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Article

Application of Sustainability Index of Tidal River Management (SITRM) in the Lower Ganges–Brahmaputra–Meghna Delta

Md. Mahedi Al Masud [1], Hossein Azadi [2,*], Abul Kalam Azad [3], Imaneh Goli [4], Marcin Pietrzykowski [5] and Thomas Dogot [2]

[1] Divisional Social Services Office, Department of Social Services, Ministry of Social Welfare, Khulna 9100, Bangladesh
[2] Department of Economics and Rural Development, Gembloux Agro-Bio Tech, University of Liège, 4000 Gembloux, Belgium; thomas.dogot@uliege.be
[3] Environmental Science Discipline, Khulna University, Khulna 9208, Bangladesh; azad@es.ku.ac.bd
[4] Department of Economics, Agricultural Extension and Education, Tehran Science and Research Branch, Islamic Azad University, Tehran 14778-93855, Iran; imaneh.goli@srbiau.ac.ir
[5] Department of Ecological Engineering and Hydrology, Faculty of Forestry, University of Agriculture in Krakow, 30-149 Krakow, Poland; marcin.pietrzykowski@urk.edu
* Correspondence: hossein.azadi@uliege.be; Tel.: +32-(0)9-264-46-95; Fax: +32-(0)9-264-49-85

Abstract: The sustainability index (*SI*) is a relatively new concept for measuring the performance of water resource systems over long time periods. The purpose of its definition is to provide an indication of the integral behavior of the system with regard to possible undesired consequences if a misbalance in available and required waters occurs. Therefore, the tidal river management (TRM) approach has been implemented for the past three decades (from 1990 to 2020) within the polder system in Southwest Bangladesh to achieve water sustainability. TRM plan and watershed management plan (WMP) have commonalities as both are aimed at ensuring the sustainable use of watershed resources with the management of land, water, and the wider ecosystem of the watershed in an integrated way. The TRM plan focuses mostly on coastal regions, whereas the WMP focuses on both coastal and non-coastal regions. According to this, the aim of this study was to explore the application of the sustainability index of tidal river management (SITRM) in measuring the sustainability of tidal river management in the coastal area of the Lower Ganges–Brahmaputra–Meghna (GBM) delta. In order to quantify the sustainability of tidal river management, this research first provided the components and indicators of SITRM for the coastal region. The study follows a 5-point Likert scale for opinion survey of key informants and comprises households' survey of farmers. In addition, it includes Landsat satellite images from Earth Explorer of the United States Geological Survey (USGS) and direct field observation to collect information regarding the indicators of SITRM. The study measures the index value of SITRM for identifying the water sustainability of Beel East Khukshia-TRM. The index value was 71.8 out of 100, showing good tidal river management for the Hari–Teka–Bhadra catchment. To achieve water sustainability and aid stakeholders and water managers in decision making, it may be possible to include the SITRM framework in tidal river management projects. In addition, the SITRM is more capable of facing drainage congestion, waterlogging, and climate change issues than watershed sustainability index (WSI), Canadian water sustainability index (CWSI), West Java water sustainability index (WJWSI), and water poverty index (WPI). Therefore, water professionals and policymakers can apply SITRM to assess the resilience of specific TRM schemes for greater sustainability in different coastal regions of the world.

Keywords: sustainability indicators; water resources management; waterlogging; water sustainability; coastal region; community wellbeing

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1. Introduction

Nowadays, human, land, water, and environmental interaction and development are growing significantly towards the stability of the social–ecological system (SES). The Global Water Partnership and the Third World Centre for Water Development highlight water sustainability and provide different pathways to achieve sustainable development [1]. Therefore, both the developing and developed countries (e.g., Bangladesh and the Netherlands) of the world have a long-term (100 years) water-centric plan (e.g., Bangladesh Delta Plan, 2100) for their economic growth, socio-economic development, SES stability, and environmental sustainability [2,3]. The Southwest coastal region is situated in the Lower Ganges–Brahmaputra–Meghna (GBM) delta (e.g., Jashore, Khulna, and Satkhira districts), the most disaster-prone area of the world due to climate change issues, i.e., extreme cyclone events, pluvial floods (the 1950s, 1980s, and 2000s), rising sea levels, and saline intrusion [4–6]. The coastal community of Southwest Bangladesh has initiated tidal river management (TRM) in the lower GBM delta with their indigenous knowledge of water management. In the 1990s, TRM was implemented in several tidal basins to address the existing issues. These included the Hamkura River, locally known as Beel, as well as Dakatia, Bhadra River with Beel Bruli, and Hari–Teka River with Beel Bhaina [7]. Observing positive results of TRM, government agencies have replicated it in several beels, such as Beel Kedaria, East Beel Khukshia, Beel Jalalpur, and Beel Pakhimara, in the 2000s and 2010s in the Southwest region [8,9].

Several studies have been conducted regarding TRM and the water sustainability of this region. For instance, Gain et al. [10] also demonstrated Ostrom's diagnostic framework for the qualitative assessment of 23 SES indicators of tidal river–floodplain ecosystems regarding temporal and spatial dynamics for achieving the sustainability of the Southwest coastal region. The results of Gain et al. [10] showed that the performance of resource systems and the environment was better before 1960 compared to 1960–1979 and degraded severely in 1980–1999 but improved slightly with the introduction of TRM after 1999. The SES performance (i.e., resource systems, the environment, governance systems, and actors) of Beel Bhaina (TRM implemented by local people) was better than Beel East Khukshia and Beel Pakhimara (TRM implemented by government agencies). Mutahara et al. [11] explored the trans-boundary water interaction nexus (TWINS) model for a clear understanding of the conflict and cooperation in planning and practicing TRM toward sustainable delta management. The results of TWINS demonstrate that conflict was more than cooperation for the government-implemented TRM due to the lack of multi-stakeholder partnerships and learning integration of the social network.

Adnan et al. [4] developed a model for identifying suitable beels for implementing TRM and measuring the effectiveness of TRM to reduce flood susceptibility by land reclamation in the beel. The study explored that TRM could reduce flood susceptibility by 35% and the probability of annual flooding from 0.86 to 0.57 (on average) due to land reclamation (1.4 m in five years), including examples from Bhaina-TRM, Khukshia-TRM, and Pakhimara-TRM. Masud et al. [1] introduced a set of potential components and sustainability indicators (e.g., water availability, drainage capacity, sedimentation, waterlogging, rising sea level, forest, biodiversity, salinity, sanitation, crop production, and compensation) to explore the sustainability index of tidal river management (SITRM). Islam et al. [5] conducted a study on the effectiveness of sediment trapping in raising the Pakhimara-TRM ground. They examined several factors, including the number of entrances, the method of flow regulation (using open inlets or gate entrances), different operational plans, and the seasonal variations in measuring the effectiveness of sediment trapping. The purpose of their study was to investigate how these variables impact the sediment trapping process and its effectiveness in raising the Pakhimara-TRM ground. The results show that a TRM without flow regulation (i.e., Beel Pakhimara) was more reasonable and still effective despite 20–30% less sediment deposition when it comprised two inlets located at opposite sides of the beel. Therefore, the main research gaps of these studies are as follows: a. quantitative data of the indicators are not present [10], b. climate change issues (i.e., rising sea level) are not addressed properly, and c. all issues (i.e., socio-economic, environmental, and institutional) are not examined to measure the sustainability of TRM instead of focusing on one specific TRM issue, namely conflict and cooperation [11], land reclamation [4], or transition sedimentation and land formation [5].

