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Transformation of the coastal social-ecological system in southwest Bangladesh due to empolderment

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Abstract
Initiated in the early 1960s, the Coastal Embankment Project (CEP) in Bangladesh brought more than 1.2 million hectares of low-elevation coastal land under cultivation through a complex system of embankments and drainage sluices. A significant milestone in the history of water resources management in Bangladesh, CEP catalyzed the socio-economic development of the coastal community over the following decades. However, the human intervention in the complex hydro-geo-morphological settings of the Ganges delta later manifested some challenges. As the embankments had cut off the tidal plains from the rivers, silt started depositing on the riverbeds, which eventually caused drainage congestion inside the polders. Meanwhile, significant changes in landuse occurred as saltwater shrimp farming took over traditional crop cultivation. Shrimp cultivation increased soil salinity inside the polders rendering the land unsuitable for crop cultivation. The kitchen gardens and the fruit plants that grew after the construction of the embankments disappeared from the landscape due to high soil salinity. The cyclone in 2009 badly damaged the embankments in the southwest coastal region resulting in the longstanding suffering of the people. The protected landscape became subject to tidal flooding, sweeping off the decades of development gains. This case study from Bangladesh demonstrates how physical infrastructure can significantly change the bio-physical and socio-economic landscapes in coastal settings and give rise to a new social-ecological system.

Introduction

The coastal zone of Bangladesh was exposed to saline water intrusion until the initiation of the Coastal Embankment Project (CEP) in 1961, supported by extensive foreign assistance (The World Bank, 2005). At the time of its formulation (1959), CEP was the most significant development project across all the sectors in Bangladesh (then East Pakistan). Besides the size of the investment (USD 370 million) (Thomas 1974), the extent of the work (almost 5,000 km of embankments covering over 1.2 million hectares of land) (Leedshill-De Leuw

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Engineers 1968) was also significant in the political, social, and economic contexts of that time.

With the primary objective of increasing the region's agricultural productivity, CEP created 108 polders (later, other projects added 31 more) spread across the entire coastal belt of Bangladesh (Bangladesh Water Development Board 2013b). The Bangladesh Water Development Board (BWDB) constructed 1,566 km of embankments in the southwest region alone and 282 sluices were (Dewan et al. 2015). The immediate impacts of the coastal embankments were positive (Dewan et al. 2015; Uddin and Islam 1982); from harvesting paddy only during the rainy season, people in some locations could now cultivate two or more crops per year (Firoze 2003).

Agriculture flourished within the polders, human habitation spread, and the poldered areas became densely settled (Alamgir 2010; Dewan et al. 2015). In the 1980s, people converted many polders into brackish water shrimp farms (Hossain and Hasan 2017; Rahman 2015; UNEP, 1999). Numerous unplanned inlet structures were added to the embankments to facilitate saline water intake for shrimp cultivation (Hossain and Hasan 2017; UNEP, 1999).

In 2009, cyclone *Aila* severely affected the southwestern coast of Bangladesh, killing 190 people and impacting over 3.9 million people (Mahmud and Prowse 2012). Individuals engaged in shrimp and crop cultivation lost their means of livelihood as most of the land became subject to diurnal tidal flooding due to the breaching of embankments (Mallick and Vogt 2012). The intrusion of saline water damaged the fertility of the land, rendering it unsuitable for cultivation (Bangladesh Water Development Board, 2013a). Long before the breaching of the embankments by the cyclone, siltation of peripheral rivers caused widespread waterlogging inside the polders resulting in the loss of crops, poultry, and cattle and the destruction of potable water sources (Deb 1998). It further aggravated through the spread of saltwater shrimp cultivation, which marginalized traditional crop producers in the polders. The already prevailing discrimination in terms of entitlement of land resources (Uddin and Islam 1982) and hence access to essential services, together with saltwater shrimp culture and the impact of disasters (cyclones), has led to seasonal and permanent migration of polder inhabitants to urban areas. Shattering livelihood options due to cyclone Aila reportedly compelled 78% of affected survivors to migrate to adjacent urban areas to seek alternative means of livelihood (Mallick et al. 2011; Mallick and Vogt 2012).

The current state of the physical and social environments in the southwest coastal zone of Bangladesh attributes to the structural interventions that started with the CEP. Other complementary infrastructure projects, for example, Coastal Embankment Rehabilitation Project, and Khulna-Jessore Drainage Rehabilitation Project, followed CEP. The primary objective of the structural intervention in that area was to restrict tidal flooding to increase crop production in the face of rising population growth in the country, which was achieved to a considerable level (Zaman 1983). However, it quickly became apparent that emphasizing large-scale infrastructure development plans severely underestimated local social and hydrological complexities(Royal Haskoning, 2003). It led to consequences (e.g., waterlogging inside the polders, shortage of irrigation water and subsequently soil and water salinity inside the polders, marginalization of crop farmers to shrimp cultivators.), culminating in vulnerable conditions for the community.

Over time CEP became a powerful agent of change for the entire coastal zone of Bangladesh. The embankments brought changes to the biophysical system of the hydro-geo-

morphologically sensitive Ganges plain (southwest coastal area in particular), which had extensive social-ecological implications. CEP significantly changed its biophysical features through the polderization of the coastal land. While these changes are evident all over the coast, the southwest part – owing to its unique hydro-geomorphology - experienced alterations that do not match the other parts of the coast (e.g., the southcentral coast or southeast coast). These changes in the biophysical domain consequently contributed to transforming the community's economic and social arrangements in the southwest coastal region of Bangladesh.

Social-Ecological System (SES) and its Transformation

According to Berkes and Folke (1998), social-ecological systems are linked systems of people and nature, emphasizing that humans must be seen as part of, not apart from, nature. SESs are nested, multilevel systems that provide essential services to society, such as the supply of food, fiber, energy, and drinking water. Social-Ecological Systems are also referred to as 'socio-ecological systems' or 'human-environment systems' (Binder et al. 2013). Before the embankments, the coastal areas grew crops, mostly paddy, and they were home to varieties of fish species. Agriculture was nature-dependent, and the destruction of crops was a common phenomenon. Ecological features dominated the social system developed in the coastal area in the pre-polder period. The tidal cycle in the rivers influenced the development of human settlements and their activities. Mobility and socialization were restricted. Access to social services and utilities (e.g., education, health) was limited. However, all these features formed a particular social-ecological order, which later the coastal embankment project altered.

