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Peer-reviewed author version

Sustainability Impacts of Tidal River Management:
Towards a Conceptual Framework

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Abstract

The Southwest Coastal people of Bangladesh have introduced Tidal River Management (TRM) as an environmentally acceptable water resource management practice based on their indigenous knowledge of water logging of low lying coastal land. TRM helps to address problems resulting from different anthropogenic and structural development activities, and it has been successful in helping coastal communities to adapt to climate change and rising sea level vulnerability by forming new land in Tidal Basins. Hence, it is essential to measure sustainability impacts of TRM from the environmental, socio-economic and institutional perspectives. Therefore, firstly, the study identifies sustainability indicators of TRM considering ecosystem services and secondly, develops an inclusive conceptual framework to understand the important impacts of each indicator at various spatial and temporal scales. The conceptual framework is followed by the construction of a Sustainability Index of Tidal River Management (SITRM). It has advantages over the Ramsar Convention framework (2007) and the World Meteorological Organization (WMO) framework (2012) to measure water sustainability as it includes a sustainable model to project future vulnerability of the community, river and Tidal Basin, emphasizing on climate change issues. It also involves trade-offs analysis, livelihood analysis and SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis for a complete impact assessment to enable decision-makers to focus on those services most likely to be of risks and weaknesses or opportunities and strengths for the sustainability of TRM. Moreover, the framework is a useful guide for policymakers in identifying the sustainability impacts of TRM so that they can choose best coping strategies for coastal people to effectively deal with adverse effects of water-logging and undesired climatic events as well as environmental and socio-economic changes in coastal areas.

Keywords

Sustainability Indicators; Sustainability Index; Water management; Climate change; Sedimentation; Water-logging.

1.1 Introduction
What is Tidal River Management (TRM)?

TRM is one of the forms of water management, developed from indigenous practices of coastal community people, to create ecologically sustainable, water-logged free environment in the Southwest region of Bangladesh (Tutu, 2005; Kibria et al., 2011; Paul et al., 2013). TRM introduces a temporary cross-dam (the dam is opened in rainy season and closed in summer and winter for every year during TRM) to the upper stream and joins the tidal River with a *Beel*[1] which is called a Tidal Basin where the sediment-carrying tidal water comes from the sea through the lower stream two times in a day (Sterret, 2011). The *Beel* should have to require 600 to 800 hectares of land or more/less depend on tidal prism for perfectly operation of TRM, and it must be surrounded by an embankment (village protection dam) in an enclosed TRM. The tidal water enters during high tide and over time, it deposits sediment to aggregate in the *Beel* (Figure 1). Besides, during low tide, the outgoing strong current water erodes the river bed and intensifies the drainage capacity (Sterret, 2011; Kibria, 2011; Paul et al., 2013). In this process, community people of the TRM *Beel* and its surrounding *Beels* which are occupied by River Basin are freed from water-logging due to enlarging drainage capacity of the river. During TRM, the Tidal Basin is not suitable for practicing any agriculture but its surrounding 20 to 25 *Beels* go under agricultural production properly with favorable ecological conditions like TRM in *Beel* Bhaina and TRM in East *Beel* Khukshia (De Die, 2013; Gain et al., 2017). The people of TRM *Beel* mainly depend on natural fisheries of this tidal wetland. It is in fact a soft engineering process of natural water management. Eventually, the expecting results will come by the strong participation of stakeholders and consensus among them with a great deal of sacrificing their swamped agricultural land (*Beel*) for a specific period (3 to 5 years or more) depending on how much water comes into the *Beel* (Ullah and Rahman, 2002; Gain et al., 2017) and demanding new land formation. Moreover, TRM has been implemented by the government agency, Bangladesh Water Development Board (BWDB) since 2002 with the support of stakeholders, NGOs and line department of GOs in several *Beels* and Rivers of the coastal region (De Die, 2013).

Importance of TRM has been captured in terms of increased drainage capacity of river with sediment management (Khadim et al., 2013), removing water-logging from *Beel* (Tutu, 2005; Paul et al., 2013; Jakarya et al., 2016), raising land from 1 to 2 m with sediment deposition in *Beel* and combating climate change induced sea level rise (Sterret, 2011; Paul et al., 2013; Jakarya, 2016), extending agriculture and fisheries and eventual increase in livelihood options (Tutu, 2005; Khadim et al., 2013), growing biodiversity with strengthening environment and finally, improving socio-economic conditions of the coastal people (CEGIS, 2003; Paul et al., 2013). The above mentioned benefits of TRM may be outweighed by several economic and environmental problems coupled with institutional complexities. These are riverbank erosion, increase in salinity in varying degree, disruption of local road networks, inundation of agricultural land, weak coordination between government and community people, complexity of compensation process or low rate of compensation/subsidy to land owners by government (Paul et al., 2013; Gain et al., 2017). As positive outcome of TRM become visible even after several years, non-acceptance of TRM may trigger conflicts among different stakeholders to carry it on from one *Beel* to another *Beel* (Kibria, 2011; De Die, 2013; Gain et al., 2017).

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[1]A *Beel* is a term for billabong or a lake-like wetland with static water in the Ganges - Brahmaputra flood plains of the Eastern Indian states of West Bengal, and Assam and in the country of Bangladesh.

Among 35 Beels in the South west region of Bangladesh (Khulna-Jessore-Satkhira districts), TRM has already been implemented in 12 Beels (Gain et al., 2017). TRM has gradually been accepted and acknowledged as an effective tool to remove water-logging problem by the local communities and afterwards by public bodies. TRM, as the indigenous engineering technique has few advantages over other techniques, such as excavating of the river bed and resultant increase in drainage capacity. This process entails the removal of sediment from the river beds by excavator machine and deposits those sediments on the bank of the river and makes the river narrow. Besides, the deposited sediments by excavating again fall into the river through runoff in a rainy season. Therefore, this technique is not eco-friendly and cost effective and is more time consuming to manage the huge drainage congestion in the study area. Unlike excavating, TRM is more eco-friendly, cost effective (it does not need any large scale engineering tool), less time consuming (and perfectly deposits sediments in the Tidal Basin with protecting runoff) as it can increase drainage capacity to a long distance up to 20 km of the lower stream at a single intervention from the place of TRM implementation.

