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Exploring institutional structures for Tidal River Management in the Ganges-Brahmaputra Delta in Bangladesh

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Abstract
Tidal River Management (TRM) is a local adaptation strategy for coastal floodplains in the Ganges-Brahmaputra Delta in Bangladesh. TRM involves the periodic opening and closing of embankments to accelerate land accretion (or reclamation) in a floodplain. Although the approach is considered a promising adaptation strategy, there have been both positive and negative outcomes from recent TRM implementation. The aim of this study is consequently to explore the institutional (community, rules-in-use, and also biophysical) factors influencing successes and failures of TRM implementation for managing common-pool resources, as a basis for making recommendations on future institutional design. The Institutional Analysis and Development (IAD) framework, first developed by Ostrom (2010) and revised by Bisaro and Hinkel (2016), is therefore used to conduct comparative analysis of TRM institutional effectiveness in three Delta floodplains or beels: one led by a local community and the other two by national authorities. Our research employs a mixed method approach involving focus group discussions, stakeholder interviews, site visits, along with secondary literature analysis. The results of this assessment provide insights into coastal adaptation governance that could inform TRM implementation in Bangladesh and other similar contexts worldwide.

Zusammenfassung
Das Management von tidalen Flussgebieten, Tidal River Management (TRM), ist eine lokale Anpassungsstrategie in küstennahen Überflutungsgebieten des Ganges-Brahmaputra Deltas in Bangladesch. TRM beinhaltet das regelmäßige Öffnen und Schließen von Dämmen zur Beschleunigung von Sedimentablagerung (oder Landgewinnung) in Überflutungsgebieten. Obwohl diese Vorgehensweise als vielversprechende Anpassungsstrategie betrachtet wird, zeigten jüngste Umsetzungen sowohl positive als auch negative Auswirkungen. Daher ist das Ziel dieser Arbeit die Untersuchung der institutionellen (d.h. biophysikalischen, gemeindebasierten und umsetzungsbedingten) Einflussfaktoren, die zu Erfolg oder Misserfolg bei der Implementierung von TRM führen können, zu analysieren. Das Ergebnis dieser Analyse soll als Empfehlungsgrundlage zukünftiger institutioneller Gestaltung dienen. *Ostrom*'s (2010) Konzept der institutionellen Analyse und Entwicklung (Institutional Analysis and Development/IAD), weiterentwickelt von *Bisaro* und *Hinkel* (2016), wird genutzt um eine vergleichende

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Analyse von institutioneller Effektivität im Rahmen des TRM in drei Überflutungsgebieten im Ganges-Brahmaputra Delta, sog. *beels*, durchzuführen, wobei eines der Projekte der Fallstudien von einer lokalen Gemeinde geleitet wird. Die beiden anderen stehen unter der Leitung nationaler Behörden. Unsere Arbeit verfolgt einen „mixed methods“- Ansatz, der sowohl Interviews in Fokusgruppen als auch Ortsbegehungen und die Analyse von Sekundärliteratur umfasst. Die Ergebnisse dieser Analyse liefern Einblicke in die Steuerung (*Governance*) von Küstenanpassungsprozessen, die für die Implementierung von TRM in Bangladesch und darüber hinaus weltweit genutzt werden können.

Keywords Tidal River Management (TRM), Institutional Analysis and Development (IAD) framework, Institutional design, Ganges-Brahmaputra Delta, Coastal management

1. Introduction

The coastline is the area where the land meets the sea. While there is no commonly agreed definition of the coastal zone, several important criteria such as tidal fluctuations, salinity, and storm surges are considered important characteristics. Complex interdependencies between humans and nature are critically important issues in the coastal zone (*Gari* et al. 2015) due to the interaction of multiple components and processes (*Lewison* et al*.* 2016). In coastal zone systems, the multiple ecologic, social and economic elements are highly vulnerable to various external (e.g. climate change induced sea level rise, natural hazards such as storm surges, tsunamis and pluvial floods, upstream development activities that affect freshwater supply and sediment) and internal (e.g. land use change) processes (*Wolters* and *Kuenzer* 2015). However, until recently, research on coastal zones has mainly encompassed single-component (either ecologic, social or economic) and/or single-process studies, which outnumber multi-component and multi-process studies (*Ramesh* et al*.* 2015). In addition, these studies typically provide only limited knowledge of complex coastal systems, meaning that adaptation decisions are, as a result, less effective for addressing complex management problems. Comprehensive, integrated frameworks and methods are therefore needed for assessing the implementation of coastal adaptation policy options.