Transformability is defined as:

> The capacity to create a fundamentally new system when ecological, economic, or social (including political) conditions make the existing system untenable. Transformability means defining and creating new stability landscapes by introducing new components and ways of making a living, thereby changing the state variables, and often the scale, that define the system. (Walker, Holling, Carpenter, & Kinzig, 2004).

Transformations fundamentally change the structures and processes that alternate feedback loops in SESs (Olsson et al. 2006). The Coastal Embankment Project (CEP) changed the coastal landscapes in many ways that transformed the coastal social-ecological system. Polders were created by constructing earthen embankments that isolated the tidal plains from the rivers. They allowed secure cropping, and the diversity and intensity of cropping increased. Besides, embankments provided improved communication options, which eased people's access to essential services (e.g., education, health). We argue that all these contributed to the changes in the people's way of life as much as they changed the ecological settings.

Political and economic contexts

Political and economic elements are the underlying issues that configured Bangladesh's overall national development approach as a nation-state. The creation of polders on the Bangladesh coast came as part of the holistic water resources development program driven by desires for economic gains. The legacy of political and economic discrimination that started during the colonial period continued through the Pakistan era, widening the gap between the west and the east wings. Built on the colonial structure, Pakistan encouraged private enterprise as a pathway to development. It offered generous subsidies and facilities to private entrepreneurs and supported overconcentration on defense expenditure (Schendel, 2009). These eventually created a small elite class of people who had control over most of the country's resources, and almost all of them were in West Pakistan. While West Pakistan utilized considerable resources from East Pakistan to finance its development, the government spent only a quarter of its budget in East Pakistan, which was home to the majority of the people (Schendel, 2009). The growing political and economic discrimination by the West Pakistani rulers and their utter disregard for the well-being of the people of East Pakistan eventually led to the war for liberation, and Bangladesh earned its independence in December 1971.

A weak economic infrastructure inherited from decades of colonial oppression, the brunt of the war, and later a series of political crises left Bangladesh reliant on foreign aid for her development. The development prescriptions from donors were mainly devoid of consideration for local ecology (Thomas 1974), and this redefined the human-environment relationships in the coastal part of the country. The social and ecological manifestation of the external political and economic elements became evident through succession to the current fragile state of the polders.

The evolution of water resources development in Bangladesh shows that economic reasons drove the adoption of structural interventions (IECO, 1964a). It was justified in the growing need for food for a growing population. Also, structural development was the desired means for the economic development of any nation, and the concern about the 'environment' was yet to become an issue. Leading firms from Europe and America formulated the Master Plan for water resources development in Bangladesh (then East Pakistan). However, in the early 1960s, there was no provision to assess project impacts from the environment or social perspectives (IECO 1964b; Leedshill-De Leuw Engineers 1967, 1968) as would be the standard case now.

The former Irrigation Department of the Government of then East Pakistan originally conceived of the Coastal Embankment Project. The Flood Control Branch of the Department started repairs on old embankments in 1958-59 and prepared a report and estimate of the cost of construction of new embankments and repairing and remodeling existing ones in the coastal areas (Rashid and Rahman 2010). Ordinance No. 1 of 1959, which created the East Pakistan Water and Power Development Authority (EPWAPDA), also granted it broad powers, including taking over the works in progress under the agencies absorbed by the Authority (Rashid and Rahman 2010; Thomas 1974). That is how the Coastal Embankment Project came under EPWAPDA.

EPWAPDA submitted the report produced by the formerly Irrigation Department to the Government of Pakistan, and they approved the proposed project for construction in the middle of 1960 (Rashid and Rahman 2010). Under EPWAPDA's supervision, the work

started during 1960-61. However, the progress was relatively slow due to the absence of a comprehensive and coordinated plan and adequate supervision and effective control (Rashid and Rahman 2010). Consequently, EPWAPDA requested the International Engineering Co. (IECO), their general consultant, to review the layout and project design and submit a report thereon. IECO submitted its report in June 1961, where they recommended conducting additional detailed engineering investigations and designs (Rashid and Rahman 2010).

Following IECO's recommendations, the embankment program was accepted for execution (Rashid and Rahman 2010). The IECO plan proposed constructing, repairing, and strengthening over 4,500 km of earth dikes along the bank of rivers, drainage channels, and tidal estuaries. Internal drainage from these enclosed units was supposed to be managed by installing over 5,200 metal or concrete pipe sluices at more than 3,300 sites to drain the land inside the dikes (IECO 1964b). The automatic flap gates installed on the saltwater end of the sluice pipes would prevent saltwater intrusion. However, there was no consideration for controlling the freshwater level within the polders other than during periods of excessive rainfall. The proposed plan was said to protect against saltwater intrusion and flooding to 1.4 million hectares of land, of which nearly 1 million hectares were under cultivation (Rashid and Rahman 2010). In April 1962, EPWAPDA signed an agreement with M/s. Leedshill-De Leuw Engineers as the engineering consultant for the Coastal Embankment Project (Rashid and Rahman 2010). Consequently, for technical support and guidance to local engineers on the project's planning, design, and construction, Leedshill consultants were integrated into the field and office organization of the EPWAPDA Chief Engineer for the Southern Zone (Leedshill-De Leuw Engineers 1968).

Active construction of the project commenced in 1961 using funds from the Government of East Pakistan and based on the IECO report. The Provincial and Central Governments sanctioned the project in 1963. A combination of funds from the Government of East Pakistan and grants and loans from the United States Government through their Agency for International Development (USAID) financed the project.