Reflecting back to the history of TRM implementation, it is noticed that TRM was initially a community driven approach, later being taken over and managed by BWDB. For example, the Tidal Basin- *Beel Dakatia* (1991 to 1994) and *Beel Vayenia* (1997 to 2001) were selected for TRM operation by local community; the Tidal Basin- *Beel Kaderia* (2002 to 2004) and East *Beel Khukshia* (2006 to 2013) were initiated and managed by BWDB. Available evidence and recent literature only shed light on the success and failure of TRM implementation in the floodplain area. Assessing the sustainability impact of TRM is of prime importance due to its acceptance as a dynamic and context-specific process (Gain et al., 2017). Major challenge in this case is the absence of a well-defined and recognized set of indicators, which may provide a benchmark to measure the derived and potential benefits of TRM. The present study tries to overcome this barrier by developing a conceptual framework of Sustainability Index of Tidal River Management (SITRM).
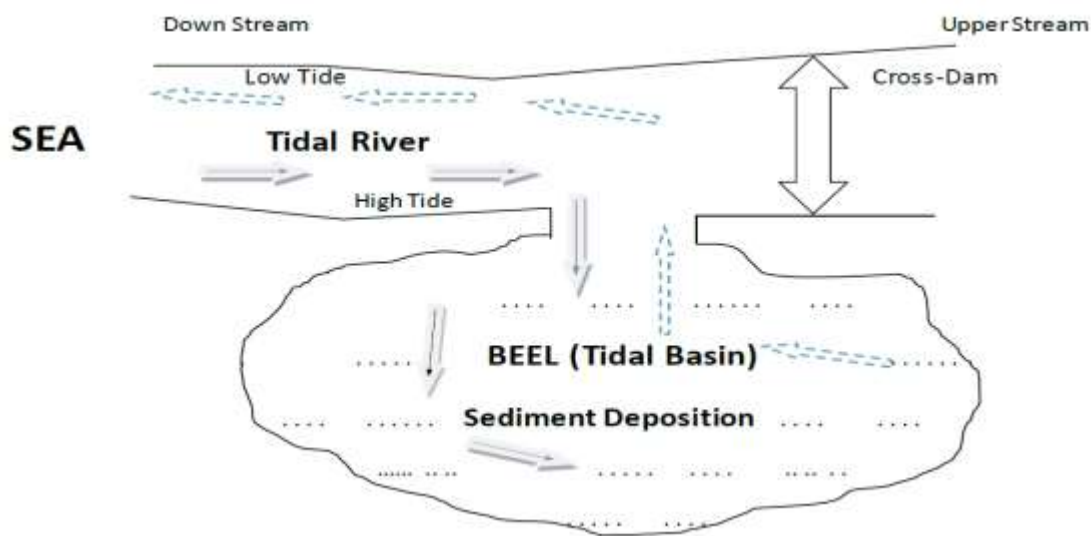

Figure 1: The TRM (Adapted from Paul et al., 2013)

Firstly, this paper summarizes the standards for identifying the primary set of components and indicators for measuring the impact of TRM. After that, on the basis of identification, a detailed justification for choosing each component and indicator is presented. The study has involved four important water sustainability indices including Water Poverty Index (WPI), Canadian Water Sustainability Index (CWSI), Watershed Sustainability Index (WSI) and West Java Water Sustainability Index (WJWSI) that were effectively recognized in the field of water resources management (Plummer et al, 2012; Vollmer et al., 2016). The indices have been developed since the first age of 21st century. There are some successes with fruitful involvements and implementation of these indices in some regions to satisfy their own perspectives (Juwana, 2012) especially for poverty reduction, water supply to the urban dwellers, rural and aboriginal communities, as well as waste water management, forest protection, sewage improvement, water policies and finally water resource sustainability. The Southwest region of Bangladesh is totally different for its geographical location, ecological sensitivity as well as water-related problems. Above mentioned indices are not fit to fulfill its objectives appropriately with respect to sustainability due to their uniqueness in applications and aims. They are not feasible to address the siltation of river beds, drainage congestion, water-logging problem, sediment management and rising sea level issues in the ecologically sensitive Southwest region. Hence, it is essential to develop SITRM for this coastal region with participation of local and national water experts and stakeholders. Besides, the SITRM is based on ecosystem services of coastal region, which is important to be generated to assess the sustainability status of TRM along with prioritizing other water-related issues and integrated coastal zone management. To develop the framework, this study undertakes two following steps:

a. Identifying a primary set of SITRM components and indicators, and

b. Developing a conceptual framework

This paper is structured in three parts. In the first part, the paper clarifies the concepts and principles of water resource sustainability and river management motives. A comprehensive review on existing indices of water resource sustainability has been made in the first sub-section of the second part, which is followed by different guidelines on sustainability impact assessment. On the basis of this discussion, a conceptual framework has been developed for sustainability impact assessment. Third part of the paper tries to identify and explore the potential components and indicators of SITRM followed by its justification. Last of all, the study introduces a flowchart to make those indicators compatible with the social, economic, institutional and environmental characteristics of the Southwest region of Bangladesh in assessing the sustainability impacts of TRM.

1.2 Sustainability Concepts, Principles and Water Resource Sustainability

Dublin Principles (1992), Third World Centre for Water Management (2001) and Stockholm International Water Institute (SIWI, 2010) have given different pathways for water sustainability and sustainable development. The Global Water Partnership (GWP), a principal global campaigner of water and sustainability, discusses that sustainable development will not be achieved without a water-secure world, and provides more precise characteristics that further clarify the concept of water and sustainability (GWP, 2009). The well-known and wider

accepted method of measuring the sustainability is by using a set of indicators which known as sustainability indicators. In case of decision-making for sustainability, scientists identify sustainability indicators as an important and influential tool (Cloquell et al., 2006; Dhal, 2012; Pinter et al., 2012, Waas et al., 2014). Many scholars (Gallopin, 1997; Meadows, 1998; Spangenberg and Bonniot, 1998; Shields et al., 2002) introduced sustainability indicators with their maximum and minimum threshold values in the context of national and international standards that provide information to the users and policymakers that they could easily understand the impacts and take decision in respect of sustainability. The recent water sustainability indices are mostly evolved from components and indicators. Water scientists (Sulivan, 2002; Chaves and Alipaz, 2007; Policy Research Initiative, 2007 and Juwana et al., 2010) familiarized few indicators with components for measuring water resource sustainability. A popular principle in the field of sustainability is the "triple bottom line approach" (Farsari and Prastacos, 2002; Ekins et al., 2003; Cui et al., 2004), which includes the main three aspects of sustainability i.e. social, economic and environmental where the 'prism of sustainability' (Spangenberg and Bonniot, 1998) has four dimensions which are described by environmental, institutional, economic and social indicators having influential inter-linkages among all dimensions. However, Michael (2009) integrated five domain principles (the material, economic, life, social and spiritual domains) for conceptualizing and realizing sustainable development. In this regard we see that water sustainability indicators in recent indices are mostly involved in environmental, social, institutional, economic and life components. In addition, Scoones (1998), Ellis (1999), Department for International Development (DFID, 2000) familiarized five household assets (the natural, human, social, manufactured and financial capital), to integrate these capitals with policies, institutions and processes in the context of vulnerability for choosing livelihood strategies to understand sustainability impacts as livelihood outcomes. Sustainable livelihood approach is a checklist that can be used for livelihood analysis to assess the fitness of development activities in the livelihood of the poor (Kollmair and Gamper, 2002). Nazer (2009), Beckanov (2010) demonstrated Strength, Weakness, Opportunity and Threat (SWOT) analysis for sustainable water use, technical feasibility and economic efficiency in water resource sustainability. Therefore, livelihood analysis and SWOT analysis are important to understand risks and opportunities in the field of sustainability. Moreover, the group of sustainability indicators of a component under a sustainability index or a framework is mainly suitable to compare and select policy options (Farrell and Hart, 1998) as they are able to address composite and multidimensional issues with escaping information surplus due to an increase in understanding level (Costanza, 2000). According to these sustainability concepts, principles, frameworks, water management guidelines and water sustainability indices, the proposed framework of SITRM is developed.