Water provision is increasingly being evaluated in the context of integrated water resource management. An index comprises several components and indicators that can measure sustainability [12,13]. In the field of water sustainability, indicators are selected based on socio-economic, environmental, and institutional factors of water resources management. Each indicator requires a standard threshold value to measure sustainability. Therefore, sustainability and indicators are strongly interconnected, and SITRM was developed involving twenty indicators under five components to address socio-economic, environmental, and institutional issues of the tidal river–floodplain ecosystem of the Southwest region of Bangladesh. SITRM supports a comprehensive approach to water resource management that aims to be socially equitable, economically feasible, and ecologically conscious. The issue emphasizes the need for a comprehensive approach to planning and implementation, beyond the commonly used "triple bottom line" approach. It emphasizes the importance of adopting a systems approach that takes into account the interdependence between human and natural systems. Furthermore, it acknowledges that such an approach may require alterations in political, social, economic, and administrative systems. Urban areas have long been recognized as playing a significant role within SITRM. The main objective of this study is to investigate potential ways to enhance service delivery by implementing effective management strategies and promoting collaborative efforts. It takes into account the effective management of all available water resources, including rainfall, groundwater, and surface water. In order to improve living circumstances and provide communities more control over the development and management of sustainable livelihoods, it also takes social and economic factors into account. Additionally, the study discussed in this paper exemplifies a particular aspect of SITRM in that it aims to create a structured framework for a multi-dimensional assessment of water systems in order to specify how the sustainability goal can be encountered. The current study, however, has addressed every concern pertaining to SITRM's components and metrics for evaluating the sustainability of TRM. This study is exploring the quantitative results of the indicators for making better decisions for water sustainability and community wellbeing of the Southwest coastal region, as stated in Bangladesh Delta Plan (BDP), 2100 [13,14]. In addition, it emphasizes issues such as sedimentation, waterlogging, and rising sea level for disaster reduction and coastal people's adaptation in the lower GBM delta. Therefore, the novelty and innovation of this study can be summarized as follows:

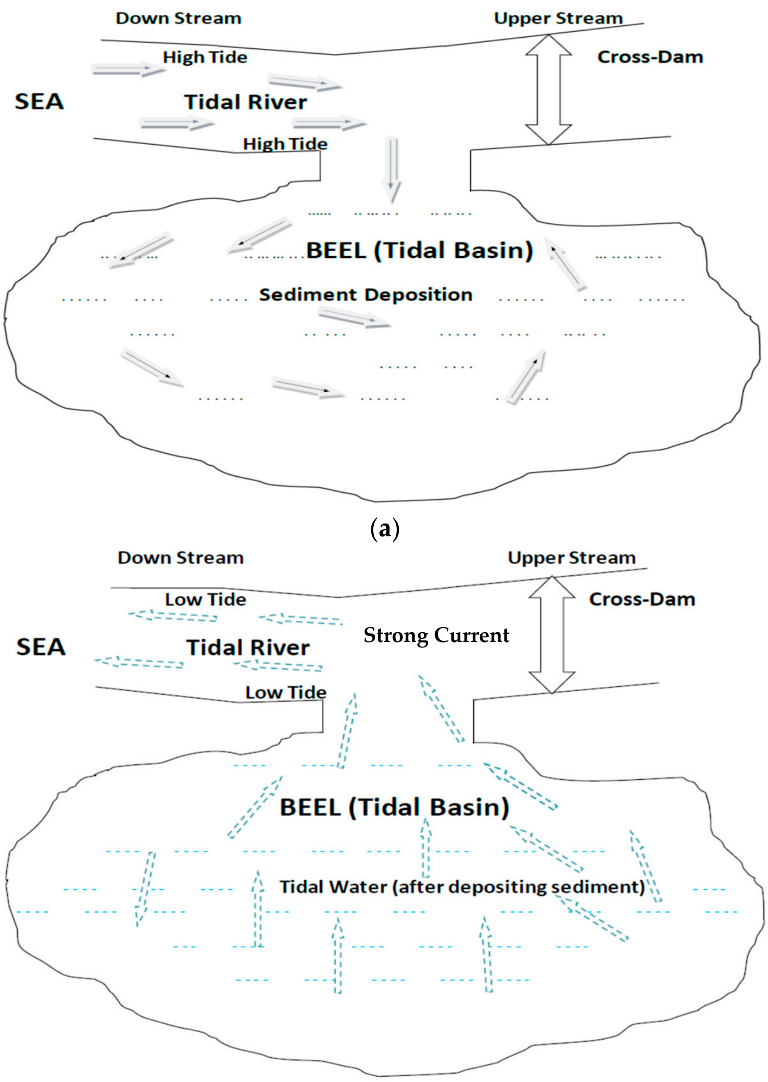
(a) Comprehensive approach: This study aims to address the limitations of previous studies [5,13,14] by taking a comprehensive approach to examine the sustainability of TRM in the Southwest coastal region of Bangladesh. By considering all socio-economic, environmental, and institutional factors that contribute to TRM sustainability, this study provides a more holistic view of the challenges and opportunities that exist for achieving sustainable water resource management in the region.
(b) Quantitative data: This study seeks to collect quantitative data on various sustainability indicators to provide a more rigorous assessment of TRM sustainability. This approach will enable policymakers and planners to measure the effectiveness of TRM in reducing flood susceptibility, managing sedimentation, maintaining water availability, improving drainage capacity, preserving biodiversity, etc.
(c) Integrated water resource management: This study considers TRM within the broader context of integrated water resource management (IWRM), which emphasizes a holistic and systems-based approach to water resource management. By examining how TRM fits into the larger IWRM framework, this study provides insights into how TRM can contribute to socially fair, economically feasible, and environmentally sensitive water resource management in the region.

Overall, the study's comprehensive approach, its focus on quantitative data, its consideration of climate change, and its integration with the broader IWRM framework make it a novel and innovative contribution to the literature on TRM sustainability in the Southwest coastal region of Bangladesh. Additionally, the study's findings may have implications for other regions of the world that are experiencing water shortages. Therefore, the main objective of this study is the application of the SITRM framework in measuring the sustainability of TRM towards achieving community wellbeing in the Southwest coastal region. In addition, the research questions of the study are as follows:

i. What are the quantitative results of SITRM indicators?
ii. How is the sustainability of TRM measured by the SITRM?

1.1. Theoretical Background

TRM connects tidal rivers and floodplains (Figure 1), storing tidal flow, improving the drainage capacity of the river, and reducing waterlogging from floodplains [15,16]. It employs the temporary de-pondering of embankment to enhance the ecosystem services of the tidal river–floodplain ecosystem [1] while strengthening the social–ecological system to achieve water sustainability [1,10,14].



(**a**) (**b**)

Figure 1. Tidal river management (TRM) mechanism in the Hari–Teka–Bhadra basin of the GBM delta. (**a**) Land reclamation due to sediment deposition in the tidal basin during high tide. (**b**) Strong

current of tidal water erodes riverbed during low tide. Adapted from Masud et al. [1].

1.2. The Components and Indicators of SITRM

SITRM is developed by following recent indices, i.e., WPI [17,18], WSI, CWSI [19], and WJWSI [20]. It comprises environmental, social, institutional, economic, and life components for achieving water sustainability. The study presents the components (5) and indicators (20) of the SITRM framework, including all sub-components (2) and sub-indicators (23) with their standard threshold values (Table S4 OSM).

2. Materials and Methods

2.1. Study Area

Jashore, Khulna, and Satkhira districts of the Southwest Bengal Delta (Figure 2) are severely affected by riverbed sedimentation and waterlogging due to CEP. Therefore, several TRMs have been implemented for remedying the problems of this coastal region, which is selected as the study area. The total area of Jashore, Khulna, and Satkhira districts is 2570 km^2, 4394 km^2, and 3858 km^2, respectively. These districts are situated between 21°36′ and 23°47′ north latitudes and between 88°40′ and 89°50′ east longitudes. The Bhairab (Rupsa), Hari, Teka, Sree, Bhadra, Betna, Kobadak, Arpangachhia, Shibsa, Pashur, Koyra, Shalikha, and Kholpetua rivers flow through this region [21]. The total populations of Jashore, Khulna, and Satkhira districts are 2,471,554, 2,318,527, and 1,985,959, respectively, whereas population density is 703/km^2, and the annual growth rate of population is 1.46 (BBS, 2015). The study mainly focuses on the Hari–Teka–Bhadra catchment, which includes 26 beels of Khulna and Jashore districts in Figure 2 [21]. Among these 26 beels, it randomly selects 11 (two of which are TRM beels—Beel Bhaina and Beel East Khukshia—and the other nine of which are non-TRM beels). TRM beels are those where TRM operation is carried out. This research only captures the Beel Pakhimara (TRM beel) from the Kobadak River catchment of Satkhira district. It has also randomly selected villages both from TRM beels and non-TRM beels along with the administrative boundaries, which are shown in Table S1 OSM. In this study, Beel Kedaria serves as a non-TRM beel since very little sedimentation occurred in the Kedaria tidal basin during TRM operation.