The floodplain in the Ganges-Brahmaputra Delta forms a vital source of livelihood for rural people (*Brammer* 2014). Both physical (e.g. geological land subsidence, climate change induced sea level rise) as well as anthropogenic processes (e.g. upstream water withdrawal, intensification of shrimp aquaculture, construction of coastal polders (low-lying tracts of land enclosed by embankments)) play a vital role in complex human-nature interactions within the Delta (*Auerbach* et al*.* 2015; *Roy* et al*.* 2017). The inter-dynamics of physical and social processes lead to multiple problems in the floodplain: waterlogging, salinity, siltation of river beds, and drainage congestion. To address these problems local people in the Delta have identified TRM (*Hossain* et al*.* 2015; *Gain* et al*.* 2017; *Mutahara* et al*.* 2018) as an adaptation measure for the coastal floodplains. This management approach was first implemented in Dakatia, in the Khulna-Jessore district of Bangladesh.

Tidal River Management is the process of temporarily inundating floodplains through periodic opening and closing of polders for accelerating land accretion or reclamation (*van Staveren* et al. 2017; *Masud* et al*.* 2018; *Seijger* et al*.* 2018). This approach serves two main purposes: reducing waterlogging and drainage congestion, and increasing the navigability of adjacent rivers. Such management requires adequate river flow for scouring the adjacent river bed and depositing sediments within the floodplain. In the downstream areas of the Delta, river flow is usually higher than in upstream sections. Hence, TRM needs to be implemented from ‘downstream’ to ‘upstream’ floodplains sequentially. In addition, the size of the floodplain should be small enough to enable successful sedimentation. The TRM approach has been applied in several floodplains, within low-lying depressions (we use the local term *beel* hereafter) in the coastal area but under different institutional arrangements, providing an opportunity for comparative learning or ‘lesson-drawing’ (*Benson* and *Jordan* 2011) on effectiveness.

Although TRM is considered a promising adaptation strategy, there have been both positive and negative outcomes for resource management in coastal floodplains from recent TRM implementation. It is known that institutional factors play a major role for contributing to different outcomes of TRM. The central question of this study is therefore: what institutional characteristics contribute to successful TRM? To answer this question, the Institutional Analysis and Development (IAD) framework developed by *Ostrom* (1990); *Ostrom* (2005); *Ostrom* (2010) is applied to comparatively analyze adaptation governance in three TRM *beels* in the southwest coastal part of the Ganges-Brahmaputra Delta. Institutional characteristics that contribute to the successes and failures of TRM implementation are then theoretically examined, in order to make recommendations for institutional design for future policy in Bangladesh and other countries.

2. Methods

Effectiveness was examined using a multiple comparative case study design (*Yin* 2017). A case study design fitted the research aim in that it allowed the isolation of a complex social process in the form of TRM, thereby facilitating focused application of the IAD theoretical framework, which is described in detail in this section.

2.1 Selection of case studies

The TRM approach is potentially applicable for reducing waterlogging and related multiple challenges in 35 *beels* in the southwestern part (Khulna and Jessore districts) of the Ganges-Brahmaputra-Meghna (GBM) Delta (*Gain* et al. 2017). According to the Government of Bangladesh (*Uddin* and *Kaudstaal* 2003), these *beels* are located in the coastal zone. Until recently, the TRM approach has been implemented in only five *beels* (Dakatia, Bhaina, Kedaria, Khukshia and Pakhimara) under different institutional settings. Initially, TRM was developed as a bottom-up approach by local people in Dakatia and Bhaina *beels*. Afterwards, the approach was institutionalized and formally implemented in Kedaria and Khukshia by the Bangladesh Water Development Board (BWDB). The BWDB is still implementing TRM in the Pakhimara *beel*. Evaluation of implementation is limited but *Mutahara* et al. (2018) examine the performance of four TRM *beels* based upon the perceptions of local people, finding differing degrees of perceived effectiveness.

In contrast to this study, to theoretically assess TRM institutional effectiveness we consider three *beels*: Bhaina, Kedaria, and Pakhimara (*Fig. 1*). These *beels* represent different biophysical settings, actor constellations and institutional arrangements. Bhaina is the longest established, founded in 1997 by local people, in contrast to Kedaria and Pakhimara which were created more recently by government agencies (*Gain* et al. 2017). Different physical and social outcomes of TRM in these *beels* are summarized in *Table 1*. Primarily, Bhaina proved more successful than Kedaria and Pakhimara in terms of its physical and social outcomes. These outcomes are derived from the actions of different actors and related external biophysical, socio-economic and rules-based factors, and we therefore evaluate these characteristics by using the IAD framework.