Southwest region is a coastal part of Bangladesh, located near the Bay of Bengal. The Ganges, Himalayan River which flow into Bangladesh (Kibria, 2011) and its tributaries (Modhumati River, Vairab River, Rupsha River, Pashur River, Kabadek River, Sholmari River, Bhadra River, Hamkura River, Hari River, Gengrile River, Hari-Teka River, Mukteshawri River, Teligati River, Betna River, Moricchap River) that carry a huge siltation (Uttaran, 2013) are flowed over this region and mingled with the sea. This region was affected with flood and caused damage to agricultural crops, livestock and houses in every year in the first half of 20th century. Coastal embankment (massive earthen) was 6000 km long introduced by BWDB

(previously known as East Pakistan Water Development Authority) in mid-1960s by installing 139 polders[2] to limit the floodplain and protect this region from flood and saline intrusion as well as intensifying agricultural crops (Kibria, 2011; De Die, 2013; Cardno, 2015; Gain et al, 2017). Coastal Embankment Project (CEP) gave a good result for 10 to 15 years. After that the polder system of CEP restricted the tidal flow and de-linked the rivers from the catchments (Kibria, 2011). In addition, it interrupted indigenous river and sediment management system that leads to coastal rivers further going under a huge siltation and drainage congestion (CEGIS, 2003a; Khadim et al., 2013 and Kibria, 2011) followed by water-logging in the Tidal Basin. TRM is an eco-technical process, particularly fitted into the Southwest region of Bangladesh unlike Southeast and South-central coastal region due to its unique geographical and morphological characteristics as well as varying natural and anthropogenic forces active in that region. Among natural processes, land compaction in this flood plain (alluvial soil in nature) area is continuing with subsidence at a rate of 2-3 mm/year which makes physical threats in the Southwest region (IPCC, 2014; GED, 2015; Roy et al., 2017). Apart from this, climate change induced sea level rise and cyclonic extreme events are leading in that region. Anthropogenic and structural initiatives for instance, Farraka barrage since 1975 includes reduced freshwater flow during dry season due to the upstream withdrawal of water (Shampa and Paramanik, 2012; De Die, 2013; GED, 2015; Gain et al., 2017; Roy et al., 2017). In addition, Ganges-Kibadak (G-K) irrigation project contribute to increased water salinity and high rates of sediment deposition in the Southwest coastal region. Moreover, effects of these human interventions have again been aggravated by the construction of coastal polders in mid-1960s to protect agricultural land from disastrous flood. These coastal polders have prevented silt from the rivers from being deposited on flood plains, causing high rates of sedimentation on the river bed and resulting huge drainage congestion (EGIS, 1998; De Die, 2013; Gain et al., 2017). Therefore, the Southwest coastal region appears more appropriate as the case study for adopting TRM to solve drainage congestion and water-logging problem. Water-logging degrades environment with pollution (Adri, 2009) resulting in biodiversity and yield loss (Masud et al., 2014b) as well as leading people to unemployment in crisis of livelihood (Haider et al., 2008; Tutu, 2005). Khulna-Jessore Drainage Rehabilitation Project (KJDRP) was initiated in 1995 that accepts indigenous knowledge and introduces TRM again to solve water-logging problem in this region (EGIS, 1998). Therefore, this coastal region has been undergoing water problems and adopting several methods for water resources management since the middle of 20th century (De Die, 2013). As the complexity of water problems is increasing, there is a need for the integration of social, economic and environmental aspects in managing water resources in the Southwest region of Bangladesh.

Masud et al. (2007-2008), in their paper, find the relationship between sanitation and diarrheal disease of children. Poor sanitation is positively associated with increased frequency of diarrheal disease. Again the impacts of water-logging on biodiversity have been captured by Masud et al. (2014b), who showed that their study area suffers from environmental degradation and biodiversity loss in terms of reduced plants, livestock, birds, wild animals and fisheries due to water logging. Apart from this, Haider and Moni (2008) try to explore the

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[2] The Dutch term "polder" is used to designate areas that are enclosed on all sides by dykes or embankments, separating them hydrologically from the main river system and offering protection against tidal floods, salinity intrusion and sedimentation. Polders are equipped by in- and outlets to control the water inside the embanked area.

socio-economic consequences of water-logging in the Southwest region of Bangladesh. Aftershocks of water-logging, makes disruption of houses, scarcity of pure drinking water, poor sanitation and inundation of agricultural land in the floodplain area. In addition, its resultant creates reduced productivity, low income, unemployment, low level of utility services and migration which are the socio-economic consequences captured under the study. The aforementioned works of the authors provide a baseline for identifying the socio-economic and environmental dimensions of the sustainability impact indicators of TRM.

1.3 River Management Motives:

The inclusion of motives of community people and management personnel is of great importance in the field of river management. The motives are mainly governed by socio-economic and environmental issues of the corresponding community based on its ecosystem services. The conceptual framework of SITRM from the very beginning of sustainable river management should have comprised motives based on ecosystem services of tidal river (Figure 2). This framework will involve both societal and environmental motives, (Wheaton, 2005) suggested for the inclusion of societal motive, for a concise conceptual framework in the river management project.
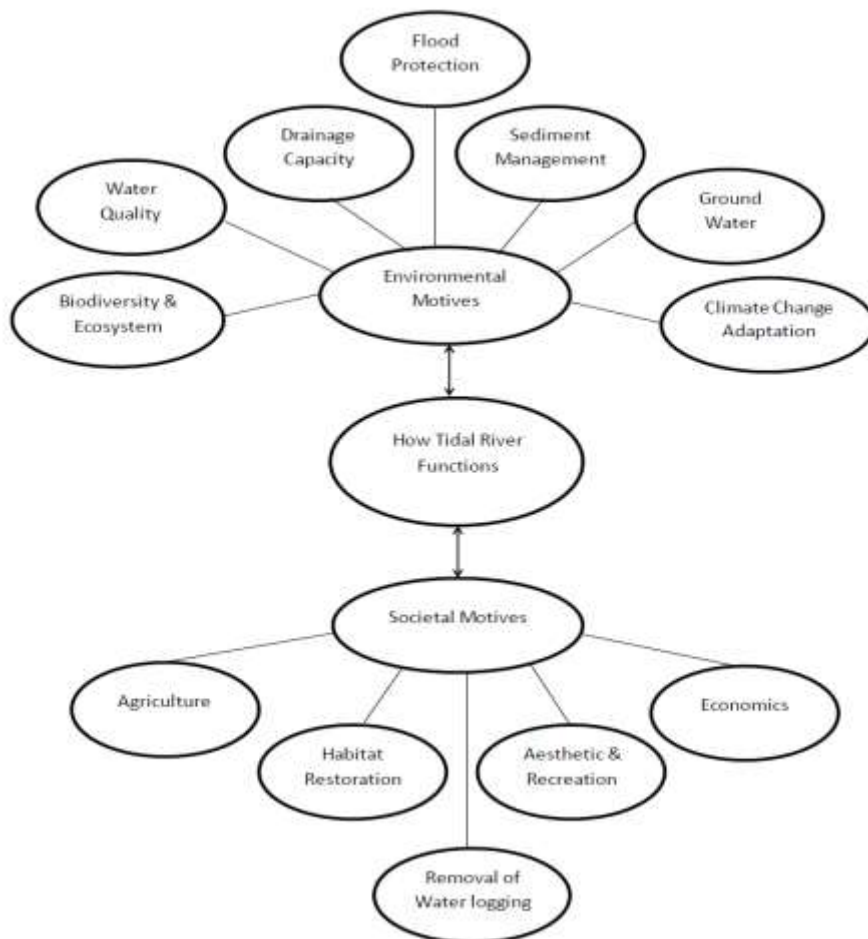

Figure 2: Societal and environmental motives of TRM (Adapted from Wheaton, 2005).

Figure 2 shows that TRM is focused by two groups of motives which are directly (agriculture, economics, removal of water-logging, biodiversity and ecosystem, water quality, drainage capacity and sediment management) and indirectly (habitat restoration, aesthetic and recreation, flood protection and climate change adaptation) related to the evolving SITRM framework. Eventually, a primary set of indicators and their target levels in form of threshold values (maximum and minimum) is built on specific motives with their corresponding ecosystem functions and services to measure sustainability impacts (Doyle et al., 2000; Levy et al., 2000; Merkle and Kaupen, 2000; Smeets and Weterings, 1999; WMO, 2012; Wheaton, 2005; CEGIS, 2003b; Juwana et al., 2010; Gain et al., 2012a). Then stakeholders and policymakers can certainly understand how the SITRM interacts and responds to various motives and set TRM objectives. Finally, a comparison between the predicted indicator responses to TRM intervention versus inaction should be made to decide whether river management is effective.