Table S1 shows the TRM beels (i.e., Beel East Khukshia and Beel Bhaina) and non-TRM beels (e.g., Beel Bruli, Beel West Khukshia, Beel Tawalia, Beel Madhugram, and Beel Baruna) of the Hari–Teka–Bhadra catchment. Beel East Khukshia and Beel Bhaina capture three (3) and four (4) villages, respectively; other beels (i.e., Beel Bruli, Beel West Khukshia, Beel Tawalia, Beel Madhugram, and Beel Baruna) involve only one (1) village of the catchment. In addition, Beel Kopalia, Beel Kedaria, and Beel Panjia and Had (two separate beels are jointly presented for this research) of the Hari–Teka–Bhadra catchment and Beel Pakhimara of Kobadak catchment do not include any village for this study.

Figure 2 shows the selected TRM (East Khukshia-TRM beel no. 1 out of 27 beels) and non-TRM beels of the Hari–Teka–Bhadra River and Kobadak River catchments.

2.1.1. Estimating the Land Elevation of the Tidal Basin

Masud [21] provided the following equation for analyzing sediment deposition on the tidal basin and estimating the land elevation:

$$G_e = SD_B \div A_L \quad (1)$$

G_e = the average land elevation of the tidal basin by TRM (m)
SD_B = the total quantity of sediment deposition on the tidal basin (m^3)
A_L = the total area of land where sediment is deposited (ha).

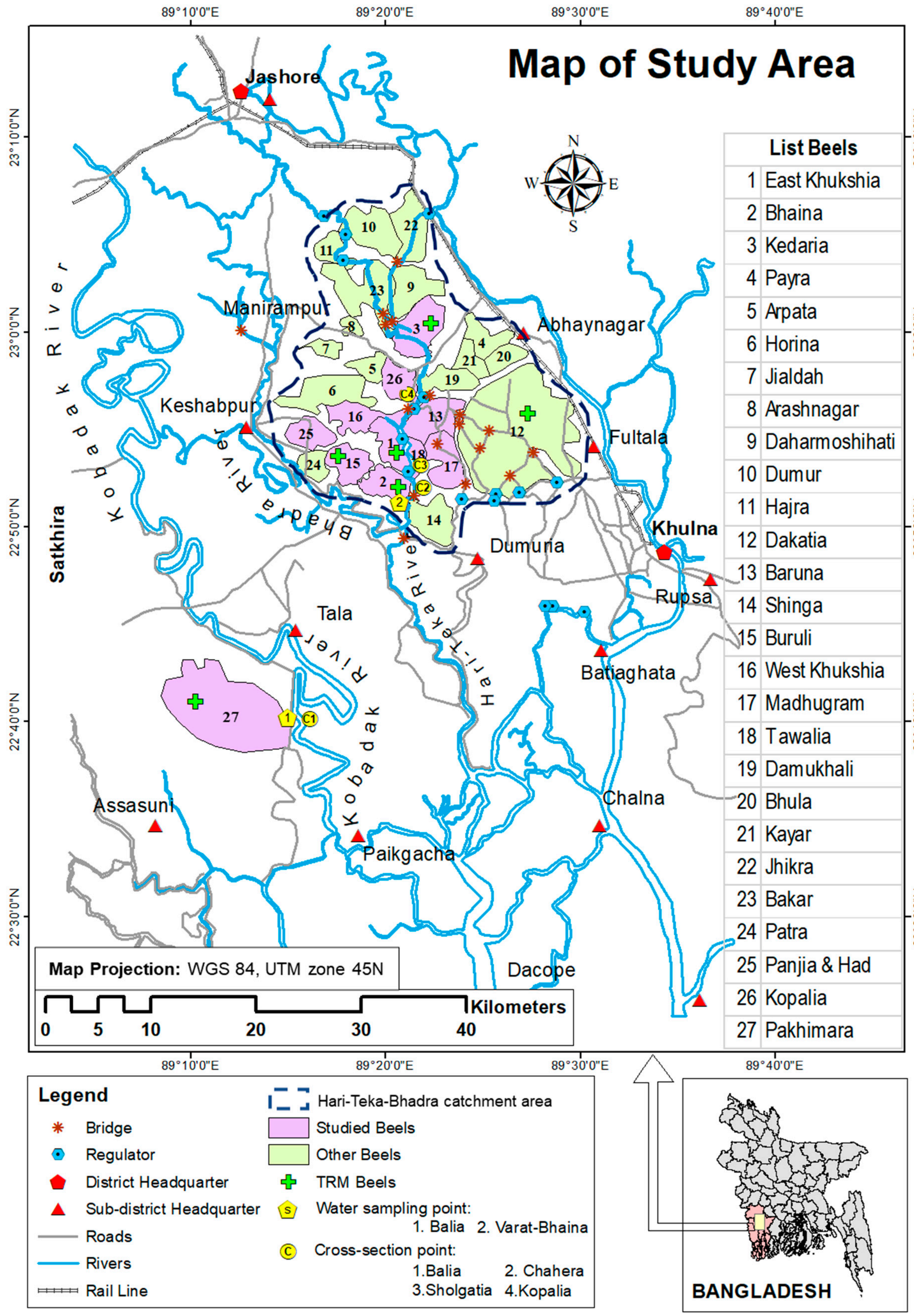


Figure 2. Rivers and beels at the Hari–Teka–Bhadra River and Kobadak River catchments of the GBM delta.

2.1.2. Assessing the LUC in the Hari–Teka–Bhadra Catchment

Capturing satellite images is a well-known and less time-consuming method for the assessment of LUC. It is accepted for its accuracy in detecting LUC in the context of water sustainability [22–25]. This work used Landsat 4–5 TM (2006, 2011) and Landsat 8 OLI multi-spectral 30 m × 30 m resolution satellite images data that were collected from Earth Explorer of the United States Geological Survey (USGS) depending on the condition of 10% cloud covering to evaluate LUC in the catchment region [21,26]. Six images were considered to assess land use change, with the 2011 images showing a "TRM" scenario, while the 2006 and 2016 images provide a concept of a "TRM-free" scenario. Furthermore, the study classified all satellite images into three land use classes with color effects by assigning per-pixel signatures based on a specific Digital Number (DN) value (i.e., a water body in blue, agricultural land in light green, and vegetation with settlement in dark green) [26].

2.1.3. Assessing Changes in Crop Production in the Hari–Teka–Bhadra Catchment

In order to estimate the changes in agricultural output in several TRM scenarios for the catchment, the project collects data using key informant interviews (KIIs), household surveys, and remote sensing data of agricultural land (26 beels comprising 44,237 ha of the Hari–Teka–Bhadra catchment) [21]. It comprises 45 (3–5 in each *beel*) KIIs (farmers experienced with more than 20 years) for all the 11 *beels*, and 131 surveyed households for 7 *beels* in 2017 and 2018, respectively [21]. The study identified the sample size (131 households) randomly from the total number of households (3500) with farming families (Table S2 OSM).

Only KIIs were used in the study to collect (i) land coverage (% of the total area in the beel) data for agricultural production. It also obtained the following information from KIIs and household surveys: (ii) the amount (ton/ha) of agricultural yields. For the assessment, this article used five types of crops: Boro rice, summer and winter vegetables, prawn (Macrobrachium rosenbergii) known locally as 'golda,' shrimp (Penaeus monodon) known locally as 'bagda,' and white fish. It indicates 'with-TRM' and 'without-TRM', respectively, for the time periods of 2007–2013 and 2014–2016.

2.1.4. Assessing the Changes in Livestock and Trees, Employment, and Health Impact in the Hari–Teka–Bhadra Catchment

The study also conducted the same household survey to collect data regarding livestock and trees, agricultural-related employment, and health impact (diarrhea) issues for the assessment for the time periods 2002–2006 (without-TRM), 2007–2013 (with-TRM), and 2014–2018 (without-TRM).