Social Context

Agriculture has been the predominant occupation of the households in the southwest coastal region as it has been in the rest of the country. However, the types of crops in the coastal areas were limited to paddy and some winter crops. Transformation of the southwest coast has seen the replacement of traditional land protection measures, which allowed only a single or partial crop annually. Before the embankments, when the land was subject to diurnal tidal flooding, most people were engaged in subsistence agriculture (they could grow food only for themselves). There were no other significant means of livelihood. The following statement from the concept note on Coastal Embankment Project prepared by the East Pakistan Water and Power Development Board (EPWAPDA) gives a clear idea about the socio-economic condition in the southwest coastal zone.

> …The trade-in fish, timber, and the few industries that have recently grown up in the neighborhood of Khulna are hardly sufficient to offer employment to the mass of people, and more than 80% of the total labor force is engaged in agriculture, which is the primary source of subsistence in the area. With most of the population dependent

> on agriculture, crop failure in the area meant poverty and famine…Accordingly, the economic condition is very weak, crop failures are disastrous, and famines are common. (EPWAPDA, 1960)

Access to primary education was difficult for most as there was no school nearby, and communication was difficult. Even for the essential groceries, people had to travel far, and those who did not have a boat sometimes had to cross the rivers and creeks on their way by swimming (Source: A respondent in polder 32). Polders, in the first place, protected agricultural land from tidal flooding. They allowed more diversity and frequency of crops. Embankments also served as roads to connect people to neighboring areas, which enabled them to engage in diversified income-generating activities (IECO 1965).

With the changes in the external political and economic contexts, the southwest's local social and economic patterns and processes also changed. Better communication and improved technology enhanced the local economy, while the changes in the country's political landscape transformed the local level governance system. The traditional village administration system shifted to formal elected local government arrangements introducing different social institutions (e.g., Upazila Council and Union Council). Various community-based social groups emerged as donor-driven development projects were commissioned and implemented (Parvin et al. 2009).

The influence of external economic elements was manifested by the introduction of brackish water shrimp cultivation in the polders in the early 1980s. Before initiating the embankment project, the people in the southwest coastal area cultivated shrimp on a limited scale (in the paddy field after harvesting and in small ponds) (Leedshill-De Leuw Engineers 1968). Because of the increasing global demand and a favorable physical environment provided by the embankments, shrimp cultivation became popular in the southwest coastal polders. Shrimp cultivation proved to be economically profitable, and more and more people tended to switch to shrimp cultivation instead of crops (Deb 1998; Hossain and Hasan 2017). That gave rise to a new element in the social institutions of the polders. The politically powerful groups started capturing small land holdings for expanding their shrimp cultivation, squeezing the marginal farmers. Large-scale shrimp cultivators and the politically connected business people or politicians cum businesspeople forced the farmers to lease off their lands (Deb 1998). The forced leasing of land was mainly administered through obstructing surface irrigation to the lands (Source: Semi-structured interviews). In most cases, these large-scale shrimp cultivators are absentee landlords who live in cities and have workers to supervise the shrimp ponds.

Large-scale shrimp cultivation has other social implications. As shrimp cultivation is far less labor-intensive than crop cultivation, many agricultural laborers in the polders became unemployed (Deb 1998). These laborers mainly were the sharecroppers who grew crops for their consumption. Now losing their lands to the largescale shrimp cultivators and finding no work to do in the polders, they tend to move to the parts of the country where there is a shortage of agricultural laborers during the harvesting time. This seasonal migration of labor forces has both positive and negative sides. On the positive side, these people earn a good amount of money working away from home to keep their families going. On the negative side, they have to compromise their family life as they are away for a significant amount of time (3–4 months).

Ecological context

The southwest of Bangladesh is part of the Ganges delta. It is intersected by many rivers and estuaries, connected by innumerable interlacing cross-channels. Like other deltaic lands, the southwest is flat. The surface was slightly above the flood level before the construction of polders. The riverbanks were higher than the adjacent land, so the land sloping away from them on either side formed a series of depressions between their courses, and there were numerous marshes (O'Malley 1908).

Even within the rest of the Ganges delta and all the coastal areas of Bangladesh, the southwest has unique ecological features because of the Sundarbans, the world's largest natural mangrove forest ((Swapan and Gavin 2011)), to the south of the south zone. All three case study polders are along the Sundarbans, and the embankments forming the polders provide demarcation between nature and humans. The rivers and estuaries running from north to south are connected by an intricate network of branches further dissected into numerous smaller channels. This whole track was a maze of waterways, and after constructing the embankments, the enclosed parcels of land looked like a collection of islands of different sizes and shapes.

Agriculture has been the way of life for the people in the southwest since recorded history (O'Malley 1908). However, the people's livelihoods in the polders adjoining the Sundarbans are significantly connected. The Sundarbans are a source of timber, firewood, and building materials. Many people are engaged in collecting honey from the Sundarbans.

Historical documentation suggests that the Sundarbans were spread further inland until the settlers cleared the forest for cultivation (O'Malley 1908). In 1785 the British administrators leased off parcels of land to local Zamindars. The forest land was considered 'utterly unproductive,' and the vast tract of land was converted into 'immense rice fields' for earning revenue (O'Malley 1908). Polders 7/1, 32, and 33 were part of the Sundarbans until the intervention of the British administrators. The abundance of water for irrigation was considered an added advantage for increasing the rice reserve against seasons of famine (O'Malley 1908) which led to the conversion of the forest land into rice fields.

Settlements in the southwest started growing slowly as the formal colonization began and were clustered along the riverbanks as they were naturally higher than the surroundings. Besides the cultivators' permanent settlements on the Sundarbans' clearances, many people from the surrounding locations came only during the plowing and harvesting seasons. These temporary migrants lived in their temporary huts and left after the growing and reaping of their paddy. The highly fertile land reclaimed from the Sundarbans rendered it easy for cultivation without requiring too many workmen (O'Malley 1908).