2.1 Review of Existing Indices on Water Resource Sustainability

The literature review is undertaken extensively on the existing water sustainability indices of WJWSI, CWSI, WSI and WPI (presented in Table 1) to recognize their components and indicators. Generally, one or more indicators construct A component of a sustainability index (Pesce and Wunderling, 2000; Swamee and Tyagi, 2000) as well as each indicator can have several sub-indicators when it demands to measure impacts broadly (Juwana et al., 2009; 2010). As shown in Table 1, the WJWSI has 4 components and 12 indicators, WPI has 5 components and 17 indicators, CWSI has 5 components and 15 indicators and WSI has 4 components and 12 indicators. Agreeing with these indices, the study has proposed 6 components and 20 indicators for SITRM.

Regarding sustainable development, water scientists firstly introduced water as a commodity to alleviate poverty providing an integrated assessment of water stress and scarcity by WPI (Sullivan, 2002). The index developed an active relationship between poverty and water accessibility in several countries and made comparisons among 147 national levels with their status across the world, effectively satisfied its objectives (Juwana et al., 2009; 2010). Moreover, the WPI provided a framework based on sustainability principle to measure water sustainability by eradicating poverty. Canadian Policy Research Initiative evolved a framework named CWSI in 2007 to measure water sustainability in Canada by accepting the framework of WPI. CWSI was capable to evaluate the fresh water necessities for the welfare of urban dwellers emphasizing rural, remote and aboriginal communities along with waste water management issues (Policy Research Initiative, 2007). The WSI was initiated particularly in Southern Brazil to develop an integrated method in a framework to assess the sustainability of basin management. This framework was able to satisfy water sustainability, and provide suitable information to the decision makers that make them capable to diminish sewage pollution, improve forest protection and progress water resources pollicies (Chaves and Alipaz, 2007, Juwana, 2009). The WJWSI was developed to examine water resource sustainability status of West Java Province in Indonesia (Juwana et al., 2012).

From the review above, we can summarize some conceptual gaps. Firstly, none of the indices consider sedimentation in downstream rivers and water related problems in the coastal area.

Secondly, water-logging, the important phenomenon of human interventions (coastal embankment, dam, bridge etc.) and climate change effects (sea level rise, flood etc.) are not covered in their water sustainability index. Thirdly, the lack of consideration for forward-looking aspects (or future aspects) is one of the main shortcomings of sustainability assessment in general. Fourthly, most of them emphasize a particular issue for assessing the water resource sustainability. Moreover, integrating multiple objectives into ecosystem services with wetland assessment is essential for the sustainability of river management that is not properly described in the above-mentioned frameworks. The vulnerability of water resources at present and for future generations should be considered for water resource sustainability but these indices do not portray such types of vulnerability. They do not reflect indigenous practices of community people and their strong participation for sustainable TRM. In TRM, sediment is managed in a *Beel* (Tidal Basin) but these indices do not consider Tidal Basin for sediment management. Finally, by following Dublin Principles, the involvement of local stakeholders at major steps of management process is necessary (Gain et al., 2012a) to move in more complex assessments based upon the concept of socio-ecological system (UN-Water, 2008) with economic valuation to serve multiple objectives (WMO, 2012) and achieve the goal of sustainability.

Table 1: Components and Indicators of recent water sustainability Indices (Adapted from Juwana et al., 2010)

WJWSI		CWSI		WSI		WPI	
Component	Indicator	Component	Indicator	Component	Indicator	Component	Indicator
Water Resources	Availability	Resource	Availability	Hydrology	Pressure	Resource	Internal flows
	Demand		Demand		State		External flows
	Quality		Supply		Response		Population
	Land use changes						
Water Provisions	Coverage	Ecosystem Health	Stress	Environment	Pressure	Access	Clean water
	Water loss		Quality		State		Sanitation
	Finance		Fish		Response		Irrigation
Human Health	Sanitation	Infrastructure	Demand	Life	Pressure	Capacity	Income
	Access		Condition		State		Mortality
	Health impact		Treatment		Response		Education
							Income distribution
Capacity	Poverty	Human Health	Access	Policy	Pressure	Use	Domestic
	Education		Reliability		State		Industry & agriculture
			Impact		Response		
		Capacity	Financial			Environment	Water quality
			Education				Information
			Training				Biodiversity
							Pollution
							Regulation

2.2 Sustainability Assessment

Sustainability assessment is the following generation of both environmental impact assessment and strategic environmental assessment (Ness et al., 2007; Bond et al., 2012), mainly associated with the impacts of indicators, which generate essential and powerful decision to the users and policymakers. There have been different groups of thoughts on sustainability assessment in scientific research. These are biophysical, monetary tools and sustainability indicators to deal with the triple bottom dimensions of sustainability (environmental, economic and social) (Gasparatos and Scolobig, 2012; Van Passel and Meul, 2012; Kloepffer et al., 2008). But biophysical and monetary tools are not able to capture some economic and social issues such as capital, education and culture (Gasparatos et al., 2008; 2009 and Maes and Van Passel, 2014). However, "Ecosystem services" centred indicator is a tool that is broadly applied to establish human well-being (TEEB, 2010; Hossain et al., 2016) by developing the linkage between ecosystems and household assets. Recently, numerous studies have purposely aimed to incorporate ecosystem services grounded sustainability assessment into decision making processes (Ranganathan et al., 2008; TEEB, 2010; WMO, 2012).

2.3 Conceptual Framework

The conceptual framework of TRM comprises provisioning services, regulating services, supporting services and cultural services of tidal river and its floodplain ecosystem to develop sustainability indicators as a model to assess water resource sustainability. The generic principles and guidelines on wetland restoration which have been developed for well-being of several environments by the Ramsar Convention is fruitful in the ground of restoring floodplains as a part of sediment management and flood protection strategies (Ramsar Convention Secretariat, 2007). Whilst floodplain restoration project is hypothetically exceptional, the guidelines are neither universally appropriate nor definitive (WMO, 2012).

Figure 3 shows that the conceptual framework of TRM is developed based on involving stakeholders in all aspects of work (step- 1). The River Skerne, Elbe and the larger Rhine Delta Upper Mississippi are important examples (WMO, 2012) for the involvement of local communities and wider stakeholders to derive and implement sustainable solutions to flood risk management options. At every time, key stakeholders need to attempt for decisions to meet sustainability followed by involving all other stakeholders in all plans and processes (Loucks and Gladwell, 1999; Juwana, 2010). This is the core element for water sustainability (Juwana et al., 2010; WMO, 2012; Gain et al., 2012a), ensuring that all ecosystem services to be completely considered in the framework.