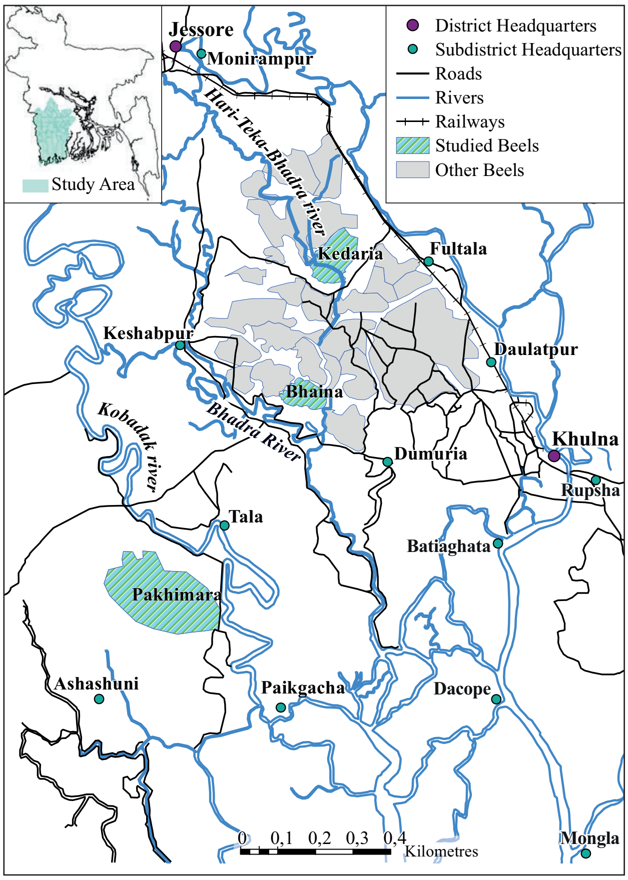

Fig. 1 *Location of the study area in the Ganges-Brahmaputra Delta in Bangladesh. Source: Gain et al. (2017: 115); Gain et al. (2019: 3)*

Table 1 Physical and social outcomes of selected TRM projects. Source: adapted from Mutahara et al. (2018)

Name of *Beel*	Year of operation	Institutional settings	Physical outcomes	Social outcomes
Bhaina	1997-2001	Bottom-up (formal local institutions such as the Paani Committee and informal rules)	Waterlogging was solved in most parts of the *beel*. Uneven sedimentation created drainage congestion in the north-western part. Navigability in the river was restored just after operations began but was later reduced by siltation.	Local conflicts were resolved before starting the TRM project. Initially, there were conflicts between formal and informal institutions (local people). Local people were mostly happy with the performance of the project.
Kedaria	2002-2005	Top down (formal government institution)	Although sedimentation occurred, waterlogging was not solved. Very limited and uneven sedimentation. Navigability in the river was restored one year after operations but it later silted up quickly.	Due to local conflicts, TRM was stopped. Huge conflicts remained throughout the project period. Local people were mostly unhappy with the performance of the project.
Pakhimara	2015-ongoing	Top down (formal government institution)	Sedimentation was uneven. Navigability was restored. River bank erosion at the embankment cut-point and associated economic damage was a central issue.	Due to internal conflicts, the project started late. There were conflicts between local people and formal institutions. Overall, local people were unhappy with the project.

2.2 Institutional Analysis and Development framework

The Institutional Analysis and Development (IAD) framework was originally developed by *Ostrom* (1990, 2010). The IAD framework is a systematic approach to explaining and predicting outcomes by formalizing the structures, positions and rules involved in managing common-pool resources (CPRs). The IAD framework provides guidance for highlighting key insights on institutional, technical and participatory aspects of collective action problems and their effects (*Benson* et al. 2013; *Nigussie* et al. 2018). In the framework, a set of external variables affect an 'action situation' to generate patterns of interactions and outcomes creating feedback on both the external variables and the action situation (*Ostrom* 2010). The internal action situation, comprised of providers and beneficiaries of a collective good, refers to the social space where individuals interact, exchange goods and services, solve problems, dominate one another, or fight (*Bisaro* and *Hinkel* 2016). The external variables refer to the biophysical conditions, community attributes and rules-in-use. In this study, the biophysical conditions refer to coastal floodplain characteristics. Attributes of a community include the history of prior interactions, and the knowledge and social capital of those who participate or are affected by participants. Rules-in-use comprises informal and formal rule-sets that frame the context within which an action situation occurs.

To apply the IAD to the case studies, we use a simplified framework (*Fig. 2*) similar to that employed by *Bisaro* and *Hinkel* (2016), specifically for adaptation governance analysis. We explicitly elaborate action situations in the framework. The revised framework is then used to explain what institutional characteristics contribute to the outcomes identified in *Table 1*.