2.1.5. Assessing SITRM Indicators through the Likert Scale

The study also involved 20 KIIs to assess the information of SITRM indicators, i.e., (i) awareness and coordination, (ii) water governance, (iii) rotation of TRM *beels*, and (iv) riverbank erosion, following a 5-point Likert scale. The scale uses a minimum of 1 for very low satisfaction and a maximum of 5 for very high satisfaction of a statement/activity/performance, 2 for low satisfaction, 3 for neutral/moderate satisfaction, and 4 for high satisfaction. It also collected information regarding land reclamation of the tidal basin, migration of day laborers, and crop compensation issues without following any scale.

2.1.6. Assessing the Sustainability of TRM Using the SITRM Framework

The study chose a similar weight, i.e., an equal value [18,20,27], for every indicator, and a fixed score (a "fixed score" refers to a predetermined or constant value assigned to an indicator in the assessment of the sustainability of TRM (Hari-Teka-Bhadra Reservoir Management) using the SITRM framework) (5) for an indicator. The score of the sub-indicator varied from a minimum of 1 to a maximum of 4. This paper calculated the score (S) of an indicator or sub-indicator by applying Equations (2) and (3).

$$S = \frac{Vobs - Vmin}{Vmax - Vmin} \times Sf \tag{2}$$

where a > b

$$S = Sf - \frac{Vobs - Vmin}{Vmax - Vmin} \times Sf \tag{3}$$

where a < b. Note: 'a' for preferable threshold value and 'b' for not preferable threshold value of a specific indicator or sub-indicator.

Here, *Sf* is the fixed score, and *Vobs*, *Vmin*, and *Vmax* are, respectively, the observed, minimum, and maximum threshold values of an indicator or sub-indicator.

The SITRM framework involved 20 indicators, which captured a total score of 100. Finally, the study developed a performance scale [20] based on the indicators' scores of the SITRM. Table S3 OSM provides the 6-grade performance scale of the SITRM framework. It comprises 0–1, 2.51–3, and 4.01–5 scores for very bad, satisfactory, and very good performance of an indicator, respectively. Furthermore, the scale indicates 0–20, 51–60, and 81–100 scores for very bad, satisfactory, and very good performance of the sustainability index, respectively. Therefore, the index or an indicator needs very high action, low action, and no action individually for very bad, satisfactory, and very good performance.

3. Results

3.1. Assessment of the SITRM Indicators

3.1.1. Estimation of Land Elevation of Tidal Basins

This study estimates the indicator land reclamation (elevation) of the tidal basin (Ge) due to sediment deposition by TRM following Equation (1). Table S5 OSM shows that maximum land elevation occurred because of sediment deposition at Beel Bhaina, which was 1.14 m, and the minimum was 0.083 m at Beel Kedaria. Furthermore, the land elevation of Beel East Khukshia was 1.1 m. Therefore, Beel East Khukshia-TRM was better than Beel Kedaria-TRM.

3.1.2. Assessment of the LUC in the Hari–Teka–Bhadra Catchment

This study provided the assessment of the land use changes (LUC) of the Hari–Teka–Bhadra catchment in terms of agriculture, water body, and vegetation with settlement based on Beel East Khukshia-TRM. Figure 3 shows the study of land cover data using satellite images obtained across the whole watershed (with 44,237 hectares of land) during the monsoon (August) and post-monsoon (December) periods in 2006, 2011, and 2016. The results obtained utilizing satellite images are summarized in Table S7 OSM. It displayed the accessibility of agricultural land for production and principally two signs, namely waterlogging and vegetation with settlement. According to the findings, the watershed was free from waterlogging in 2011 by 53% of the monsoon season and 72% of the post-monsoon season. It was 5% more than in 2006, and 9% more than in 2016 during monsoon; additionally, the result was 10% more than in 2006, and 23% more than in 2016 during post-monsoon due to TRM operation in 2011. This reduction in waterlogging increased agricultural land and crop yields in the catchment area. In addition, the catchment was covered with vegetation and settlement by 16% during the monsoon and 33% during the post-monsoon period in 2011. This value was 2% more than in 2006, and 9% more than in 2016 during the monsoon period; moreover, the result was 7% more than in 2006, and 14% more than in 2016 during the post-monsoon period. According to the findings, TRM operation at Beel East Khukshia increases agriculture and vegetation with settlement in the Hari–Teka–Bhadra catchment region while reducing waterlogging.

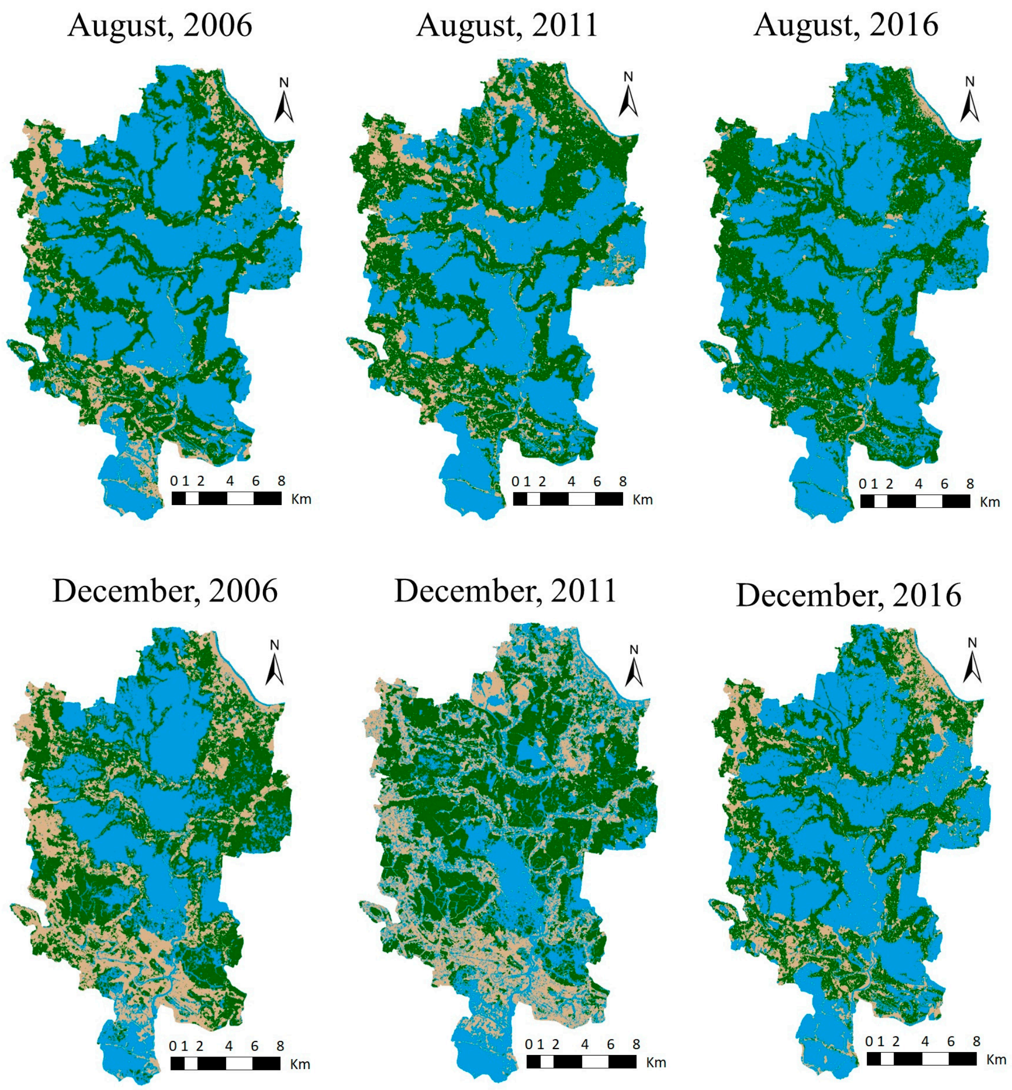


Figure 3. Satellite images in the monsoon and post-monsoon seasons in 2006, 2011, and 2016 from the Hari-Taka–Bahadra catchment in Khulna and Jashore areas [21].

