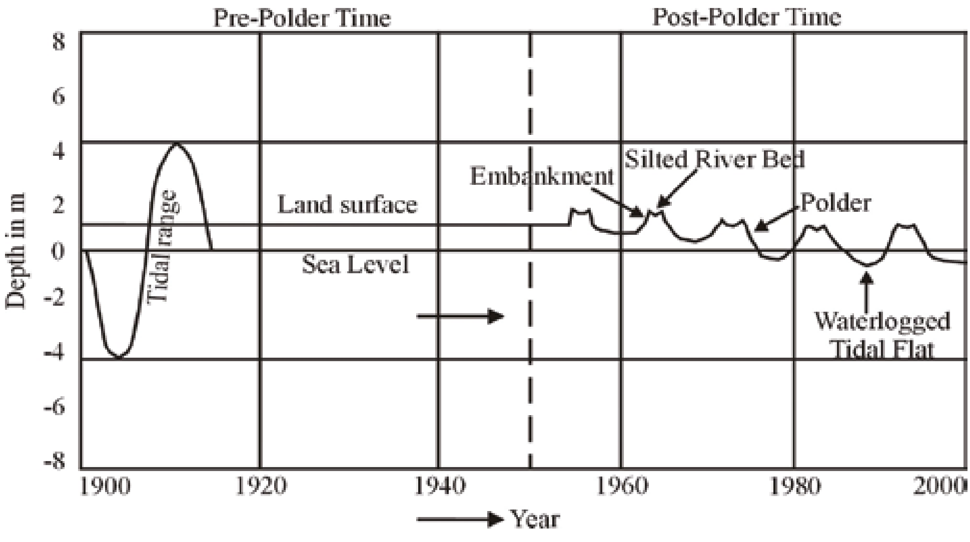

Fig. 4. Relation between evolution in water management and subsidence of tidal flat in south western part of Bangladesh.

delta specially the southern part has been sinking at a rate of about 8-18 mm/year (SYVITSKI *et al*. 2009, SARKER *et al*. 2013 and REITZ *et al*. 2015). As a result of the above discussion it can be concluded that the area has been subsiding, but the subsidence rate varies from place to place.

In the present study, six peat samples from different geomorphic units of the area have been dated through C^{14} dating method to estimate the subsidence rate (Table 1). Estimated rate of subsidence at different locations in Satkhira and Khulna districts is found as maximum ~4.40 mm/year and minimum ~0.71 mm/year.

Table 1. C^{14} dating results of different peat layers from Satkhira and Khulna.

Location Satkhira/Khulna	Sample no.	Depth in m	Age in BP (C^{14} Method)	Age	Estimated rate of subsidence in mm/year
L-27 (89°11′54.08"E 22°37′44.98"N)	S-29	1.07	905 ± 70	1030-1225 AD	1.10-1.02
	S-32	4.05	3295 ± 75	1675-1460 BC	1.20-1.17
L-28 (89°21′53.26"E 22°34′35.02"N)	S-35	1.10	1445±55	595-655 AD	0.72-0.70
L-50 (89°06′16.57"E 22°45′05.18"N)	S-69	4.70	970±55	1015-1160 AD	4.54-4.32
	S-72	5.40	1320 ± 75	120-325 AD	3.90-3.70
	S-75	5.95	2640 ± 70	830-790 BC	2.28-1.90