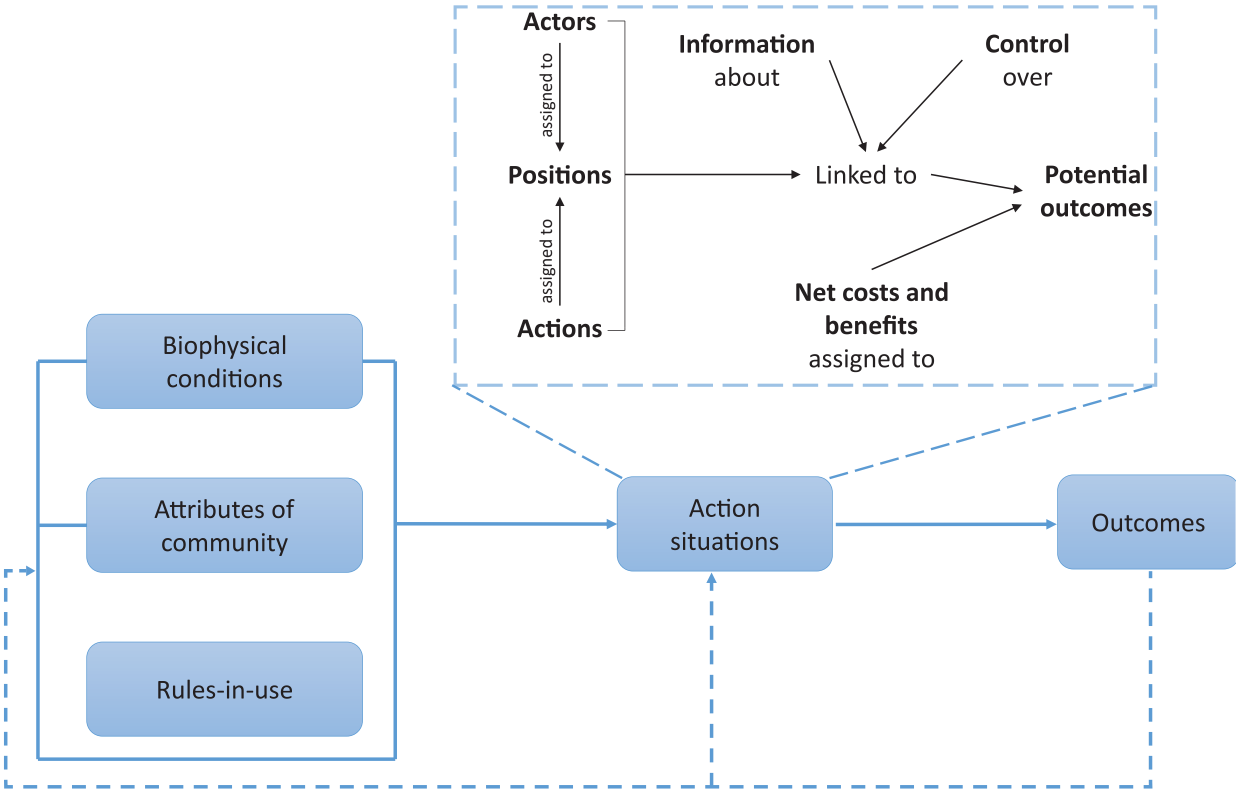

Fig. 2 The Institutional Analysis and Development (IAD) framework. Source: adapted from Ostrom (2005: 15, 33); Bisaro and Hinkel (2016: 355)

To specify the internal action situation (*Fig. 2*), the following elements are taken into account: the set of actions that actors can take; characteristics of actors and their positions; the amount of information available, costs and benefits, degrees of actor control, and patterns of interaction and outcomes (*Ostrom* 2010; *Bisaro* and *Hinkel* 2016). It is also important to understand the action situation in terms of the specific context of TRM. A coastal floodplain or polder can be conceived as a local public good, and thus the provisioning of services is the focal action in coastal floodplain management (*Gain* et al. 2019). This specific provisioning action for TRM includes management of coastal embankments or dikes by temporarily inundating floodplains for reducing waterlogging, increasing economic activities, and increasing navigation in adjacent rivers through sediment deposition in the floodplain. This broader provisioning service was broken down in a subset of actions (*Table 2*) that are undertaken by several actors.

Once this internal action situation was established for each *beel,* case study data were collected on the IAD external factors (i.e., biophysical conditions, community attributes and rules-in-use) that are influencing outcomes. *Table 3* shows the external factors, empirical indicators for each variable and the characteristics of these indicators. For example, the size, location, discharge amounts and sediment load are important external biophysical factors for TRM implementation.

	Key Actions	Acronym
1	Selection of embankment cut points	SelectEmbankCut
2	Setting duration of TRM operations	SetDurTRMOper
3	Acquiring land for TRM operations	AcquireLand
4	Setting compensation amount and mechanisms	Compensation
5	Construction of peripheral embankments	PeripheralEmbank
6	Reducing conflict among different interest groups	ConflictResolution
7	Routine monitoring of technical issues	RoutineMonitoring
8	Maintenance of sediment deposition in *beels*	MaintenanceSediment

Table 2 Key actions for Tidal River Management. Source: own elaboration

Table 3 Indicators and definitions of main external factors that affect action situations. Source: based on Basurto et al. (2013: 1371 f.)