3.1.3. Assessment of the Changes in Agricultural Production of the Hari–Teka–Bhadra Catchment

Firstly, the study illustrates the accessibility of crops (in percentage); then, it provides crop yields (ton/ha) at different beels of the catchment for the assessment of changes in agricultural production. Table S6 OSM shows that the accessibility of Boro rice was 77% and that of vegetables was 52% during the with-TRM scenario. The study finds that the accessibility of crops declined during without-TRM compared to with-TRM by 18%, 11%, and 28%, respectively, for Boro, prawn+white fish (mixed culture), and vegetables. Additionally, white fish (monoculture) and shrimp+prawn+white fish (mixed culture) both improved by 7% and 13% regarding without-TRM compared to with-TRM. No agricultural crop was grown in the Beel East Khukshia during the TRM operation (2007–2013) since the beel was used for land reclamation. After the TRM closed in 2013, the connecting canal was removed from the Hari–Teka River, and Beel East Khukshia returned to agricultural agriculture.

Table S6 OSM also supports the indicator crop production (Figure 4) of SITRM. Figure 4 shows crop yields of different beels in the catchment.

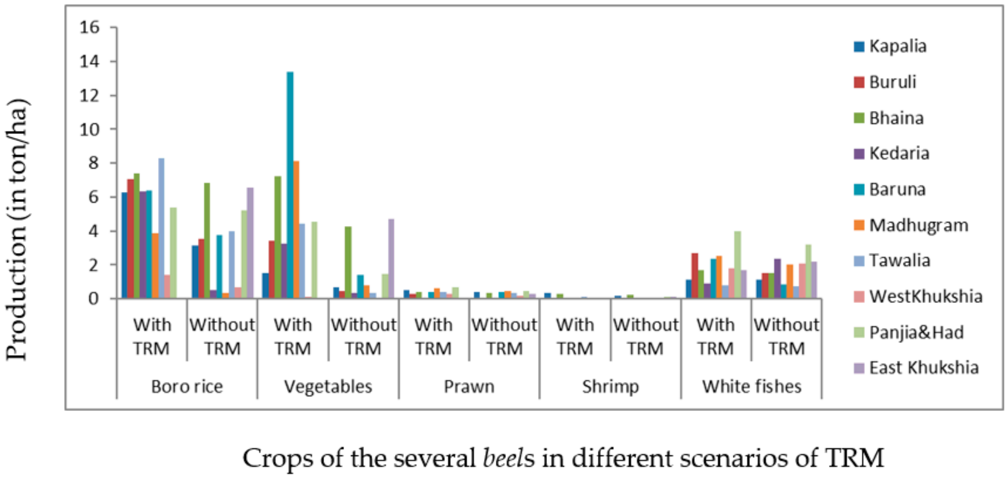


Figure 4. Crops production (Boro rice, vegetables, prawn, shrimp, and white fish) of Hari–Teka--Bhadra catchment [21].

The results (ton/ha) denoted 3.54 (1 ton of paddy is converted to 0.675 tons of rice), 4.6, 0.37, 0.083, and 1.96, respectively, for Boro rice, vegetables, prawn, shrimp, and white fish during the with-TRM scenario (Table S8 OSM). The study finds that the crop yield of Boro rice, vegetables, and fish varieties (prawn, shrimp, and white fish) reduced significantly throughout the catchments during the without-TRM scenario.

3.1.4. Assessment of the Changes in Terrestrial Biodiversity, Employment, Health Impact, and Migration of the Hari–Teka–Bhadra Catchment

This study found that hen was the most abundant in the catchment, followed by duck and goose, respectively. The number of flying animals with-TRM (2007–2013) increased by 23.6% compared to without-TRM (2002–2006); it also decreased by 6.3% in 2014–2018 compared to 2007–2013 (Table S9 OSM). Furthermore, cow was the most abundant, followed by goat for four-legged animals [21]. The total number of cows and goats increased by 2.3% in 2007–2013 based on (2002–2006), and decreased by 15.1% in the catchment area in (2014–2018) (Table S9 OSM). The research studied the changes in fruit trees such as mango (Mangifera indica), jackfruit (Artocarpus heterophyllus), and coconut (Cocos nucifera) in the Hari–Teka–Bhadra catchment. The results indicate that coconut was the most abundant, followed by mango and jackfruit in these time periods, respectively. According to Table S9 OSM, the number of fruit trees in 2007–2013 increased by 17% compared to 2002–2006; this number also decreased by (14.6%) in 2014–2018 compared to 2007–2013. In addition, the changes in timber trees, such as Neem (Azadirachta indica), Mahogony (Swietenia macrophylla), and Shegun (Tectona grandis), indicate that Mahogony was the most abundant, followed by Shegun and Neem in these time periods, respectively. The number of timber trees increased by 25.2% during 2007–2013 compared to 2002–2006, and this number also decreased by 1.7% in 2014–2018 compared to 2007–2013 (Table S9 OSM).

The assessment of the employment indicator of SITRM is provided in Table S10 OSM. It presents the number of days per month a day laborer is engaged in agricultural-related activities. According to the information provided, during a period of 30 days before the operation of East Khukshia-TRM in 2002–2006, the maximum duration of agricultural related day labor was 22 days for Beel Bhaina and Beel East Khukshia. This means that agricultural related job was effective in those locations for the majority of the 30-day period. On the other hand, the minimum duration of agricultural job was 10 days for Beel Tawalia and Beel Bruli. This suggests that agricultural work was less effective in those areas as it occurred for a shorter period compared to the other two locations. During the East Khukshia-TRM period (2007–2013), the researchers explored a varying duration of management intervention (in terms of the availability of agricultural job) across different beels. Specifically, the maximum intervention period of 26 days was employed for Beel

Bhaina, while Beel Tawalia and Beel Bruli received a minimum intervention period of 21 days. According to the provided information, during the period without-TRM from 2014–2018, individuals or communities in the study area engaged in agricultural work for varying durations. The maximum duration of agricultural work was 28 days for Beel East Khukshia, indicating that agricultural activities were prevalent for a significant portion of the given timeframe. The study finds that, on average, day laborers were employed for 15, 23, and 18 days, respectively, for the periods of 2002–2006, 2007–2013, and 2014–2018 in the catchment area.

This study also finds that 73% of the households in the catchment were day laborers. The indicator migration of SITRM is illustrated in Table S11 OSM. During the time periods of 2002–2006, 2007–2013, and 2014–2018, wage workers moved from the basin to urban areas. The percentages of such migrations were 50%, 13%, and 42% for those respective time frames. Additionally, there were permanent migrations, where 0.8%, 0.5%, and 0.6% of wage workers moved from the basin to urban areas during the same time periods, respectively. Therefore, the results denote that TRM operation increases employment of day laborers and reduces their migration in the catchment.

The assessment of the salinity indicator is presented in Figure 5, showing the salinity (in ppt) level of the Hari–Teka River during high tide in different years (2006, 2011, and 2016). The salinity of surface water from November to December (post-monsoon) is important for the irrigation of Boro production. The study finds that the salinity of 2011 (with-TRM event) was less than 2006 and 2016 (without-TRM event). On average, it was less than 1 ppt in November but more than 1 ppt in December.

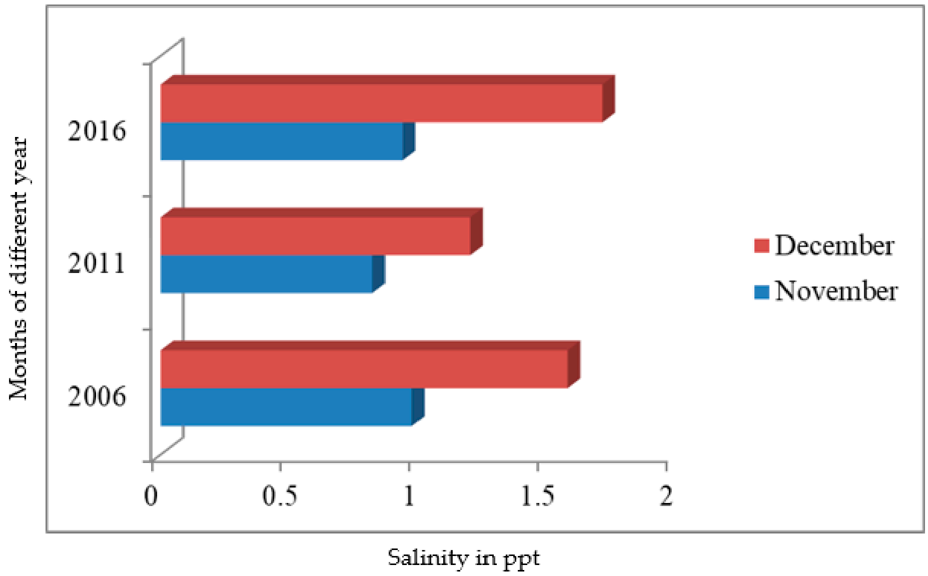


Figure 5. Salinity during the high tide of the Hari–Teka River. Source: BWDB [28].