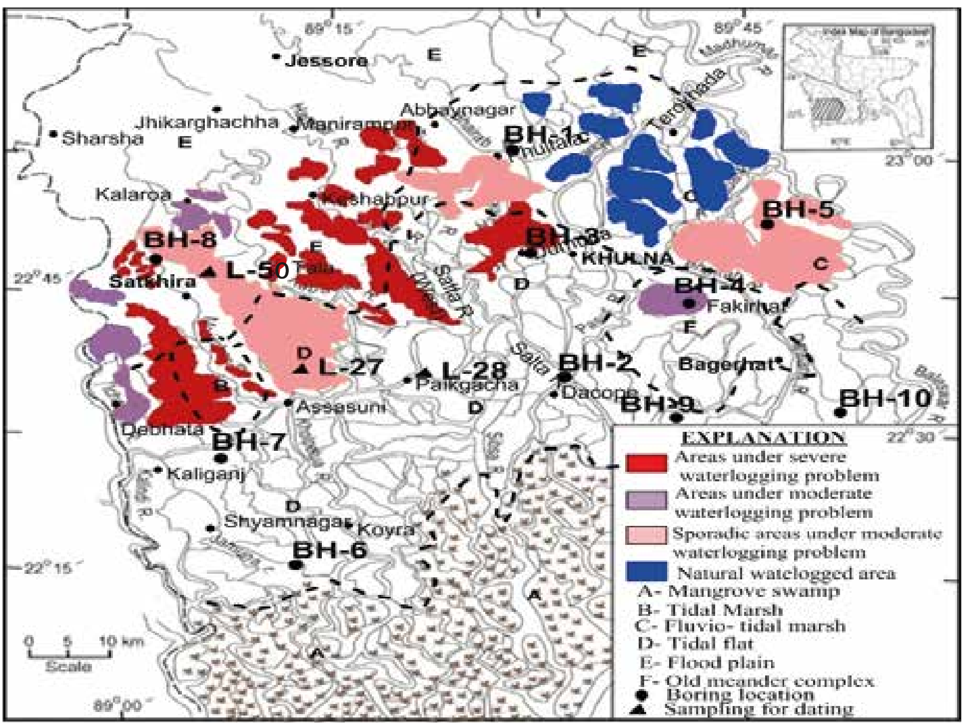

Fig. 5. Waterlogged areas mostly overlapped by peat, clay and organic rich sediments of tidal, deltaic and marsh deposits with the locations of boreholes.

The maximum rate of subsidence observed at boring points L-50, where waterlogging problem persisted and at the site L-28 subsidence rate is minimum and having no waterlogging problem (Fig. 5). In case of the Ganges delta, during polder construction and management, the geological aspects of the areas were not properly considered. Specially, clay-rich and peaty areas (peat basins) should have been treated as separate units from land management point of view. Locals introduce same land and water managements practice in non-clay and clay/peat-rich areas. Due to improper management, areas with clay and organic rich areas/peat areas, mainly areas with marsh clay and peat deposits, north of tidal deltaic deposits and south of deltaic silt deposits have acute waterlogging problem and became waterlogged earlier than the other polders.

Conclusion

Watelogging problem in the southwest of Bangladesh has been affecting people socially, economically as well as environmentally. Moreover, ill-planned rehabilitation/development activities and climate change have been aggravating the situation day by day. At present, people have no option instead of leaving the area as climate refugee.

Question raised, why different initiatives by the government and development agencies failed to solve the problem sustainably. Presently, all the initiatives are short term and target to have quick return like excavation of silted channels, dewatering of waterlogged areas, construction of sluice gates, culverts, closures etc. without considering the geology, geomorphology, tectonics and physico-chemical properties of sediments.

From the study, it has been found that water management of land having fine textured organic materials like peat, clay, silty clay, organic clay, etc. require different water managing systems than sandy areas. This is due to the physico-chemical processes like oxidation of peat/organic matters, mineralization, compaction of peat and clay, shrinkage of clay and organics, etc. All these processes were dominated in organic and clay rich areas just after poldering and continue till waterlogging. In the meantime, land has lost its height considerably combined with tectonic subsidence of the area, and has become a suitable bowl to retain water. Later, sedimentation on channel beds aggravated the waterlogging. Unfortunately, these very slow processes of oxidation, mineralization, consolidation and shrinkage of sediments were not considered while running a project. Traditionally the duration of the projects are only 3 to 5 years, and at the beginning of the project formulation all these processes are not considered. This is one of the main causes why all the activities have not yet been able to mitigate the problems of waterlogging sustainably. Although more than 70 years have already been passed, but still there are some scopes to take long term non-structural sustainable projects to solve this problem considering the rapid processes like sedimentation as well as the slow processes like tectonics, physico-chemical changes of sediments and climate change.