External variables	Indicators	Characteristics/definition
Biophysical attributes	Size	Absolute or relative descriptions of the spatial extent of a resource system
	Location	Location of the floodplain whether in downstream or upstream area of the catchment
	Discharge amount	Discharge of adjacent river
	Sediment load	Amount of sediment load in adjacent river
	Flow velocity	The flow velocity of the adjacent river
	River width	The width of the adjacent river
	River depth	The depth of adjacent river
	Condition of waterlogging	Level of water logging in the floodplain
	Land use pattern	Land use pattern in the floodplain
Community attributes	Socio-economic attributes	Characteristics of actors, related to social and economic dimensions affecting floodplain dynamics
	No. actors	Number of actors affecting decision-making processes related to floodplain management
	Trust	Trust is a measure of the extent to which members of a community feel confident that other members will live up to their agreements even if doing so may not be in their immediate interest.
	Reciprocity	Reciprocity is a symmetrical response to a previous cooperative or defective action by a member of the community.
	Social capital	Degree by which one or several individuals can draw upon or rely on others for support or assistance in times of need. Here we use level of relationships among local people.
	History of past experience	Past experience of waterlogging by the community
	Knowledge of social-ecological system (SES)	Degree to which stakeholders understand and make sense of the characteristics and/or dynamics of the SES. Here we use levels of awareness of local people within the floodplain
	Leadership capacity	Actors who have skills useful to organizing collective action and are followed by their peers
Rules-in-use	Property rights	Particular types of rules determining which actors have been authorized to carry out which actions with respect to a specified good or service
	Formal rules	Operational, collective-choice and constitutional rules, which are formally agreed, written and legally binding
	Informal rules	Human behavior shaped by beliefs, perceptions and the biophysical setting. These are the unwritten, customary norms (*North* 1992)

2.3 Data Collection

We adopted a mixed method approach for collecting data on the internal action situation and external factors. The mixed method approach employed includes a qualitative case study design using three focus group discussions (FGDs), stakeholder interviews, and site visits during May to November, 2018, along with quantitative data collected from secondary sources and published articles (*Gain* et al. 2017; *van Staveren* et al. 2017; *Masud* et al. 2018; *Mutahara* et al. 2018). FGDs were held in three selected *beels*: Bhaina, Kedaria and Pakhimara, each with around 15 TRM participants. In addition, 15 stakeholder interviews (5 interviews per *beel*) were carried out for collecting individual perceptions on selected indicators. The participants of the FGDs and interviewees were from diverse occupational groups (e.g. farmers, fishers, teachers, members of local government, water managers, and housewives). They were selected based on our prior experiences of coastal floodplain management and through a 'snowball' sampling approach, where interviewed participants suggested other relevant interviewees. Data on biophysical systems (e.g. flow, width, depth) were collected from secondary sources and published articles.

3. Results

The results show the comparative analysis of action situations in the three TRM cases and the external institutional factors shaping them. The comparative analysis of the internal action situations, along with key actors and patterns of interactions is summarized in *Table 4.* Diverse external biophysical, socio-economic and rule-based institutional factors that affect these action situations, drawn from the IAD framework, are summarized in *Table 5.*

Results show significant differences between the three case studies in terms of the internal action situations and external institutional factors. Firstly, *beel* Bhaina (1997-2001), established by local people supported by social activists and NGOs to provide protection from waterlogging, was primarily engaged in selecting embankment cut-points, conflict resolution, monitoring and maintenance of sediment deposition (*Table 4*). Local actors took a lead position while the role of formal government institutions (i.e., BWDB) in this TRM project was minor. To perform these actions, the actors had sufficient socio-economic background information. However, they lacked specific technical information (such as river and floodplain morphology data, hydraulic information) for implementing TRM. The actions undertaken were characterized by excellent communication and collaboration among local people, civil societies and NGOs but conflicting interaction between local people and formal institutions (i.e., BWDB). Several external factors (see *Table 5* for summary information) played important roles in shaping action situations. The *beel* is small, comprising an area of about 600 ha., located downstream of the Hari River catchment. Before TRM implementation, the floodplain was severely waterlogged. The navigability of the adjacent Hari River along with discharge amounts, flow velocity, water depth, and the river width was low. Diverse farming practices (rice cultivation during February to April, shrimp cultivation during May to July, and prawns (freshwater) during August to December) were seriously hampered due to waterlogging. In terms of community attributes, the local population was socio-economically homogenous: mainly local farmers, some small-scale fishers and a few other professions. As these people had experience of waterlogging, they knew the causes and consequences of the problem. In 1990, the local people in the southwest coastal area formed a committee, locally known as a Paani Committee (PC) (*Haque* et al. 2015). With strong support of informal rules, the PC as a formal local institution helped the implementation of TRM in *beel* Bhaina. Local people built leadership capacity, social capital, trust and reciprocity. However, another formal government institution (i.e., BWDB) had conflicting roles with the informal rules and the local formal institution (i.e., PC).

Table 4 Comparative action situations in three different TRM cases. Source: field survey, 2018. For an elaboration of the acronyms of main actions, please see Table 2.