After clearing part of the Sundarbans, two things were essential for successful cultivation; embankments to prevent saltwater from entering the field and sufficient rainfall to sweeten the river water for irrigation (O'Malley 1908). The river water in the southwest is brackish from December through June. With the onset of the rainy season, the salinity in the river water subsides, and the upstream river flow further pushes the saline water downstream. Before polderization, crop cultivation was possible on flat land only between June and December with the aid of temporary earthen embankments locally known as *Ostomashi Bandh* (embankment for eight months, also known as *Dosher Bandh* or embankment for all (Nowreen et al. 2014)). The higher land along the riverbanks had some vegetation, but the vast tract of flat land had none except paddy during the cultivation season (O'Malley 1908).

Ostomashi Bandh was an enterprise of the Zamindars wherein communities, through compulsory labor, constructed the embankments and maintained the canal structures. These were functional until 1950 when the Zamindari system was abolished after the partition of India in 1947 (Dewan et al. 2015). Consequently, the maintenance of the embankments was neglected, resulting in overtopping of and breaches in the existing embankments. That eventually pushed many farmers away from the area leaving extensive tracts of cultivable land to the damaging effects of saline tidal water (EPWAPDA 1960). The following statement elaborates on the embankments' conditions between the end of the Zamindari system and the implementation of the Coastal Embankment Project.

> After the state acquisition, the Government of East Pakistan stepped into the role of the Zamindars, and the entire responsibility of maintaining the embankment fell on them. However, there was no suitable government agency to tackle such a huge problem. The government started reconstruction and maintenance of embankments through the agency of the District Magistrates, and works were done on the Test Relief measure. As the staff employed had not had the requisite technical knowledge, the embankments were neither made to the requisite section nor properly constructed. The result was that the embankments were breached as before, and damages to crops continued. Thus the matters remained as they were before. (EPWAPDA, 1960)

Polder development is centuries-old practice (Uddin and Islam 1982). It can be inferred that the Coastal Embankment Project is a scaled-up concept of the indigenous practice which was in place during the Zamindari system (Begum 2011). However, the scale and extent of the CEP were colossal compared to the non-engineered traditional practices, which targeted a single cultivating season. In contrast, the CEP sought a permanent arrangement for secured cultivation.

The present-day polders in the southwest adjoining the Sundarbans are part of the land reclaimed by clearing the mangrove forest. This coastal landscape has always been subject to disasters. Floods and cyclones are common phenomena due to geophysical settings. The flood of 1890, triggered by the bursting of the Bhagirathi embankment upstream, was aggravated in the southwest coastal region because of the siltation of the river channels (O'Malley 1908).

The infamous Bengal Famine of 1897 attributes to the lack of rainfall which created a drought-like situation preventing the desalination of irrigation water. The cyclone of October 1895 had swept a storm wave over the land, leaving a deposit of salt that the shortfall of rain in the following season could not wash out. These two factors contributed to crop failure in 1896, leading to famine in the following year (O'Malley 1908).

Materials and methods

This essay is part of a research project that explores how large-scale physical infrastructure leads to the transformation of an entire social-ecological system through alteration of natural environments and eventually causes community vulnerability to disaster. We adopted a case study approach to trace the transformation in the Southwest coastal region of Bangladesh triggered by the commissioning of the coastal embankments. We chose three

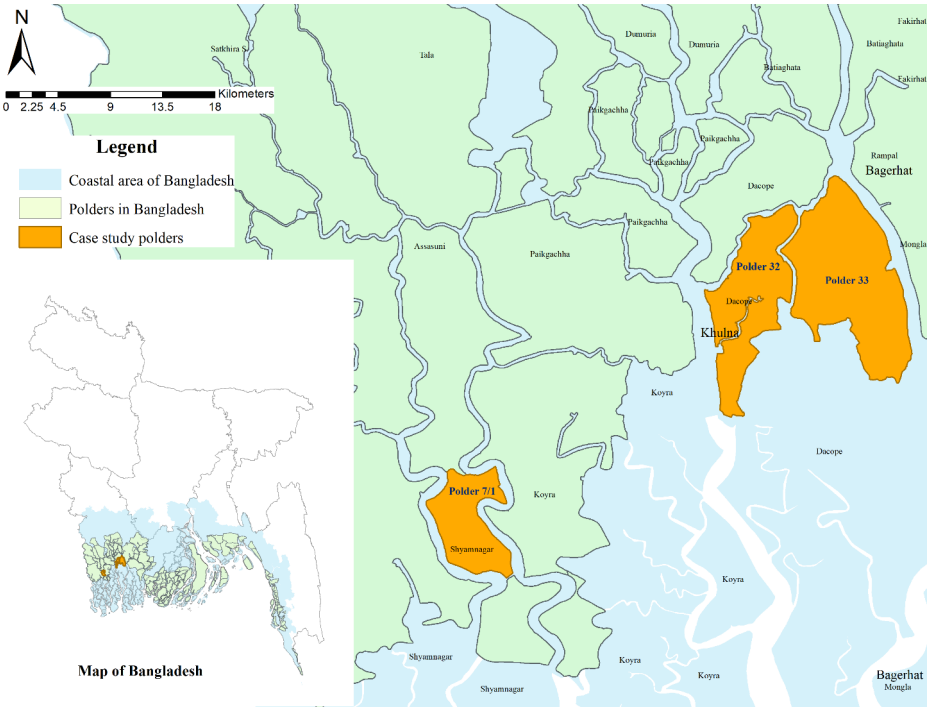

Fig. 1 Location of the case study polders

case study polders from the districts of Khulna and Satkhira (Fig. 1); they are polders 32 and 33 of Dacope Upazila (sub-district) in Khulna, and polder 7/1 of Shyamnagar Upazila of Satkhira. The case study polders were selected to represent the southwest coastal region's typical polders and address the inherent differences. The features considered in selecting the case study locations were population and their socio-economic conditions, economic activities, physical conditions of the embankments, and the drainage systems.