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বাংলাদেশের দক্ষিণ পশ্চিমাঞ্চলের ভূমি অবনমন ও জলাবদ্ধতায় পললায়নের ভূমিকা সম্পর্কিত পর্যবেক্ষণ

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সারসংক্ষেপ

বাংলাদেশের দক্ষিণ পশ্চিমাঞ্চলে গাঙ্গেয় জোয়ার ভাটা প্লাবন ভূমি পূবের্র গড়াই-মধুমতি-বলেশ্বর এবং পশ্চিমের কালিন্দি-ইছামতি-রায়মঙ্গল নদী প্রণালী মধ্যবর্তী অঞ্চল। বর্তমানে জোয়ার ভাটা প্লাবন ভূমির ব্যাপক এলাকায় পানি নিষ্কাশন ও জলাবদ্ধতা সমস্যা বিরাজ করছে। ১৯৫০ দশকে অধিক ফসল ফলানোর উদ্দেশ্যে এলাকা জুড়ে স্থায়ী পোল্ডার নির্মাণের পর জলাবদ্ধতা শুরু হলেও ১৯৮০ দশকে ভয়াবহ সমস্যায় পরিণত হয়, যা বর্তমানে এ অঞ্চলের মানুষের সবচেয়ে বড় পরিবেশগত প্রতিযোগিতা। সরকার এবং বিভিন্ন বহুজাতিক উন্নয়ন সংস্থা, নদী বক্ষে অধিক পলি অবক্ষেপনকে মূল কারণ হিসাবে চিহ্নিত করে সমস্যা সমাধানে বিভিন্ন উদ্যোগ গ্রহণ করেছে। এ ধরণের উদ্যোগের ফলে সমস্যার সাময়িক উন্নতি হলেও কোন স্থায়ী সমাধান হয়নি।

জলাবদ্ধতার সবচেয়ে দৃশ্যমান কারণ হচ্ছে দ্রুত নদী ভরাট হয়ে যওয়া। কিন্তু অন্যসব খুব ধীর অদৃশ্যমান সহজে বুঝতে না পারা কারণ ও প্রক্রিয়া সমূহ অনেক ক্ষেত্রে দৃশ্যমান নদী ভরাট হতেও বেশী গুরুত্বপূর্ণ। পরিতাপের বিষয় হচ্ছে, পোল্ডার তৈরীর সময়, পোল্ডার পুনর্বাসনে অথবা জলাবদ্ধতা থেকে পরিত্রাণের যে কোন পদক্ষেপ বা প্রকল্পে অদৃশ্যমান খুব ধীর প্রক্রিয়া সমূহকে কখনো গুরুত্ব দেওয়া হয়নি। অদৃশ্যমান খুব ধীর উল্লেখযোগ্য প্রক্রিয়া সমূহ হচ্ছে পীট অথবা জৈব পদার্থের জারণ প্রক্রিয়া, জৈব পদার্থের মিনারেলাইজেশন, জৈব পদার্থ ও পলল দৃঢ়ীকরণ ও সংকোচন। এলাকার গড় বৃষ্টিপাতের পরিমাণ ও তাপমাত্রা উল্লিখিত প্রক্রিয়ার সাথে বিশেষ সম্পর্কিত।

অদৃশ্যমান খুব ধীর প্রক্রিয়া সমূহ এলাকার পললায়নের সাথে সম্পর্কিত। উল্লেখ্য যে, খুবই স্পর্শকাতর ভূতাত্ত্বিক উপকরণ হচ্ছে পললের জৈব পদার্থের ও কাদামাটির পরিমাণ। খুব ধীর প্রক্রিয়া সমূহের কার্যকারিতা ও তীব্রতা, পললে এ সকল ভূতাত্ত্বিক উপকরণের পরিমাণ, জলীয় অংশের উপস্থিতি ও এলাকার তাপমাত্রার উপর নির্ভর করে। এ সকল প্রক্রিয়ার দীর্ঘ মেয়াদী ফলাফল হচ্ছে এলাকার অবনমন অথবা উচ্চতা হ্রাস পওয়া আর এর সাথে যুক্ত হয় ভূ-গাঠনিক অবনমন, পরিণামে জলাবদ্ধতা। জলাবদ্ধতা সময়ের সাথে সাথে চারিদিকে ছড়িয়ে পড়ছে, যার ব্যাপকতা আবহাওয়া পরিবর্তন-জনিত সমুদ্র পৃষ্ঠের উচ্চতা বৃদ্ধির উপরও নির্ভর করছে। এলাকার কয়েকটি খননকুপ হতে সংগৃহীত পীট নমুনার বয়স রেডিওকার্বন ডেটিং এর মাধ্যমে নির্ধারণ করা হয়েছে। পীটের গভীরতা ও বয়সের উপর নির্ভর করে এলাকার ভূমির অবনমনের একটি আপেক্ষিক হার নির্ধারণ করা হয়েছে।