Name of *beel*	Main Actions	Key actors (roles)	Available information to the actors	Pattern of interaction
Bhaina	SelectEmbankCut ConflictReso RoutineMonitor MainteSediment Land use pattern	Local people (lead role) Civil societies (minor role) NGOs (minor role) Local government (minor role) BWDB (minor role but conflicting)	Socio-economic information was available but biophysical and technical information was incomplete.	Positive collaboration among local people, NGOs and local government, but conflict between local people and the BWDB
Kedaria	SelectEmbankCut SetDurTRMOper AcquireLand ConflictReso RoutineMonitor MainteSediment	BWDB (lead role) Local People (minor role) Local government (minor role) Research organizations (minor) Donor organization (minor)	Sufficient technical information was available, but socio-economic information was unavailable.	Conflict among local people Conflict between BWDB and local people ple and the BWDB
Pakhimara	SelectEmbankCut SetDurTRMOper AcquireLand Compensation PeripheralEmbank ConflictReso RoutineMonitor MainteSediment	BWDB (lead role) Local People (minor role) Ministry of Land (minor role) NGOs (minor) Local government (minor)	To some extent, technical information was available but socio-economic information was incomplete.	Conflict between BWDB, local people and other organizations

Table 5 External factors (biophysical, community and institutional) affecting the action situation in the TRM cases. For the definition of these factors, please see Table 3.

External variables	Indicators	Bhaina	Kedaria	Pakhimara
Biophysical attributes	Size	Small	Very large	Medium
	Location	Downstream	Upstream	Downstream
	Discharge amount	Low	Low	Low
	Flow velocity	Low	Low	Low
	River width	Low	Low	Low
	River depth	Low	Low	Low
	Condition of waterlogging	Severe	Medium	No waterlogging
	Land use pattern	Agriculture and small scale shrimp	Agriculture and large scale shrimp	Shrimp farming
Community attributes	Homogeneity of socio-economic attributes	Homogenous	Heterogeneous	Homogenous
	Trust	High	Low	Low
	Reciprocity	High	Low	Low
	Social capital	High	Low	Low
	History of past experience	Recent waterlogging experience	Recent waterlogging experience	No waterlogging experience
	Shared local knowledge	High	Low	Low
	Leadership capacity	High	Low	Low
Rules-in-use	Property rights	Present	Conflict	Conflict
	Formal rules	BWDB, Paani Committee	BWDB, local people	BWDB, local people
	Informal rules	Local norms	Local norms	Local norms

Secondly, *beel* Kedaria (2002-2005) was the first TRM project implemented by the BWDB, with financial assistance from the Asian Development Bank, the World Bank and the Dutch government. In relation to the internal action situation (*Table 4*), due to the complexity of TRM implementation, main actions included selection of embankment cut-points, setting of operational durations, acquiring land, conflict resolution, monitoring and maintenance of sediment deposition. Key actors in TRM implementation included local people, civil societies, NGOs, local governments and research organizations. Despite their participation, the BWDB as a government institution played an authoritative role. Sufficient technical information was collected for accomplishing these actions, however insufficient economic data were available for decision-making. Implementation was also hindered by conflicts, both amongst local people and between them and the BWDB. External factors (*Table 5*) also differed significantly from *beel* Bhaina. Most notably, the *beel* Kedaria is located upstream in the Hari-Teka-Bhadra river system, and the size is very large (1,208 ha). Waterlogging was less compared to Bhaina, while the other external biophysical factors such as navigability, discharge amount, flow velocity, water depth, and the river width were very similar to the Bhaina case. The land use pattern included rice cultivation and large-scale shrimp farming. Regarding community attributes, the local population was heterogeneous, comprised of different social groups, but there were internal conflicts between local rice farmers and large-scale shrimp farmers. In contrast to *beel* Bhaina, where the Paani Committee (PC) took a lead role in coordinating the interaction of local people, there was no active role of the PC in *beel* Kedaria after the institutionalization of TRM. Local people had low levels of leadership capacity, social capital, trust and reciprocity. Despite formal rules, set by the BWDB, and local norms, the lack of defined property rights led to conflict among local people and between the BWDB and local people.

Finally, TRM in the *beel* Pakhimara (2015-ongoing) is coordinated by the BWDB. Other key actors of this TRM project are local people, NGOs, the Ministry of Land, and local government. In addition to the types of actions undertaken in Bhaina and Kedaria, the following (*Table 4*) are formally included in the TRM implementation: setting compensation amounts and payment mechanisms, and construction of peripheral embankments. Technical information is available for management but socioeconomic data are incomplete for informing decision-making. The interaction patterns include significant conflicts between the BWDB and local people, as well as between the Ministry of Land and local people. However, there were no conflicts between local people. Again, there are differences in the institutional factors, particularly biophysical characteristics. The *beel* was not heavily waterlogged. The navigability, discharge amount, flow-velocity, water-depth, and the river width is low, but higher than in the other two cases. The *beel* is located downstream of the Kobadak River basin, with a total size of about 700 ha. Major land use types include small scale shrimp farming and the cultivation of homestead crops, mainly rice. As there is no history of strong local participation and management, the people of this *beel* have low levels of leadership capacity, social capital, trust and reciprocity. As specified in *Table 5*, formal rules were imposed by the BWDB although local norms were also apparent in TRM.