We used two tools to collect data: semi-structured interviews and document review. Field level data collection took place in Dhaka, Khulna, and Satkhira between November 20, 2017, and January 25, 2018. We interviewed a total of 40 people in 20 individual and group interview sessions[1]. These included interviewing water resources development and management professionals (both at policy-making and implementation levels), local level government representatives (members of the Union Councils), members of local civil society (schoolteachers and journalists), and development worker (NGO professionals) and above all, general community members. We carefully chose the respondents for semi-structured interviews at the community level to ensure the representation of adults from all age groups. In moving around the polders to select respondents, we gave attention to identifying older people who have experiences from the pre-embankment time. We did that to help ourselves understand the variations of lived experiences in pre-and post-embankment periods. We

[1] This article is part of a Ph.D. research project for which the data collection methods underwent a rigorous ethics approval process. Participants of all the interviews conducted for this research provided informed consent, which is crucial for obtaining ethics approval from the university.

formulated the issues addressed in the interviews to capture the transformation of the southwest coastal region due to the implementation of the CEP. We identified two separate sets of issues to guide the interview processes (provided in the supplementary material); one was for the water resources development and management professionals at the policy-making and implementation levels, and the other was for the local level respondents. Document review includes reviewing those of CEP and the follow-up projects, historical documents about the southwest coastal area, and the project documents of the ongoing Coastal Embankment Improvement Project (CEIP).

We followed the conventional narrative approach for qualitative data analysis throughout this project. Following our research objectives, we collated the data collected from document reviews and interviews. Then we structured the data according to our analytical framework, which in this case was the transformation of the social-ecological system. Then we carefully sorted out the patterns, connections, and inferences in the collected data to answer our research inquiries.

Transformation leading to new social-ecological benefits

Empolderment significantly impacted the general social and ecological settings on the southwest coast of Bangladesh. With the completion of the embankment construction, the inhabitants of the polders readily benefitted as their socio-economic conditions improved from secured cultivation (Dewan 2012). Triggered by the improved built environment, the benefits kept expanding.

The foremost objective of the coastal embankment project was to protect the cultivable land from tidal flooding so that farmers could cultivate crops safely and securely. Interviews with the communities confirm that this objective was substantially met. The traditional agricultural practice consisted of embanking individual parcels of land by temporary low-height earthen embankments (details in the Ecological Context section above). These embankments kept the land safe for eight months. Typically, these embankments would submerge in high tide after the eight months when the crops are already harvested. However, these low-height embankments were not always successful; sometimes, the flood in the Bengali month of *Bhadra* (Mid-August to mid-September) would overtop the embankments and wash away the standing crops.

Besides securing the principal crop, the coastal embankments helped prevent saline water intrusion, allowing a second crop where irrigation water was available. In recent times, this prospect of crop diversification has inspired many farmers to move away from shrimp cultivation which has detrimental effects on land. An interview in Polder 33 revealed that some people earned more from dry season crops (*Robi* crops) than the traditional wet season paddy. In the statement of a respondent:

> Earlier, there was only one crop in a year, but now there has been crop diversification. We grow pumpkin and watermelon; we hardly have any time to kill. (Source: Field level data from polder 33)

According to the inhabitants, the second most important benefit of the Coastal Embankment Project was improved communication within and outside the polders. The raised earthen

embankments served as the designated means of road communication (IECO 1965), and this further safeguarded the internal roads in polders which otherwise would get inundated in tidal flooding.

Before CEP, there was no such provision, and the mode of communication was restricted to boats only. Those who did not have a boat would have to travel on foot and cross the channels swimming. Even for groceries, people had to travel to *Chalna*, the closest local growth center located roughly between 18 and 20 km from the farthest points of polders 33 and 32, respectively. However, now, they can easily travel to Khulna, the district and divisional headquarters and the largest city in the country's southwest, roughly over 70 km from the farthest points of polders 32 and 33. In the statement of an interviewee from the community in polder 32:

> [2]Before WAPDA was constructed, if anybody had a piece of work in *Chalna*, they would have to go there one day ahead of schedule to be on time. However, now, people are going to Khulna and coming back on the same day so conveniently, which was unimaginable back in those days when we did not have the embankments. (Source: Field level data from polder 32)

One significant benefit that came with improved communication was access to formal education. There were not many primary schools in the now poldered southwest coastal area, and the number of high schools was even fewer. As a result, most of the older people who were born before the implementation of the CEP had no formal education; some of them attended informal, traditional schools (*Pathshala*), while most of them remained illiterate. The physical connectedness offered by the embankments enabled children to attend schools away from their homes. Some of them pursued higher education in different parts of the country. These have a positive bearing on the overall quality of life of the people living in polders.

All three case study polders (polders 7/1, 32, and 33) were once part of the Sundarbans mangrove forest which was cleared off for cultivation starting as early as 1785 (O'Malley 1908). As part of the coastal ecology, the reclaimed landmass was suitable for certain salinity tolerant plants but unfavorable for market gardening. Vegetables were grown on the highland near the riverbanks, but most of the land was barren except for the cropping season (O'Malley 1908). The coastal embankments offered the opportunity to grow fruit and vegetables by restricting soil salinity inside the polders. However, this benefit was reversed when the cyclones breached the embankments at several locations, and tidal flooding persisted - for some places for more than two years. This reversal can be compared to the pre-embankment situations when vegetation was scarce.

The former greater district of Khulna (which also included Satkhira) was considered unsuitable for cattle rearing as the water of many rivers became saline during the dry season. Salt in the soil would also not permit any fodder for the cattle. Only cattle were kept as necessary for agriculture, and when these cattle died, they had to be replaced from other districts (O'Malley 1908). It was true in the statement of the community members in all

[2] WAPDA is the short form of EPWAPDA which stands for East Pakistan Water and Power Development Authority, the predecessor of the Bangladesh Water Development Board (BWDB). Since EPWAPDA implemented the Coastal Embankment Project, local people in their conversation refer to the embankments as 'WAPDA' as a short form for 'embankments constructed by WAPDA.'

three case study polders. The situation changed with the construction of the embankments. Families started raising poultry and cattle, which primarily supplied eggs, meat, and milk to the families and contributed to families' income. As it was noted in an interview with a community member in polder 7/1:

> Poultry and cattle are very good sources of income for families. Every year, they grow in size and number, and families can make good money. (Source: Field level data from polder 7/1)

Access to potable freshwater has been a challenge for the inhabitants of the southwest coast since the inception of human settlements there. Before constructing the polders, people used river water for drinking, cooking, and other household purposes. Consequently, diarrhea and dysentery prevailed when salinity in river water increased in the dry season.