The framework considers ecosystem services i.e. provisioning services such as water availability of the tidal river, removal of water-logging from floodplain; regulating services such as keeping drainage capacity, sediment management, taking mitigation measures against rising sea levels, crop production, forest productivity, water quality, biodiversity, rotation of TRM *Beel,* water governance, land use changes, health impact; supporting services such as new land formation, protection locality from salinity, and cultural services such as awareness and coordination, compensation to establish TRM goals, objectives and performance standards (step- 2). It makes the TRM site compatible with objectives and performance

standard by conducting preliminary site investigation (step- 3). It is important to link ecosystems to economic activities for accounting ecosystems (Boyd and Banzhaf, 2007; Maler et al., 2008; Edens and Hein, 2013; EC et al., 2013; Obst et al., 2013). The supply and demand of any good or service can monetarise ecosystem services (Schagner et al., 2013). It derives opinion from stakeholders and local experts to create TRM goals and objectives with performance standard and finalize the site selection of TRM by choosing scale. The concern about temporal units, biophysical units and social units in scales is important with regard to water sustainability assessment (Gain et al., 2012a) because they directly affect the purposes and the final users of the assessment exercise (Van Passel and Meul, 2012). The framework involves choosing the scale with defining the biophysical, social and temporal boundaries of the area under assessment, gathering information on the physical environment, community people and the biodiversity it supports, and linking this information with the values that stakeholders derive from the ecosystem. We consider sub-basin in biophysical scale, community in social scale and annual in temporal scale to develop the conceptual framework of TRM.

Figure- 3: The Proposed Framework for Sustainability Impact Assessment of TRM (adapted From Ramsar Convention Secretariat, 2007; WMO, 2012 and Gain et al., 2012a).
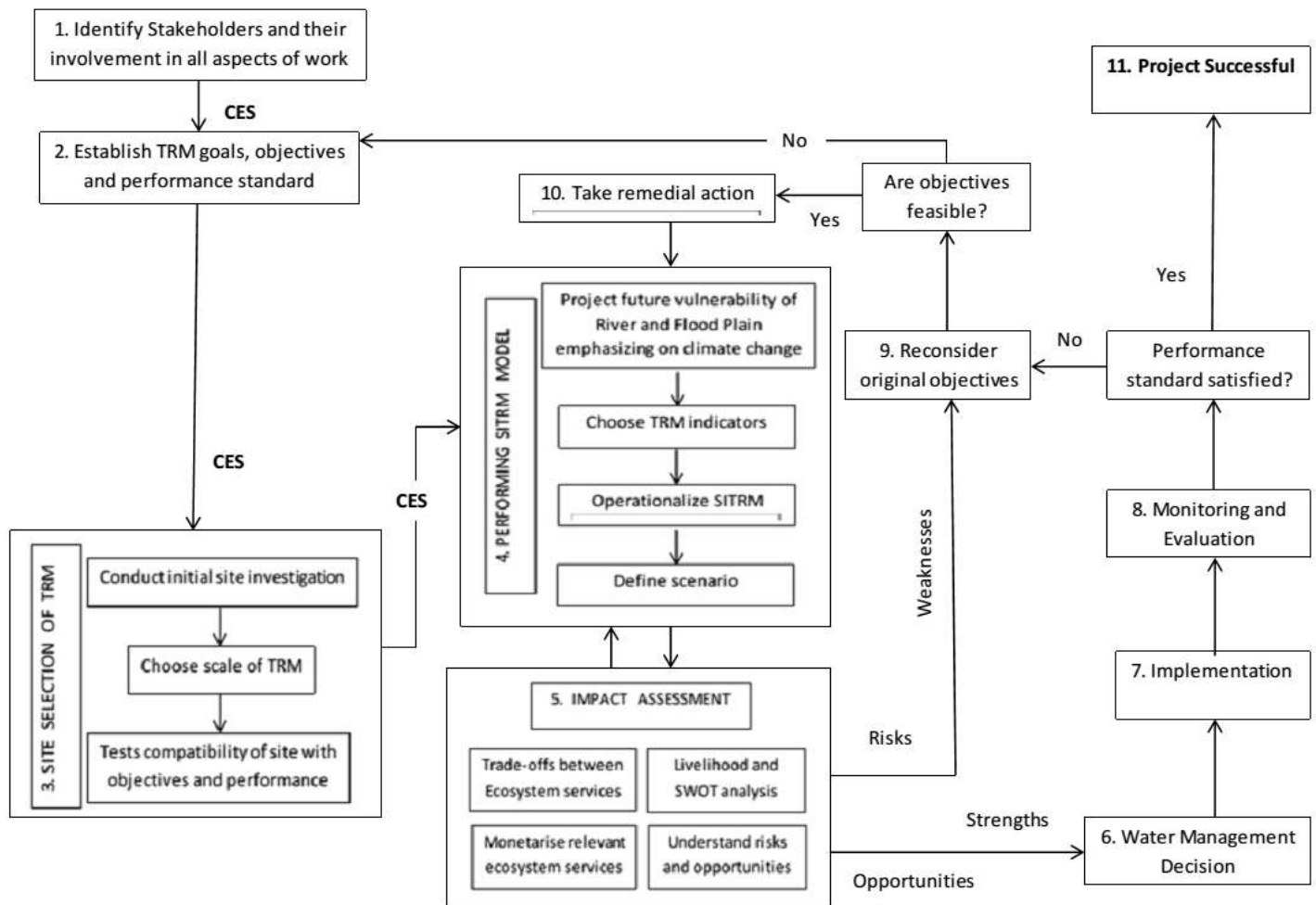
CES: Consideration of Ecosystem Services

It is significant to select a sustainable model and operationalize it for defining scenario with indicators as well as project future vulnerability of the community, river and Tidal Basin, emphasizing on climate change issues (step- 4). Based on artificial neural network (ANN) technologies, Xie et al. (2006) proposed the hybrid adaptive time-delay neural network (ATNN) model to improve multi-stem-ahead (MS) prediction in forecast and involved case study for analyzing classical time series (yearly average) of the sunspots. In addition, Chau and Wu (2010) offered a hybrid model, and ANN-SVR (incorporating with support vector regression) and Wu et al. (2010) provided the modular artificial neural networks (MANN) model. Then these models were coupled individually with data processing techniques-singular spectrum analysis (SSA) and strongly improved the forecasting with accurate overall predictions by involving case study to analyze low, medium and high intensity daily rainfall data series from Da'ninghe basin (1988-2007) and Zhenshui basin (1989-1998) of China. These models will play significant role in ecological assessment by predicting water-logging vulnerability in floodplain area and to drain out the excess water through tidal river. Besides, Muttil and Chau (2007) used ANN and genetic programming (GP) to select the ecologically important input variables and Wang et al., (2014) proposed an integrated variable fuzzy evaluation model (VFEM) based on the theory of variable fuzzy sets (VFS) and the fuzzy binary comparison method (FBCM) to solve interval form grading standards perfectly for assessing water quality data of river. Muttil and Chau (2007) included case study from Tolo Harbour, Hong Kong and identified accurately algal bloom dynamics by improving future prediction in algal bloom warning system of coastal waters. Wang et al., (2014) took two case studies from Gorges and Tseng-Wen River of China and enhanced the accuracy for water quality assessment by delivering water cleanliness to the superior level. Furthermore, to assess both qualitative and quantitative data in the context of environmental impacts, Zhao et al. (2006) presented multi criteria data envelopment analysis (MCDEA) method. It was an important method to assess environmental impacts for water resources management. It comprised 17 multiple criteria data where 10 qualitative data (under water quality, geologic, hydrography and biology units) and 7 quantitative data (submerged valuable land, resettlement, water supply, generate electricity, irrigation, breed aquatics and economic benefits) for a case study of a dam project. MCDEA can avoid biasness of human judgment by providing the effective decision making options with scientific nature and objectivity. Therefore, MCDEA method may play a significant role for the site selection of TRM project in coastal region. The conceptual framework, which involves a complete impact assessment considering ecosystem services in trade-offs analysis, livelihood analysis and SWOT analysis and monetarises relevant ecosystem services where possible (step- 5), has created an approach to enable decision-makers to focus on those services most likely to be of risks and weaknesses or opportunities and strengths for the sustainability of TRM. Step- 5 of Figure 3 is the most important step of this framework. It measures the impacts of an indicator in the context of sustainability. If an indicator affects livelihood and reduces livelihood assets is regarded risky for ecosystem services. On the other hand, when an indicator impacts