4. Discussion

The comparative analysis of three TRM projects suggests that the *beel* Bhaina case was able to develop more positive physical and social outcomes (*see Table 1*) than the other two cases (Kedaria, Pakhimara). This prompts an analysis of institutional factors shaping effectiveness using the IAD framework outlined above.

By comparing the cases (*Table 5*), it can be shown that these different outcomes are associated with several important factors, biophysical (e.g. size and location of the *beels*), community attributes and rule-based settings, which could be explained through the IAD framework. Firstly, the external biophysical factors (severe waterlogging, low navigability of rivers) demanded implementation of TRM in all the cases. However, the favourable resource conditions of the *beel* Bhaina such as its location at the downstream point of the Hari River and its smaller size made for easier application of the provisioning actions. As identified above, *beel* Kedaria is located upstream in the Hari-Teka-Bhadra River and has a significantly larger size, making such actions more difficult. This biophysical condition was not favourable for TRM implementation because there is a requirement for sequential implementation of TRM projects from downstream to upstream *beels*.

Secondly, the community attributes of the *beel* Bhaina (e.g., homogeneity, social capital, leadership, trust and reciprocity) helped the active involvement of local people, thereby partly supporting TRM success. Local people did not have sufficient technical knowledge such as data on discharge amounts, timing and density of fine sediments and Suspended Sediment Concentration (SSC). Due to a lack of this technical knowledge, it was not possible to distribute sediment evenly throughout the *beels*, and thus waterlogging was not completely solved. In both Kedaria and Pakhimara, trust, social capital and reciprocity between actors were much lower than in Bhaina, with TRM in both *beels* also lacking local knowledge and leadership in comparison. In the case of *beel* Pakhimara, there were no serious conflicts among local people. However, local people did not face the impact of waterlogging in their daily activities, although the navigability of the rivers was deteriorating, and thus, TRM implementation was not their main demand. Instead, they argued for compensation during TRM operations and construction of peripheral embankments. The procedures for that were complex and highly bureaucratic. Local people also lacked trust in government institutions. Due to these conflicts and the unplanned construction of a canal, local people experienced severe erosion of their land and associated economic damage and social problems.

Thirdly, rules-in-use differed between the cases. In the *beel* Bhaina, property rights were established, along with the Paani Committee and the BWDB to oversee implementation. That said, a conflict did emerge between formal and informal rules. As a consequence, BWDB took legal action against several hundred local people for cutting embankments (*Mutahara* et al. 2018). In both Kedaria and Pakhimara *beels,* there was conflict over property rights and difficulties that emerged from the involvement of multiple actors as formal rules-based arrangements were established, i.e. between the BWDB and local people. These complexities stemmed from difficult actions such as setting the duration of TRM operations, agreeing compensation amounts and payment mechanisms, and the construction of peripheral embankments. In *beel* Kedaria, local people were from diverse groups with conflicting interests (e.g. large-scale shrimp farmers and local agricultural farmers).

To an extent, these 'rules-in-use' observations coincide with arguments forwarded by *Ostrom* (1990, 2005, 2010) and *Cox* et al. (2010) on the optimal 'design principles' for specific rules which contribute to long term institutional effectiveness. Here, *Ostrom* (2010: 653) refers to the need for: clear user boundaries for resources, resource boundaries that delineate common-pool resources from broader socio-ecological systems, congruence of rules with local socio-environmental conditions, congruence of appropriation rules with provision rules, collective choice arrangements that allow individual participants to make or modify rules, rule-based monitoring of appropriation and provision, monitoring of resources rules, graduated sanctions for rule violations, conflict resolution mechanisms, recognition of local rights, and governance organized in nested layers. In all three cases, the resource and user boundaries were clearly defined. In the *beel* Bhaina case, local biophysical and socio-economic conditions were congruent with the actions taken by local people, although formal rules conflicted with informal rules. However, the provisioning actions in Kedaria and Pakhimara were not compatible with the physical and socio-economic conditions there. Distribution of sediment for developing soil in the floodplain was the appropriation action. Provisioning rules for *beel* Bhaina worked well in performing this task. However, sediment deposition did not take place equally throughout the *beel* due to lack of geomorphological and topographical knowledge of the *beel*. Specifically, there was no deposition in the downstream part. For *beel* Kedaria and Pakhimara, the provisioning (e.g., selection of each *beel*, selection of the location of embankment openings, construction of peripheral embankment) and appropriation rules (e.g., distribution of sediment) were not congruent. For example, the embankment opening was not appropriate for adequate sediment distribution in the large *beels.* Collective choice rules also varied in terms of participation. In *beel* Bhaina, the lead role of local people was clear, while for *beel* Kedaria and *beel* Pakhimara the BWDB took an authoritative role and the participation of local people and other actors was not clearly defined. *Beel* Bhaina performed better for other rule-based indicators compared to *beel* Kedaria and Pakhimara, including monitoring resources and users and recognition of rights. In *beel* Bhaina, there was common agreement among local people to monitor provisioning rules, while monitoring mechanisms were not available in *beel* Kedaria and Pakhimara. Although conflicts remained in Kedaria and Pakhimara, there was an agreed approach to resolving them. However, there was no mechanism for graduated sanctions and nested interaction in all the cases.