Coastal embankments, through the prevention of saline water intrusion, offered the opportunity of preserving fresh water in tanks and ponds. It resolved one of the greatest problems in the area (IECO 1965). In 1967-68, investigations were made near Mongla in Khulna to locate a suitable drinking water supply for the Mongla Port Development. Water from several test wells drilled to 1,500 feet was too saline for domestic purposes (Leedshill-De Leuw Engineers 1968). It left rainwater harvesting as the sole option for securing access to freshwater. For years, communities have done this by preserving a pond or tank exclusively for drinking and cooking purposes. Over time, pond-sand filtration and other means have emerged to make the water safer. The embankments prevented contamination of the freshwater reservoirs by tides. They played a significant role in making freshwater supply more stable, not only for the case study polders but also for the entire coastal zone. It unequivocally improved the health and living conditions of polder residents.

The coastal embankments were not designed to protect against cyclonic surges but tidal flooding. Although the primary objective was the protection of crops from salinity and enhancing agricultural production, these embankments played a significant role in saving household assets, including the homesteads, from tidal flooding (IECO 1965). Traditionally the houses in the southwest coastal areas were mud-built- with mud-floor and mud-walls, and the *goal-patta*[3] roof (IECO 1965). Before constructing the embankments, a sudden rise in tidal level or a cyclone-induced surge would severely damage the houses, leading to the collapse of the structures. Coastal Embankment Project extended protection to the mud houses in the case study polders and hence played an important role in improving the quality of life of people. The effort and cost for the maintenance of the mud houses were also reduced (IECO 1965).

Even though the design heights of the embankments did not consider cyclonic surges, they provided a high degree of safety against many severe cyclone events (Haq 1982). The embankments were the first line of defense against storm surges (Nowreen et al. 2014), and people admit that they did not feel much of the ravaging effects of cyclones because they were living inside the polders. It became evident when the CEP was still underway. The damages in the unprotected areas were notably greater than the damages in the completed and even partially completed polders (Leedshill-De Leuw Engineers 1968). Even in the devastating cyclone of 2009, when the embankments in all three case study polders (7/1,

[3] The longleaf of the *Nipa fruticans*; grows extensively in the Sundarbans. It is a popular thatching material in the areas adjoining the mangrove forest.

32, and 33) were breached at many locations and submerged the settlements, most people found refuge on the top of the parts of embankments that were unaffected. In the statement from a resident of polder 32:

> We realized how embankments had protected us from nature's fury after cyclone Aila struck, breaching the embankments at various points and submerging our homesteads. We had to live on the top of the embankment as that was the only raised ground free from tidal flooding. It continued for two years until the breaches were repaired to keep tides away, and we were able to rebuild our homesteads. (Source: Field level data from polder 32)

The Coastal Embankment Project (CEP) paved the way to diversify income-generating activities. First, the project was a means of income for the local labor force since almost the entire embankment construction task was carried out by employing manual labor (Haq 1982). The construction of more than 8,000 km of the earthen embankment using hand tools to circumvent more than 1.2 million hectares of land by forming 108 polders (Leedshill-De Leuw Engineers 1968) required a huge workforce. During the dry season, the construction work took place when the locals had no work as the cropping season had already ended (Haq 1982). So, it can be asserted that the construction of the coastal embankment offered a considerable means of income for the locals.

Improved physical communication, which came as an associated benefit of the project, opened up access to many income sources. The people who were earlier engaged in subsistence agriculture could then move within and beyond the region in search of work. Secure cropping and improved communication encouraged small to medium-scale crop processing and marketing facilities, such as rice processing mills. With the improvement of purchasing power of the people, demands for household goods and services also increased, giving rise to local businesses (Leedshill-De Leuw Engineers 1968). With the construction of embankments for all the 108 polders under CEP, the local and regional economic activities changed. Many businesses evolved catering to the Mongla seaport (Asiatic Society of Bangladesh, 2012) located just across the *Passur* River from polders 32 and 33. Meanwhile, starting in the early 1980s, shrimp cultivation for export boosted the local economy (Deb 1998; Hossain and Hasan 2017) until its detrimental social and ecological aspects began to be recognized. The overall contribution of coastal embankments can be noted in the following statements of two inhabitants from polder 32 and 7/1:

> Back in the old days, there was hardship. However, now, there is no shortage of money or work. …When we do not have jobs here, we go almost everywhere in the country to work. We are not any short of food now. For all the year-round, we have enough stock. We do not have to worry about feeding our guests. (Source: Field level data from polder 32)
>
> The poor people are now better off. After the cultivation season is over, they go to the sea for fishing. When they come back from the sea, they go to other parts of the country for work. So, they are much better off now. (Source: Field level data from polder 7/1)

Transformation resulting in new social-ecological challenges

The benefits of coastal embankments, as elaborated above, did not come without some costs. Interference in the natural environment manifested some challenges which started surfacing as early as within a decade (Thomas 1974), and they kept recurring over the whole social-ecological system. An obvious change that all elderly polder dwellers recalled was the loss of varieties of fish they used to catch. It can be attributed to altering the fish habitat by cutting off the polder from the river system. The swamps and natural depressions (locally known as *Beel*) had abundant estuarine species of fishes that disappeared after the embankments were put in place. In the polders near the coast, including the case study ones (7/1, 32, and 33), the age-old practice of raising shrimps in paddy fields was curtailed as embankments eliminated the entry of saline water into the polders (Leedshill-De Leuw Engineers 1968). Although the account of the loss of fish, both in amount and in variety, was not accurately substantiated, the project appraisal documents (namely IECO 1965 and Leedshill-De Leuw Engineers 1968) supported this phenomenon. The abundance of fish before the implementation of the Coastal Embankment Project and their subsequent disappearance is noted in the following statements of two polder-dwellers from polders 7/1 and 33:

> We could not consume all the fish we caught. However, they disappeared after the construction of the embankments. (Source: Field level data from polder 7/1)
> Fish was sold so cheaply, but there were not many people to buy them because it was easy to catch. There was no ice to preserve the fish and transport them to other places. (Source: Field level data from polder 33)

The closing of small rivers and streams by embankments and sluices adversely affected local waterway transportation in the southwest coastal area. Before the Coastal Embankment Project (CEP), people and cargo could freely move inside and within the current polders using boats. In contrast, people needed to change boats to move in or out of the polders after constructing the embankments. This involved extra time and cost as boats had to take longer routes, particularly when transportation of bulk products was concerned (Leedshill-De Leuw Engineers 1968).