The indicator health impact of SITRM is presented in Table S12, showing that people of the catchment suffered from diarrhea in different TRM periods. The study identified 100, 29, and 34 cases of diarrhea from 1000 people for the periods of 2002–2006, 2007–2013, and 2014–2018, respectively. Therefore, TRM operation reduces waterlogging from floodplains and also minimizes water-borne diseases such as diarrhea in the catchment.

3.1.5. Assessment of SITRM Indicators through the Likert Scale

This study on the river erosion index suggests that, among people residing along the coast, the awareness level was most pronounced among community-based organizations (CBOs), reaching a score of 3.6. On the other hand, the lowest level of awareness (score 1.4) was recorded for resettlement efforts carried out by government officials or non-governmental organizations (NGOs) as part of a scale ranging from 1 to 5 (Table S13 OSM).

In addition, based on these four practices (average score 2.4), this article estimates that 48% of the population was satisfied with government officials for their activities to protect public property from erosion of the riverbanks during the TRM operation on the Hari–Teka River.

This study indicates that the evaluation scores for the active involvement of CBOs and NGOs in the TRM project, as well as the collaboration between governments and CBOs to ensure the stability of the TRM project timeline, ranged from a maximum of 4.2 points to a minimum of 1.8 points out of a total of 5 points. These scores were assigned based on the level of awareness and coordination concerning the mentioned indicators, as detailed in Table S13 OSM. Therefore, the awareness sub-indicator (aggregating community people's awareness and active role of CBOs and NGOs) gained 78% satisfaction, and the coordination sub-indicator (village protection dam, time fixation, and compensation, collectively) gained 48% satisfaction.

The evaluation of the indicator rotation of TRM beel suggests that the Bangladesh Water Development Board (BWDB), responsible for the management, received a commendable score of 3.6 out of 5. This score highlights their proactive efforts in initiating the preparation for the upcoming TRM beel even before concluding the activities at the present Beel East Khukshia-TRM. In addition, a minimum of 2.8 out of 5 points was obtained for the BWDB published in the long-term (50-year) plan for rotational TRM at different basin excavators (Table S13 OSM).

Moreover, Table S13 OSM illustrates five important activities/performances under the indicator water governance at the local catchment level regarding the Beel East Khukshia-TRM project. The evaluation shows that a maximum of 4.4 and a minimum of 2.8 points are obtained from 5 points, respectively, for connecting the main shovel channels to the tidal rivers in the catchment area and learning from the past problems of Beel Bhaina-TRM and Beel Kedaria-TRM projects.

3.1.6. Assessment of Land Reclamation, Compensation, and Alternative Livelihood Issues of Hari–Teka–Bhadra Catchment

The study found that the average land reclamation (elevation) is 1.1 m at Beel East Khukshia (Table S5 OSM). Sediment distribution in the beel was not evenly distributed. For this reason, this study reported that only 40% of the land of the beel was raised by 0.5 m with sediment deposition during TRM operation at Beel East Khukshia.

In addition, this study argues that crop compensation for landowners is essential for smooth TRM operation in the beel. The research emphasizes the critical importance of providing indicator-based compensation for landowners' crops to ensure the seamless operation of the TRM in the beel area. It identified that only 13% of marginal farmers and 58% of other farmers received crop compensation due to complex compensation payment procedures.

Governments should provide alternative livelihood options during TRM operation for poor people who are very much dependent on beel for their daily income or needs. This study shows that there was no alternative livelihood for beel's trusted individuals during the Beel East Khukshia-TRM.

3.2. Measurement of the Sustainability of TRM by the SITRM Framework

Finally, the study applied the SITRM framework to measure the sustainability of TRM at the Hari–Teka–Bhadra catchment during the TRM period of Beel East Khukshia-TRM (2007–2013). It measured the sustainability of Beel East Khukshia-TRM by calculating the scores for every indicator and sub-indicator of SITRM following Equations (2) and (3).

Table 1 shows the list of indicators for the final measurement. The indicators were grouped under the components to address the socio-economic, environmental, and institutional issues of TRM for achieving sustainability. This table also involved the SITRM framework to assess twenty indicators under five components and calculated the index value out of 100. Moreover, it assessed three indicators, i.e., tidal flow, drainage capacity, and riverbank erosion, under the component of the tidal river for measuring the sustainability of TRM. Based on Beel East Khukshia-TRM, the flow velocity of Hari–Teka River in May 2012 was 1.26 m/s during high tide and 0.85 m/s in low tide at Ranai. Moreover, the cross-sectional area was 515 m^2 to 486 m^2 considering maximum water level and lunar effect during high tide, and 297 m^2 to 263 m^2 in low tide considering minimum water level and lunar effect [28]. Then, the tidal discharge was 649 m^3/s to 612 m^3/s during high tide, and 252 m^3/s to 224 m^3/s in low tide at Ranai in May 2012 considering the results of Beel Bhaina-TRM [29] and personal communication (with Mahir Uddin Biswas, President, WMF, Bangladesh on 7 July 2018). Therefore, the indicator tidal flow scored 5 out of 5. The drainage capacity was 548 m^2 at Ranai, involving 13 m depth and 77 m width in May 2012. Therefore, this indicator scored 5 out of 5. By the assessment of four important activities regarding the protection of peoples' assets from riverbank erosion, the indicator riverbank erosion captured 48% satisfaction and scored 2.4 out of 5 (Table S13 OSM).

This study assessed three other indicators, sedimentation, waterlogging, and land reclamation, under the component of sediment management. There was no sedimentation on riverbeds during the TRM operation at the Hari–Teka River. In addition, the drainage capacity was improved through eroding sediment from riverbeds by strong currents. Therefore, the indicator sedimentation scored 5 out of 5. The study finds that the catchment area was free from waterlogging by 53% and 72% of land for monsoon and post-monsoon, respectively, in 2011 (Table S7 OSM). Therefore, the indicator waterlogging scored 4 out of 5. This study argues that 40% of the land of the tidal basin was raised by 0.5 m with sediment deposition during TRM operation at Beel East Khukshia. In this circumstance, the indicator land reclamation scored only 2 out of 5.

The SITRM index under its environment component comprised seven indicators, i.e., crop production, vegetation with settlement, rising sea levels, employment, salinity, terrestrial biodiversity, and migration, for assessing sustainability. The study finds that paddy (Boro), vegetables, and joint shrimp and prawn production were 3.54 tons/ha, 4.6 tons/ha, and 0.45 tons/ha, respectively, in the catchment area (Table S8 OSM). Therefore, the indicator crop production scored 4 out of 5. This study shows that the basin in 2011 was covered with vegetation, with 16% habitat and 33% of land for monsoon and post-monsoon in 2011 (Table S7 OSM). Therefore, the indicator vegetation with settlement scored 5 out of 5. This study estimates that the average land elevation of the tidal basin was 1.1 m by sediment deposition during TRM operation at Beel East Khukshia (Table S5 OSM). In this circumstance, the indicator sea level rise scored 5 out of 5. Agricultural employment was 23 days out of 30 days in the basin (Table S10 OSM). Therefore, the indicator employment scored 3 out of 5. The number of bird animals and four-legged animals of livestock increased by 23.6% and 2.3% individually (Table S9 OSM). In addition, the number of fruit trees and timber trees was improved by 17% and 25.2% separately (Table S9 OSM). Therefore, the indicator terrestrial biodiversity scored 5 out of 5. The minimum salinity level of tidal water was 0.8 ppt in November and the maximum salinity was 1.2 ppt in December for Boro production (Figure 5). Therefore, this indicator scored 4.5 out of 5. Temporary and permanent migration of day laborers due to unemployment was 13% and 0.5% of the basin, respectively (Table S11 OSM). Therefore, the indicator migration scored 3.4 out of 5.