positively on livelihood and improves livelihood assets is considered as opportunities for ecosystem services. After TRM interventions, open wetland of the TRM *Beel* has been converted into agricultural land, terrestrial biodiversity has taken place of the aquatic biodiversity and culture fish species are increased by decreasing local fish species. It demands effective monetarising the ecosystem services not only socio-economic point of view but also properly environmental consideration.   Every service of ecosystem has both economic value and environmental value. Therefore, trade-offs analysis is important to evaluate a group of ecosystem services to maximize the benefits (see figure 4). Besides, the expected value of an indicator may fall by technical problems of TRM operation and its institutional arrangement. In this case, SWOT analysis plays significant role to evaluate TRM operation and its institutional arrangement by providing strengths and opportunities for positive impacts and weaknesses and threats for negative impacts of ecosystem services. Moreover, minimizing the weaknesses and threats, the expected outcomes from an indicator are possible. For the outcomes of opportunities and strengths, these are able to implement (step- 7) through water management decision   (step- 6). For the outcomes of risks and weaknesses, these are reconsidered with original objectives (step- 9). Finally, the framework examines the satisfaction of performance standard in monitoring and evaluation process (step- 8). If satisfied, the project is successful (step- 11); otherwise, it goes into taking remedial actions (step- 10) or establishing TRM goals (step- 2).

Stakeholders play an important role in understanding ecosystem services and its trade-offs. For assessing sustainability in various dimensions, trade-offs is an essential tool (WMO, 2012; Frigge and Hahn, 2012). The trade-offs analysis suggests examining the biophysical, the socio-cultural, and the monetary value dimensions of ecosystem services to generate different information outputs that help decision makers to take an effective decision of sustainability.
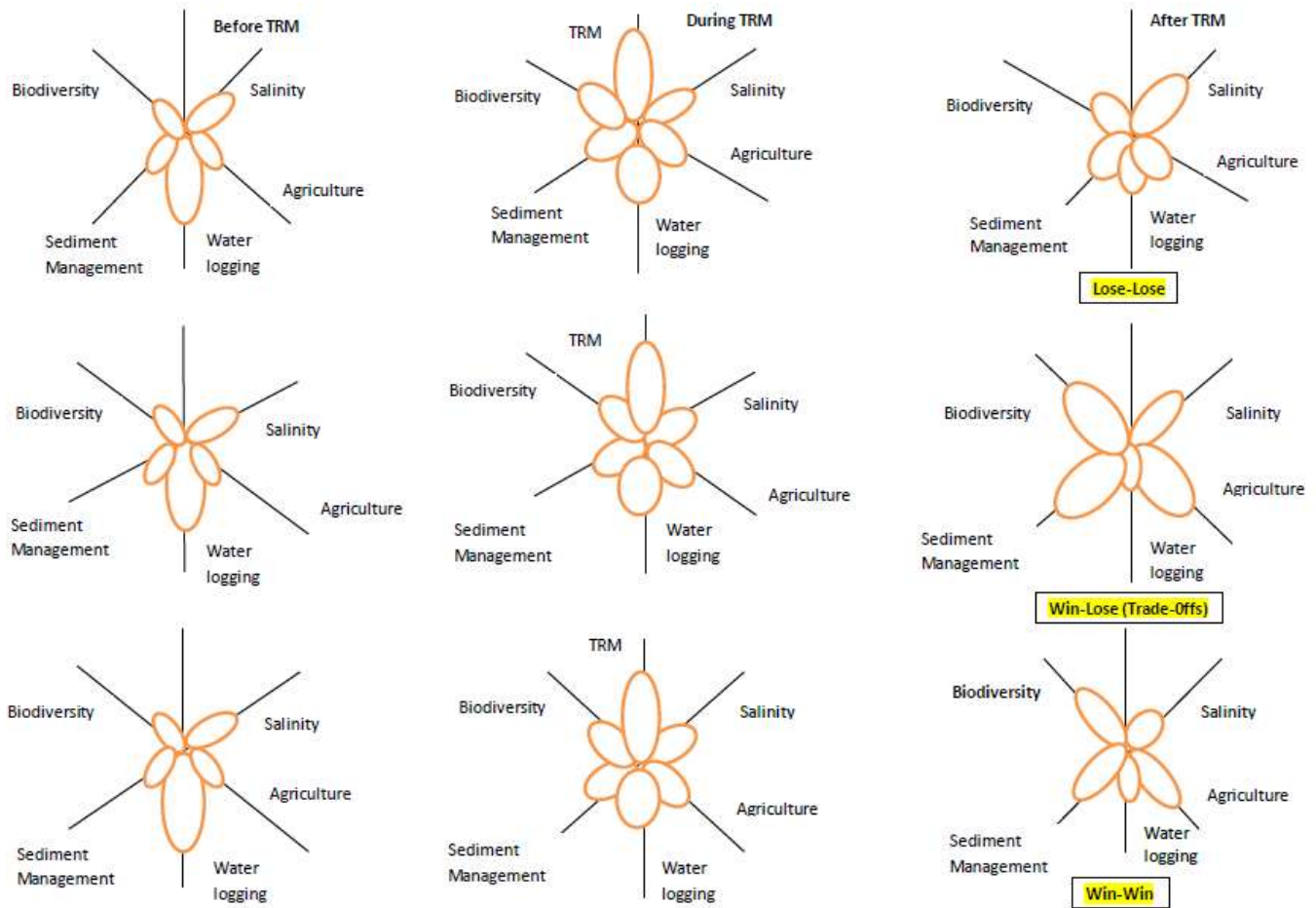
Figure 4: 'Trade-off flowers' portraying alternative scenarios for TRM projects aimed at biodiversity protection and economic growth: (a) unrestrained TRM can lead to more salinity that degrades ecosystem services and it causes biodiversity loss, less agricultural production and sediment to be managed improperly (loss-loss situation); (b) TRM applied (more time is invested, generally five to six years) with proper sediment management and with trade-offs to increase salinity so that more economic growth comes from maximizing agricultural development and improved terrestrial biodiversity and ecosystem services (win-loss situation); (c) TRM applied (less time is invested, generally two to three years) without tradeoffs for salinity causes comparatively less economic growth from reasonable agricultural production and moderately improved biodiversity with inadequate sediment management (win-win situation) (Adapted from Tallis et al., 2008).

Figure 4 shows three scenarios of TRM interventions. These are before TRM, during TRM and after TRM. Before TRM is the situation of water-logging due to siltation in river beds and drainage congestion. It degrades environment with water pollution and soil filth. Ecosystem services are declined by the harm of biodiversity and minimum agricultural yield. During TRM is the position of TRM implementation. It permits tidal flow into the Tidal Basin two times in a day by connecting Beel to the tidal river. During interferences of TRM, water-logging is gradually reduced by the management of sediment in the TRM Beel. It expands biodiversity and increases crop production by improving ecosystem services of surrounding Beels. It

involves increasing salinity in dry season and reducing salinity in rainy season in the TRM Beel. There are several Beels which alongside the tidal river (except TRM Beel) go under good agricultural production and develop livelihood options. After TRM is the condition of water-logged free environment by completing TRM interventions to fulfill the community expectations. The economic growth is intensified by maximizing agricultural production, with strengthened biodiversity and improved ecosystem services that create more job facilities, by reducing poverty forming livelihood stability and minimizing salinity steadiness. The loss-loss situation has happed at an Open TRM system (without village protection dam during TRM implementation). The win-loss position has created at an Enclosed TRM system (with village protection dam during TRM application) and by the inclusion of trade-offs. Moreover, the win-win condition has occurred at an Enclosed TRM system (with village protection dam during TRM operation) and exclusion of trade-offs.