The Ganges delta is subject to land subsidence because of the compaction of the old layers due to the high sediment load on top. Apart from the natural process, land subsidence on the southwest coast is also attributed to the coastal embankments. The soil under the embankments is loaded, and local subsidence may be appreciable (UNECAFE 1966). Moreover, the lands inside the polders were deprived of the sediment that spread over it to offset the natural subsidence arising from compaction processes. Moreover, this sediment rests on the riverbed raising its height every year and thus increasing the net elevation loss of land inside the polders. In a study on the Ganges-Brahmaputra tidal delta plain, Auerbach et al. (2015) report that the lands inside the polders on the southwest coast of Bangladesh have lost 1.0-1.5 m of elevation since the embankments isolated them from the tidal processes.

In some parts of the case study polders, limited cultivation was possible during the dry season. Farmers used to preserve sweet water accumulated from rain and internal runoff in the *khals* (canals) by putting up small embankments across them so that the high saline water from the river could not contaminate the sweet water. Those *khals* would again be opened up during the rainy season to permit freshwater to flood the paddy field. The coastal

embankments built under CEP obstructed this inflow of freshwater during the rainy season from the rivers into the poldered lands. As a result, the provision of dry season agriculture in those polders was hampered. The cultivators made unauthorized cuts in the embankments to obtain irrigation water (Uddin and Islam 1982) because CEP initially did not consider water management inside the polders as a project component. However, recognizing the impediment of freshwater inflow into polders, the latter part of the project addressed this issue (Leedshill-De Leuw Engineers 1968).

Because of the absence of an effective water management plan as part of the project, the polders constructed in the first phase suffered from these two contrasting phenomena, waterlogging and shortage of irrigation water (Uddin and Islam 1982). As the embankments blocked the natural drain ways, some areas were deeply flooded after heavy rains damaged standing crops. Efforts were made in some instances by digging ditches to connect blocked drain ways to *khals* (canals) linked to the drainage sluices (Leedshill-De Leuw Engineers 1968). However, these piecemeal approaches were insufficient and required a comprehensive solution that initiated a new pilot program incorporating additional water control works, pumps, and regulators (Thomas 1974). Although waterlogging is a more serious phenomenon for the polders upstream (Nowreen et al. 2014), the case study locations are also not free from this problem. The lands inside the polders have varying elevations; the highland is always free from flood, but the low-lying land suffers from waterlogging. The drainage channels are incapable of draining off excess rainwater that accumulates inside the polders. The deposition of silt in the river channels outside the embankments aggravated the situation over the years. It restricted the operations of the sluice gates and led to limited provision for gravity drainage from the polders.

Shrimp has been part of traditional crop cultivation in the coastal area of Bangladesh. Before the coastal embankment project, people cultivated shrimp in paddy fields (Leedshill-De Leuw Engineers 1968). However, following increasing global demand (Deb 1998) and the fact that tropical coasts are ideal for shrimp cultivation, the crop farmers in the coastal area of Bangladesh were inclined to move to saltwater shrimp cultivation from the beginning of the 1980s (Hossain and Hasan 2017). It led to large-scale cropland conversion into shrimp ponds all over the coast, including the case study polders. Small landowners were initially tempted by the hard cash they received leasing out land for shrimp cultivation, but they later realized that it did more harm than good as they could not grow food for their subsistence. The brackish water brought inside the polders for *Baghda* (saltwater shrimp) cultivation made the soil saline and unsuitable for cropping. Over the years of shrimp cultivation, vegetable gardens and fruit plants became extinct, which were part and parcel of every household since the embankments were constructed. There was no green inside the polders, no fodder, and consequently no cattle or poultry. Since the embankments were not designed and constructed considering the provision for shrimp cultivation, the shrimp cultivators had to make unauthorized cuts in the embankments for brackish water intake, which is necessary for the shrimp ponds. These small cuts were numerous, and, owing to erosion, they became large openings in the embankments over the years. The large landholders for shrimp cultivation made permanent inlet structures in the embankments to allow enough brackish water intake for their ponds. These inlets made the embankments weak over the years. They were the access points for the cyclonic surges in 2007 and 2009, leading to the devastation of the socio-economic and environmental conditions in the polder system.

Shrimp cultivators are politically connected and powerful people (Deb 1998). They started by leasing government land (*Khas land*) and then coercing people to lease off their land by various means despite their unwillingness. One common practice is to block irrigation into adjacent small lands of others so that they cannot cultivate and are forced to lease off the land to them. It is possible only for the economically powerful and politically connected people. The frustration of the common people with shrimp farming can be traced in the voice of a marginal farmer from polder 7/1:

> Shrimp cultivation is beneficial only to the owners who have big shrimp ponds and are powerful. Subsistence level farmers, which most of us are, do not get much benefit from shrimp cultivation. (Source: Field level data from polder 7/1)

Discussion

The establishment of EPWAPDA in 1959 was the beginning of the institutionalization of water resources development in Bangladesh. The planning and designing of large-scale water resources development projects, including the Coastal Embankment Project (CEP), were carried out by EPWAPDA-appointed foreign consultants. Development practitioners later criticized those plans and designs for following a narrow approach to development, disregarding the local contexts (see Thomas 1974). Although, back in the early 1960s, there were no established norms of conducting environmental or social impact assessments as can be found now, it does not necessarily mean that there was no provision for considering them in the project planning and designing. A review of the water resources development projects in Bangladesh (then East Pakistan) carried out in the early 1970s states that:

> The problem lies in undertaking major construction that transforms basic elements in the existing relationships between land, water, and human activity. With only superficial knowledge of the environment and human behavior, WAPDA and its consultants have seldom established adequate contact with the project area and the intended beneficiaries. Project designs have not been adequately planned based on specific conditions, and too little effort has been made to inform and work with the farmers and other residents of the area. (Thomas, 1974)

This observation is echoed in the following statement of a senior water resources development professional in Bangladesh whom we interviewed as part of this research:

> Apart from engineering aspects, the polders have some socio-environmental issues which need to be addressed for the proper functioning of the structures. Engineers alone cannot solve the problems; they must work with communities. (Source: Field level data.)