Table 1. Measurement of the sustainability of Beel East Khukshia-TRM in the Hari–Teka–Bhadra catchment.

Component	Indicator	Sub-Indicator		Threshold Values					
				Standard Values		With-TRM		Score	
				Max	Min	Max	Min	Earned	Fixed
Tidal River	Tidal flow	High tide		600 [a]	<550 [b]	649	612	2.5	2.5
		Low tide		250 [a]	<200 [b]	252	224	2.5	2.5
	Drainage capacity	Depth		12 [a]	<10 [b]	13	-	2.5	2.5
		Width		75 [a]	<70 [b]	77	-	2.5	2.5
	Riverbank erosion	-		1 [a]	0 [b]	0.48	-	2.4	5
Sediment Management	Sedimentation	-		>5 [b]	0 [a]	-	0	5	5
	Waterlogging	Monsoon		55 [a]	<50 [b]	53	-	1.5	2.5
		Post-monsoon		70 [a]	<35 [b]	72	-	2.5	2.5
	Land reclamation	-		100 [a]	0 [b]	40	-	2	5
Environment	Crop production	Paddy (Boro)		3.5 [a]	<3 [b]	3.54	-	1.5	1.5
		Vegetables		4.5 [a]	<3.5 [b]	4.6	-	1.5	1.5
		Shrimp + Prawn		0.5 [a]	<0.4 [b]	0.45	-	1	2
	Vegetation with settlement	Monsoon		15 [a]	<12 [b]	16	-	2.5	2.5
		Post-monsoon		30 [a]	<25 [b]	33	-	2.5	2.5
	Rising sea levels	-		0.5 [a]	<0.4 [b]	1.1	0	5	5
	Employment	-		25 [a]	<20 [b]	23	-	3	5
	Salinity	-		>2 [b]	<1 [a]	1.2	0.8	4.5	5
	Terrestrial biodiversity	Livestock	Birds	10 [a]	0 [b]	23.6	-	1	1
			4-legged	5 [a]	0 [b]	2.3	-	2	2
		Trees	Fruit	10 [a]	0 [b]	17	-	1	1
			Timber	15 [a]	0 [b]	25.2	-	1	1
	Migration	Temporary		>30 [b]	10 [a]	13	-	2.1	2.5
		Permanent		>1 [b]	0 [a]	0.5	-	1.3	2.5

Table 1. *Cont.*

Component	Indicator	Sub-Indicator	Threshold Values					
			Standard Values		With-TRM		Score	
			Max	Min	Max	Min	Earned	Fixed
Human Health	Health impact	-	>100 [b]	0 [a]	29	-	3.6	5
Institution (Community participation)	Awareness and coordination	Awareness	100 [a]	0 [b]	78	-	2	2.5
		Coordination	100 [a]	0 [b]	48	-	1.2	2.5
	Compensation	Marginal farmers	100 [a]	0 [b]	13		0.5	4
		Other farmers	100 [a]	0 [b]	58	-	0.6	1
	LUC	Paddy (*Boro*)	80 [a]	<60 [b]	77	-	2.1	2.5
		Vegetables	50 [a]	<40 [b]	52	-	2.5	2.5
	Alternative livelihoods	-	100 [a]	0 [b]	-	0	0	5
Institution (Governance)	Rotation of TRM	-	1 [a]	0 [b]	0.48	-	2.4	5
	Water Governance	-	1 [a]	0 [b]	0.72	-	3.6	5

Note: "a" for preferable value and "b" for not preferable value.

This study assessed only one indicator, i.e., health impact (diarrhea disease), under the component of human health. It finds that people of the catchment area suffered from diarrhea disease during TRM operation (2007–2013) and the number of cases was 29 out of 1000 people (Table S12 OSM). Therefore, the indicator health impact scored 3.6 out of 5. The SITRM index included two sub-components, community participation and governance, under the component institution. The study assessed four indicators, i.e., awareness and coordination, compensation, LUC, and alternative livelihoods, under the sub-component community participation. It also assessed two indicators, i.e., rotation of TRM and water governance, under the sub-component governance. The indicator awareness and coordination captured 64% satisfaction and scored 3.2 out of 5 (Table S13 OSM). This study argues that only 13% of marginal farmers and 58% of other farmers received crop compensation. For this reason, the indicator compensation scored only 1.1 out of 5. The study finds that the accessibility of paddy (Boro) and vegetables was 77% and 52%, respectively, in the agricultural land of the catchment (Table S6 OSM). Therefore, the indicator LUC scored 4.6 out of 5. There was no support for alternative livelihoods provided by governmental/non-governmental organizations to TRM-trusted individuals in the basin. Therefore, the indicator alternative livelihoods scored 0 out of 5. This study analyzed five important activities for the rotation of TRM in the beels of the catchment. Therefore, the indicator rotation of TRM beel comprised 48% satisfaction and scored 2.4 out of 5 (Table S13 OSM). It further assessed five important activities considering water governance at the local level. Therefore, the indicator water governance captured 72% satisfaction and scored 3.6 out of 5 (Table S13 OSM). Finally, this study, by aggregating the total score of 20 indicators, calculated the value of the index as 71.8 out of 100 points.

4. Discussion

Recently, river management in several delta restoration projects has involved soft engineering measures that connect the river channel to the tidal basin for regenerating wetlands by restoring tidal flow [1,30,31]. It enhanced the dynamic, hydrological, morphological, and ecological processes of the tidal river–floodplain ecosystem [32–34]. Strong coordination among stakeholders is desired for the improvement in the SES of the tidal river–floodplain ecosystem to achieve water sustainability [10,16]. The present study argues for community participation, including awareness and coordination, compensation, LUC, and alternative livelihoods indicators for measuring the sustainability of TRM. The results of this paper show that the indicator awareness and coordination earned 64% satisfaction. It bears a resemblance to studies by Mutahara [16] and Gain et al. [10], and this index needs to demonstrate improvement for TRM sustainability. Adnan et al. [4] advocate for a continuous 5-year implementation of TRM in a tidal basin, highlighting the potential for heightened effectiveness through the absence of social unrest, conflicts, and compensation challenges. Such a smooth operational period could enhance the project's impact by expanding the land area and subsequently boosting agricultural production. In this study, SITRM is connected to WPI, WSI, CWSI, and WJWSI as an indicator-based index, used to enhance the resilience of a watershed ecosystem for achieving water sustainability. Koirala et al. [18] proposed a water poverty index (WPI) that encompasses 12 distinct indicators. They applied this index at a sub-national level, specifically across 27 districts within the Koshi River Basin in Eastern Nepal. The outcomes of their study revealed a WPI score of 49.75 (out of 100) for the Saptari district, signifying it as the region facing the most severe water crisis. Conversely, the Taplejung district obtained a WPI score of 69.29, designating it as the area with the least water-related challenges. Juwana et al. [35–39] introduced West Java water sustainability index (WJWSI) to examine water resource sustainability status by involving 13 indicators and demonstrated a comparative study among Citarum, Ciliwung, and Citanduy catchments in West Java Province of Indonesia. The results stated that the WJWSI index scores were 20.04, 16.94, and 23.39 out of 100 for Citarum, Ciliwung, and Citanduy catchments, respectively, and denoted poor sustainability, which demanded priority of action to improve water resources. Attari et al. [19] analyzed the Canadian water sustainability index (CWSI) including 15 indicators (e.g., demand and supply under resource, stress and quality under ecosystem health, access and impact under human health, condition and treatment under infrastructure, and financial and training under capacity component) to measure water sustainability. In the study by Ahuchaogu et al. [40], the water sustainability index (WSI) was computed, resulting in scores of 0.59, 0.60, and 0.62 out of a possible 1.00 for the Use Offot, Nsukara Offot, and Ekpri Nsukara communities, respectively. Specifically, within the University of Uyo main Campus watershed of the Ikpa River Basin, a WSI score of 0.60 out of 1.00 was recorded, indicating an intermediate level of sustainability. The provided information indicates that the sustainable integrated SITRM approach for Beel East Khukshia-TRM in the Hari–Teka–Bhadra catchment involved the utilization of 20 indicators for calculation and evaluation purposes. The calculated SITRM score for this particular location was 71.8 out of a total score of 100. This score indicates that the sustainability of Beel East Khukshia-TRM was deemed to be good. The SITRM assessment takes into account various factors related to trapping and reservoir management, and, based on the calculated score, Beel East Khukshia-TRM was determined to have a positive level of sustainability. This paper presents that Boro and vegetable production improved from 2.34 ton/ha to 3.54 ton/ha, and 1.46 ton/ha to 4.6 ton/ha, respectively, during East Khukshia-TRM. Like Gain et al. [10] and Mutahara [16], the present study demonstrates that marginal farmers obtained crop compensation only by 13% due to the complexity of the compensation procedure. In addition, there was no alternative livelihood option for the poor and beel-dependent people from Government offices (GOs) and NGOs. This creates social unrest and conflict regarding proper TRM implementation. In fact, indicators such as employment, migration, crop compensation, and alternative livelihoods are included in a wider human impact. Above 80% of the people in the Southwest region are happy and confident about the TRM project. Therefore, this paper argues for developing a simple, flexible, and farmers' friendly crop compensation procedure. In addition, existing livelihood alternatives for the poor and beel-dependent need to be facilitated by governmental and non-governmental organizations for improving people's satisfaction and confidence level in TRM projects and their sustainability.