3.1 The Potential Components and Indicators of Sustainability Index of Tidal River Management (SITRM)

The development of SITRM is initiated by reviewing (a) sustainability concepts and principles (b) water resource sustainability models and guidelines (c) river management motives (d) the existing water sustainability indices of WPI, CWSI, WSI, WJWSI, and a water vulnerability index WVI (Gain et al., 2012a). With respect to the sustainability principles, SITRM attempts to integrate all dimensions of sustainability namely the environmental, economic, social and institutional, in its components and indicators.

Table 2: The components and indicators (with their threshold values) of SITRM (adapted from Juwana et al., 2010)

Component	Indicator	Threshold Values		
		Unit	Maximum	Minimum
Tidal River	Water Availability	m^3/cap/yr	1700[a]	500[b]
	Drainage Capacity	-	1[a]	0[b]
Environmental Challenges	Sedimentation	%	100[b]	0[a]
	Rising sea level	mm/yr	20[b]	0[a]
	Water-logging	%	100[b]	0[a]
Resilience	Crop production (paddy + fish)	ton/ha/yr	(paddy)3[a]	< 2[b]
	Forest	%	25[a]	<11.2[b]
	New Land Formation	%	100[a]	0[b]
Floodplain	Water Quality		76 [a]	<51[b]
Ecosystem	Salinity	ppt	(crops)1[b]	0[a]
	Biodiversity	-	1[a]	0[b]

	Migration of Climate Refugees	%	100[b]	0[a]
Human Health	Sanitation	%	100[a]	0[b]
	Health Impact	Cases/1000/pop	100[b]	0[a]
Community	Awareness and Co-ordination	%	100[a]	0[b]
Participation	Compensation	%	100[a]	0[b]
	Land use Changes	%	100[b]	0[a]
	Employment	%	100[a]	0[b]
	Rotation of TRM *Beel*	-	1[a]	0[b]
	Water Governance	-	1[a]	0[b]

Value: a for preferable; b for not preferable and – for national or global standard

Table 2 shows that 6 components with 20 corresponding indicators and their threshold values are involved in SITRM. There exists other feasible alternative components and indicators of SITRM framework to measure the water sustainability in this coastal region. For example, Tidal River has been chosen instead of Water Resources/Hydrology. Water Resources include both tidal and non-tidal rivers as well as other water bodies, dealing with those that are practically beyond the scope of this study. As water related problems in the Southwest region mostly originates from the tidal rivers, SITRM incorporates only Tidal River as a component. Likewise, Ecosystem Health is all inclusive by its nature, due to which Floodplain Ecosystem has been chosen by narrowing down the scope of ecosystem health. Resilience is a proxy of the capacity of the community people, which particularly sheds light on production for economic resilience, forest resource and new land formation for environmental resilience. Regarding indicators, *health impact* has been chosen as the replacement for *mortality*, in order to capture the outcome of living people disease. W*ater availability* and *drainage capacity* has been included instead of *internal flow to* address the problem of sedimentation of tidal river properly. Apart from this, *salinity* and *water-logging* has been regarded as other indicators in place of *pollution*, which is justified by the fact that water pollution in the Southwest region is mostly replicated by the salinity and degradation of water quality resulting from water-logging.

Present research work attempts to introduce this comprehensive framework by considering the interactive forces underlying among socio-economic, environmental and institutional perspectives in the study area, that still remain untouched in the contemporary literature. Novelty of this framework underlies its holistic approach which has been developed for the sustainability of TRM.

The study will involve the continuous re-scaling method to obtain sub-index values for the SITRM indicators. It will produce a matching range for the values of indicators for example, 0

to 1 or 0 to 100. Then decision makers can easily understand the performance of every indicator for the same unit value and formulate the necessary action plans to address the issues related to the respective indicator in the context of water sustainability (Beck and Hatch, 2009; Heink and Kowarik, 2010; Juwana, 2012).

The study has included indicators for like, *drainage capacity, biodiversity, rotation of TRM Beel* and *water governance* with their maximum (1) and minimum (0) values by assumptions. To set the standard values of these indicators, it is mainly needed to depend on biophysical unit and social unit (Rockstrom et al., 2009; Gain et al., 2012; Vollmer et al., 2016; Roy et al., 2017). It needs strong consultations among stakeholders (GWP, 2000; Pahl-Wostl, 2007; Vollmer et al., 2016) and water experts with rules and regulations and a base line survey where it supports (Juwana, 2012). The following sub-sections discuss in detail the justification for the selection of various components and their indicators of SITRM.

3.2 Justification of Components and its Indicators

3.2.1 Justification for the Component *Tidal River* and its Indicators
Tidal River is the first component selected for SITRM, which can be utilized by current and future generations to meet vigorous ecosystem, sound environment and livelihood stability for gaining the water resource sustainability. It includes two indicators, *water availability* and *drainage capacity* (CEGIS, 2003b). Thus, the inclusion of Tidal Rivers as one of the water sustainability components is inevitable. The justification for each indicator under this component is discussed below.

Water Availability –
Water is the main indicator of life supporting, regulating, provisioning services in tidal river and its floodplain. A person ideally has to require between the minimum 500 m^3/year and the maximum 1,700 m^3/year water to sustain his or her life (Falkenmark and Rockstrom, 2004). It plays a vital role to access water sustainability (Sulivan, 2002; Chaves and Alipaz, 2007; Policy Research Initiative, 2007 and Juwana et al., 2010) and regard this assessment to take effective decision for improving the policy (Juwana et al., 2012).

Drainage Capacity –
This indicator measures the capacity of a river to drain out flooded or excess water from *Beel* and remove water-logging from the locality. It indicates the relationship between water demand and water availability. This will give an idea on the stress of water resources by reducing depth and width of the river due to siltation on river beds and drainage congestion (CEGIS, 2003a; Kibria and Mahmud, 2010). It is essential for a river to maintain its drainage capacity for providing ecological functions and services in terms of available natural tidal flows. The Hari River, which was heavily silted up before implementation of TRM in *Beel* Bhaina Tidal Basin by 1999, was enlarged radically in width and depth within only two years of TRM operation, showing free movement of tides in its channels and removed drainage congestion (IWM, 2007; Kibria, 2011; Khadim et al., 2013; Paul et al., 2013).

3.2.2 Justification for the Component *Environmental Challenges* and its Indicators

The component Environmental Challenges indicates the potential risk of present as well as future needs to face for water resource sustainability. Rising sea level and different water control structures aggravate the challenges. In this study, Environmental Challenges includes *sedimentation, rising sea level* and *water-logging* indicators which come from both by natural process and human interventions (Shoaib et al., 2013) have to deal with environmental stresses in SITRM. It measures to the extent at which community people are affected by ecological hassles caused by climatic (SEI, 2004) and non-climatic events.

Sedimentation –

It is important to know how much sediment is entering into the system and to measure the amount of sediment which is deposited in different parts of the floodplains and the intertidal areas and finally, carried into the Bay of Bengal in the natural process (CEGIS, 2003a). This indicator indicates how much sediment should be needed to deposit from river bed to the *Beel* by TRM and/or other soft engineering interventions to maintain riverine ecosystem. Water infrastructures (embankment, dam, barrage, bridge etc.) and natural process (bank erosion, rain fall and agricultural run-off) aggravate sedimentation in river beds and drainage congestion by reducing drainage capacity. TRM plays an effective role in sediment management and increasing navigability of river (Khan, 2012; Masud et al., 2014b). Sediment is properly managed and deposited in a *Beel* by TRM (Kibria and Mahmud, 2010). Therefore, sedimentation is an issue that needs to be taken into account in developing the SITRM.