That CEP did not consider the local ecology in the formulation of the plan was evident as a partial implementation of the project had taken place. The plan did not address any water management provision inside the polders, and consequently, farmers in the completed pol-

ders had problems with irrigation and drainage. Having found this, people from other places where polder construction was scheduled to take place resisted it. That is when an interim evaluation of the CEP was commissioned, and subsequently, some arrangements for drainage and irrigation were made (Leedshill-De Leuw Engineers 1968). All these observations suggest that water resources development on the southwest coast was rushed, disregarding local social and environmental aspects, perhaps to fuel the government's "grow more food" campaign.

Siltation of the peripheral rivers is the major cause of the widespread waterlogging, which is mostly affecting upstream polders (to the north of the case study polders). A review of the CEP-related documents reveals that siltation was not considered a major concern in the project's planning. CEP project documents also reveal that there was no comprehensive study on the dynamics of sediment transportation through the river system in Bangladesh. It further reinforces the notion that development was rushed without much forethought for its impact on the hydro-geo-morphologically sensitive Ganges delta.

Some of the challenges of CEP (e.g., waterlogging inside polders; shortage of irrigation water) were evident at the early stage of the project implementation, which led to the revision of the polder design for the later phase of the project to incorporate water management inside the polder (Leedshill-De Leuw Engineers 1968). However, this was not fully realized because of the shortage of funds (ibid.). It is also clear that the operation and maintenance of the embankments and sluices were not carried out as per the guidelines ('Coastal Embankment Project: Operation and Maintenance Manual') developed as part of the project. These and the unanticipated damages to the embankments for facilitating shrimp cultivation caused deterioration of the polder system at an accelerated pace.

Despite all the challenges, coastal embankments had brought a sense of permanence to the community by creating a flood-free environment that facilitated other secondary benefits (e.g., improved communication, access to basic services, and amenities). However, at the same time, intervention in natural ecology accumulated a range of challenges (waterlogging, shortage of irrigation water.). It harnessed counterproductive ecological services (e.g., shrimp production) with far-reaching social consequences (marginalization of crops, seasonal migration of labor, and eventually longstanding community exposure to vulnerable conditions). Nevertheless, the community considers the embankment a lifeline, and their perception of development is centered on it. They are thankful for the embankment as it provided shelter to them in the aftermath of cyclone *Aila*. They firmly believe that a stronger embankment would improve physical communication and socio-economic conditions.

Coastal embankments evolved a new form of land delineation called 'Polder.' Before constructing the embankments, the vast tracts of tidal land on the southwest coast of Bangladesh were crisscrossed by numerous tidal creeks connected to the rivers flowing from north to south. Subjected to diurnal tidal flooding, this vast tract of land looked like a maze of waterways. The construction of embankments reclaimed land from saline water inundation; however, it also altered the bio-physical arrangements of the open coastal tidal landmass in ways that redefined the coastal social-ecological systems. The ecological elements of the uninterrupted coastal system and those of the embanked land (polder) have stark differences. These phenomena and the external political and economic influences reshaped the social elements of the coastal system, which included both benefits (e.g., secure cropping, improved physical communication, improved poultry and cattle, protection against floods and cyclones) and challenges (e.g., shrimp taking over crops, soil and water salinity, weak-

ening of embankments, and finally breaching of embankments exposing the community to diurnal tidal flooding).

According to Renaud et al. (2013), the state of the social-ecological system in the Ganges Delta has already been altered from Holocene-Delta-SES to Anthropocene-Delta-SES, which underscores extensive human interventions into the natural delta system. We argue that, besides this shift in the Ganges Delta, the southwest coastal area of Bangladesh has transformed into a unique social-ecological system that can be recognized as the Polder Social-Ecological System.

Conclusions

Engineered constructions have made significant contributions worldwide to protect lands from river floods and enhance agricultural production to spur socio-economic development (Armaroli et al. 2019; van Staveren and van Tatenhove 2016). In Bangladesh, embankments and riverbank protection measures against erosion have brought large areas under agricultural activities while they also helped contain floods. Irrigation management, drainage improvement, and other agricultural inputs have increased crop production. Besides, fundamental changes have been made in local water resources management across the country, where communities are part of the operations and maintenance programs for embankments and other physical structures (Government of Bangladesh 2016). It is helping to make governance more participatory and hence more accountable than the centralized command and control approach that was in practice earlier.

The polders in the southwest coastal area of Bangladesh have made significant contributions to the social and economic development of the community despite the negative consequences of the embankments. Given the high density of the population of Bangladesh, it is obvious that the community cannot afford to live without embankments and other hydrological infrastructure that protect people from floods and, at the same time, allow crop cultivation. As a lower riparian country in one of the largest river systems in the world (Cornwall 2018), Bangladesh suffers from both – excess water and a shortage of water. The country is often flooded during monsoon when the upper riparian countries open up dams to release excess water. Conversely, water from the upstream is diverted for those countries' benefits in the dry season, creating drought-like situations downstream. In addition to these, Bangladesh faces significant threats from sea-level rise due to climate change because of its low elevation (Government of Bangladesh, 2017). In such a context, physical infrastructure has played a significant role in people's subsistence and the overall development of the economy. However, any irreversible damage to the environment will always put the development gains into question. For development to be sustainable and the benefits to be equitable across all strata of society, much discretion needs to be imparted in the planning and implementation of physical infrastructure development.

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