The results of SES [10] performance (including 23 indicators) provided only a qualitative assessment of Bhaina-TRM, East Khukshia-TRM, and Pakhimara-TRM. The SITRM framework comprises both qualitative and quantitative assessments of 20 indicators (including 23 sub-indicators) regarding Beel East Khukshia-TRM for achieving water sustainability in the lower GBM delta. The present study identified that sediment distribution in the beel was not evenly distributed. It finds that only 40% of the land of the beel was raised by 0.5 m with sediment deposition during East Khukshia-TRM. Adnan et al. [4] explored that land reclamation was 1.4 m in a five-year TRM project. The SITRM framework estimates that land reclamation (on average) was 1.1 m by sediment deposition at Beel East Khukshia. This framework involved a baseline survey to set the standard threshold values considering biophysical and social units [32], as well as strong consultations among stakeholders [35] and water experts [1,36]. SITRM can also include other feasible alternative components and indicators by conducting consultation meetings and KIIs of water professionals and scientists to measure the water sustainability of the coastal delta.

In addition, this study has limitations; i.e., it only includes rice cultivars after monsoon (i.e., Boro) as a SITRM sub-index, pre-monsoon rice variety (i.e., Aus), and monsoon rice cultivar (i.e., Aman) in the framework. This paper followed supervised classification to generate land use maps without considering errors. Moreover, this study did not conduct an extensive household survey for all beels (27) of the catchment because of the constraints of time and money. Furthermore, some high government officials and academicians were excluded in the second round of the opinion survey due to time limitations. Basically, SITRM is designed for coastal regions. The study explores a comparison between with-TRM and without-TRM scenarios to understand the benefits of TRM and achieve water sustainability in a catchment area. The values of indicators and sub-indicators of SITRM can be used in different coastal areas for future predictions. Furthermore, each tidal river–floodplain ecosystem has a unique ecosystem that includes some different indicators and sub-indicators for the need of water sustainability. Although the SITRM framework is very much inclusive for a tidal river–floodplain ecosystem under a polder system, some indicators or sub-indicators may be excluded and the values may be changed according to different coastal deltas.

5. Conclusions

The SITRM framework not only integrates indigenous practices of local people and formal science but also incorporates existing water sustainability indices to make it functional on a global scale. The study used different data and scales for the measurement of indicators' values and index values of SITRM. By this overall measurement, the results provide the performance of an indicator and assist in understanding the sustainability of a watershed. This study calculated the value of the Beel East Khukshia-TRM index to be 71.8 out of 100, which seems good based on the performance scale of a TRM. Moreover, the indicators of land reclamation, compensation, alternative livelihoods, and rotation of TRM scored 0 to 2.5 out of 5. Therefore, these indicators need moderate to very high action to improve their performance to achieve more coastal stability. The value of the standard threshold of SITRM indicators and sub-indices may vary from one coastal zone to another based on their geophysical configurations, hydro-morphological features, and socio-ecological relationships.

Policy Recommendations

SITRM plays an important role in exploring the sustainability impacts of TRM on restoring deltas and achieving water sustainability and community wellbeing. Therefore, the study recommends the following steps for water experts and policymakers: (a) SITRM can be used in diversion projects in the Mississippi Delta Plain and the Achafalaya Sub-Delta, and the TRM project can be used in the lower GBM Delta; (b) the SITRM index can also be implemented in the Hudson River estuary in New York, the Scheldt estuary of the Netherlands, Rhine River Delta, and Meuse River Delta for greater sustainability of coastal delta management; (c) researchers and water experts can use SITRM in both the polder and non-polder areas of the coastal delta to measure its effectiveness for sustainable delta management; and (d) because the SITRM index is a climate-friendly, environmentally friendly, and ecosystem-based service for selecting indicators, policymakers can promote it in different coastal areas of the world to achieve water sustainability and community wellbeing.

Furthermore, the SITRM index demonstrates a novel prospect for the sustainability of coastal delta management by introducing the most discussed issues, such as waterlogging, siltation and sediment management, drainage capacity of rivers, rising sea levels, and migration in coastal areas. Decision makers can use these indicators for integrated water resources management as well as integrated coastal zone management. In addition, the SITRM score is easy for physicians and hydrologists to estimate the value of the index and integrate it into the performance scale (0 to 100). In addition, sub-indicators under different indicators have different scores based on their importance in the tidal ecosystem and river ecosystem (i.e., 1 to 4). Future research is necessary regarding the economic valuation and environmental value of ecosystem services (e.g., biodiversity, agricultural production, job facilities, land reclamation, vegetation with settlement, drainage capacity, and tidal flow) related to the tidal river–floodplain ecosystem. In addition, the upcoming research could involve tidal basin management (TBM) and TRM under a framework toward sustainable delta management and identify the role of SITRM in achieving sustainable development goals (SDGs).

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/w15173159/s1, Table S1. Selection of the beels and villages in the Hari–Teka–Bhadra catchment of the GBM delta for the study. Table S2. Sample size determination for the household survey of the Hari–Teka–Bhadra catchment. Table S3. Performance scale of the SITRM framework. Table S4. The components and indicators of SITRM. Table S5. The estimation of average land elevation of tidal basins in the Hari–Teka–Bhadra catchment due to sediment deposition by TRM. Table S6. LUC (in ha) of the Hari–Teka–Bhadra catchment area based on Beel East Khukshia-TRM. Table S7. Accessibility of different crops (in percentage) at several beels of the Hari–Teka–Bhadra catchment area. Table S8. The crop production (ton/ha) using with-TRM and without-TRM scenarios in the Hari–Teka–Bhadra catchment area. Table S9. Changes in terrestrial biodiversity of the Hari–Teka–Bhadra catchment. Table S10. Changes in agricultural related employment of day laborers (in days) out of 30 days in different beels of the Hari–Teka–Bhadra catchment. Table S11. Migration of day laborers (in %) due to unemployment in the Hari–Teka–Bhadra catchment. Table S12. Cases of diarrhea of people in the Hari–Teka–Bhadra catchment. Table S13. Expert opinions on indicators following a 5-point Likert scale. Table S14. Pairwise correlations of SITRM indicators (Water Governance, Riverbank Erosion, Awareness and Coordination, and Rotation of TRM Beel). Table S15. Statistics of parameters of SITRM. Table S16. Data source of the indicators.

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Abbreviations

SI	Sustainability index
TRM	Tidal River Management
WMP	Watershed Management Plan
SITRM	Sustainability index of tidal river management
GBM	Ganges–Brahmaputra–Meghna
USGS	United States Geological Survey
WSI	Watershed Sustainability Index
CWSI	Canadian Water Sustainability Index
WJWSI	West Java Water Sustainability Index
WPI	Water Poverty Index
SES	Social–ecological system
KII	Key informant interviews
CBOs	Community-based organizations
NGOs	Non-governmental organizations
GOs	Government offices
IWRM	Integrated Water Resource Management

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