In designing effective TRM institutions for Bangladesh and elsewhere, therefore, our analysis suggests consideration of several factors. Firstly, TRM should consider key biophysical attributes, most notably the downstream-upstream characteristics and size of the resource, which appear to be critical in the *beel* system. A comprehensive assessment of biophysical *and* socio-economic local conditions is consequently needed. Setting provisioning actions based on these conditions is essential. For example, depending on the location of the *beels*, proper planning is required for sequential (from downstream to upstream) implementation of TRM in *beels*. Similarly, if the size of the *beel* is too large, TRM needs to be implemented in several compartments comprising single smaller *beels*. Secondly, as in other common-pool resource management globally (see *Cox* et al*.* (2010); *Ostrom* (1990)), community attributes such as trust, reciprocity and social capital are important prerequisites to TRM in the Bangladesh context. In addition, local knowledge is paramount. As the TRM approach can be instrumental for solving multiple problems in areas of coastal floodplains in the Ganges-Brahmaputra Delta, the combination of technical knowledge (provided by formal organizations such as BWDB) and the local cultural and social knowledge (provided by customary and/or local organizations) is needed. A role, too, is required for transdisciplinary knowledge (*Gain* et al*.* 2017). Finally, institutional design should also consider specific rules for guiding management. Based on our IAD assessment and linking it to institutional design principles (see *Ostrom* 2010, *Cox* et al*.* 2010), we find that the participatory roles of key actors in the TRM process and their forms of collaboration need to be clearly defined, i.e. 'Collective Choice Arrangements' need to be created (*Ostrom* 2010). For example, a clear role for individual groups and defined forms of interaction are needed among the PC, BWDB, local people and NGOs. The interaction among actors can generate different types of knowledge such as local practices, socio-economic and political conditions, but also hydrological and earth-works expertise. Conflicts among diverse local people and other actors are common. Therefore, proper rule-based planning is required to develop conflict resolution mechanisms before, during and after TRM implementation. Authorization and rights need to be given to the selected actors for performing each action. Finally, nested mechanisms need to be established for implementing TRMs, particularly those that link to higher level planning processes.

5. Conclusions

To address multiple challenges, the Tidal River Management (TRM) approach is considered an important local adaptation strategy for coastal floodplain management in the southwest part of the Ganges-Brahmaputra Basin. The TRM approach is being prioritised for solving waterlogging problems in the recently formulated Delta Plan (a national longer-term strategic plan up to 2100) (*GoB* 2014). The Bangladesh government is also planning to implement TRM projects in several coastal catchments sequentially – therefore assessment of institutional effectiveness is timely. In this study, the Institutional Analysis and Development (IAD) framework developed by *Ostrom* (2010) was applied for assessing institutional characteristics of three diverse Tidal River Management (TRM) projects. Based on the analysis, we identify several core institutional factors for achieving long-term survival of Tidal River Management, which are linked to the biophysical, community and rules-in-use of TRM in Bangladesh. These factors have implications for TRM policy in this country and further afield, where the approach could well provide solutions to adaptation governance in other coastal inter-tidal contexts.

Our results suggest that the qualitative differences in the outcomes for common-pool resources of the TRM implementation in Bhaina on the one hand, and in Kedaria and Pakhimara on the other hand are the result of different biophysical and socio-economic settings and of specific institutional arrangements, namely the inclusion of informal and formal institutions. In *beel* Bhaina, the favourable biophysical conditions were matched with an effective combination of: a) local informal and external institutions with b) formal institutions. In both Kedaria and Pakhimara, the biophysical and socio-economic conditions were more problematic, and the process was mostly driven by external actors, which caused internal conflicts between local people as well as between local people and external organizations. Key institutional design considerations for future TRM therefore include implementing TRM to match the biophysical conditions (e.g. upstream-downstream and size characteristics), support community attributes (trust, reciprocity, social capital, shared knowledge, leadership) and rules-based design principles, particularly collective choice arrangements that link formal and informal decision-making plus the multi-level aspects of governance.

Finally, the findings provide lessons for adaptation policy and governance elsewhere, given the increasing threat to low-lying coastal resources through sea level rise and resource overexploitation. Our results can potentially be applied to institutional design in other countries, e.g. river widening and de-poldering activities at various locations in the Netherlands (*van Staveren* and *van Tatenhove* 2016), temporarily restoring flood dynamics and capturing sediments in the Westerschelde in Belgium (*Cox* et al. 2006; *Maris* et al. 2007), and the Sacramento-San Joaquin in the United States (*Bates* and *Lund* 2013).

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