Rising sea level –

The factors like ocean thermal expansion, which expands current water volume, and glacial melt, mostly from Greenland and Antarctica that increases water to the oceans are mainly liable for rising sea level (Hemming et al., 2007; Oliver-Smith, 2009). The IPCC Fourth Assessment Report places projected sea level rise at up to 0.6 meters or more by 2100 (IPCC 2007). It is predicted that 50 million to 350 million people will be environmental refugees as a result of climate change induced global warming and rising sea levels by 2050 (UN, 2009). Most of climate refugees are coastal people. Currently overall trend in yearly sea level rise is 6mm to 20mm (Islam, 2016); and 6 mm to 21 mm along Bangladesh coast (CCC, 2016). Of course, TRM is an ecofriendly and effective way to raise submerged land if sea levels continue to rise reaching 1m or so (Ullah and Rahman, 2002; Kibria and Mahmud, 2010; Sterret, 2011; Paul et al., 2013). Therefore, rising sea level is an important indicator to be explained in evolving SITRM.

Water-logging –

Water-logging has a significant role in reducing environmental and socio-economic sustainability. Water-logging creates environmental degradation, and hampers biodiversity and ecosystem services (Masud et al., 2014b). Agriculture becomes impossible and fisheries are also depleted. People also become jobless (Tutu, 2005; Haider et al., 2008; Adri and Islam, 2012; Masud et al., 2014b). Water-logging is caused by deterioration of drainage conditions in coastal rivers of Southwest Bangladesh causing difficulties towards maintaining livelihoods. The Coastal Embankment Project (CEP) in 1959 and the commissioning of Farakka Barrage in 1975 were the vital factors for continuing the sedimentation of river beds

and drainage congestion that had a great adverse impact upon the geomorphological characteristics of Southwest part of Bangladesh (Sarker, 2004; DHV-WARPO, 2000; Adri and Islam, 2012). Climate change is another important factor that is likely to exacerbate this problem very soon (Huq et al., 1996; Choudhury et al., 2005; Adri and Islam, 2012). TRM will progress navigation of rivers, bring ecologically sounder environments and improve socio-economic conditions of local people by removal water-logging (CEGIS, 2003b; Tutu, 2005; Sterett, 2011; Paul et al., 2013; Khadim et al., 2013).

3.2.3 Justification for the Component *Resilience* and its Indicators

Crop production, forest and *new land formation* can measure resilience of the floodplain ecosystem. If the ecosystem has good resilient, it will continue better biomass production caused by environmental challenges. An ecosystem has power to grip different constituents of anthropogenic (Cairns, 1999) and non-anthropogenic wastes, at certain concentrations without degrading itself. Conway (1985) states sustainability as *"the ability of a system to maintain productivity in spite of a major disturbance"* on the basis of the ecological concept of resilience. Therefore, resilience is an important component in water resource sustainability.

Crop production (Paddy and Fish) –

Agriculture is a key indicator of ecological stability, economic development (Gain et al., 2012a) and water resource sustainability. A sustainable river management practice provides proper irrigation facilities for crop production. Water-logging advances resource depletion and generates tension in people's livelihoods and creates conflicts among different economic activities, for instance between paddy and shrimp farming, and also creates an instable social condition (Kibria, 2011). Substantial parts of the farming lands remain unplanted due to water-logging. Losing *Aman*[3] seasons strongly affects poor farmers and diminishes their food security (Adri and Islam, 2012). TRM removes water-logging by depositing sediment in the Tidal Basin that leads to crop production and expands livelihood options (CEGIS, 2003a; Tutu, 2005; Khadim et al., 2013).

Forest –

The catchments of forest area provide a huge amount of water for domestic, agricultural, industrial and ecological needs in both upstream and downstream zones (Calder et al., 2007; FAO, 2013). Forests are an important indicator to protect the downstream from the possibility of flood events by regulating runoff and erosion risks (Bujarbarua et al., 2009; Gain et al., 2012a). Moreover, it reduces salinity and increases biodiversity and ecological services (Lambin and Meyfroidt, 2011; UN, 2011). The Sundarbans, world largest mangrove forest is the safeguard for coastal people, protects them from cyclones and tidal surges. Fresh water flow from upper stream is continuously decreasing due to Farakka Barrage and several irrigation projects that increases salinity by tidal effects of the sea to the coastal rivers close to the Sundarbans. Moreover, sedimentation in river beds creates drainage congestion that confines excessive rainfall in the floodplain by polder system, and generates water-logging caused by incapability through this river channel to pass rain fed fresh water which is

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[3] Aman is a particular rice variety, which is generally cultivated in December to January

essential for decreasing salinity to the rivers alongside the Sundarbans and increasing its productivity and ecological functions. Day by day its vulnerability upsurges by mismanagement, over extraction, salinity intrusion and pollution. For a balanced ecosystem and strong biodiversity, a country needs 25% forest of its area but Bangladesh has only 11.2% forest according to ADB report (Prothom Alo, 2016). Besides, climate change affects forest's role in regulating water flows and influencing the availability of water resources (Bergkamp, Orlando and Burton, 2003).

New land formation –

In the TRM process, inundated land of *Beel* is elevated by 1 to 2 m by sediment deposition (Kibria and Mahmud, 2010; Paul et al., 2013) that forms a new land. The agriculture is extended in new land (Tutu, 2005; Kibria, 2011; Khadim, 2013). Therefore, untilled land or open water is converted into paddy or (paddy + fish) production land. The area with removal of water-logging leads to more ecological functions and services that provide wider scope of works to improve socio-economic development (Khan, 2012; Khadim et al., 2013). This ecologically strong environment provides available jobs to the poor. Finally, the new land encourages coastal people to compete with the vulnerability of rising sea levels and land subsidence of flood plain (Kibria, 2011) and it protects them from becoming climate refugees as well (Sterrett, 2011; Paul et al., 2013). Therefore, it is an urgent indicator to form a water sustainability index.

3.2.4 Justification for the Component *Floodplain Ecosystem* and its Indicators

Floodplain Ecosystem is the fundamental component which is very much connected with river and water resource sustainability. An ecosystem is composed of physical, biological and chemical components such as soil, water, plants and animals (Maltby et al., 1996). The major indicators of floodplain such as *biodiversity, water quality, salinity* and *migration of coastal people* have been influenced by the tidal river. CEP built 139 polders which limited floodplain and adversely impacted on its ecosystem (Kibria, 2011). Convention on Biological Diversity (CBD, 1995) defines the ecosystem approach as: *"a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way"*. The floodplain ecosystem plays an important role to observe and understand its natural world and to find out the anthropogenic and environmental issues that affect it as well. In this way, floodplain ecosystems are essential for the development of SITRM.

Salinity –

Salinity is a significant indicator that measures water quality. This indicator is governed by the fresh water flow into the river, salinity concentration at the mouth of the estuary and water levels in the sea. Based on the usage of water for several purposes, the critical levels could be defined such as 0- 0.5 ppt for domestic use, 1 ppt for crops, 5 ppt for shrimps and 5-10 ppt for the Sundarbans (CEGIS, 2003a). The concentration of high salinity affects crop production, biodiversity, ecosystem services as well as livelihoods. If the river gets little fresh water flows from upstream, it will lead to salinity rise at downstream (Adri and Islam, 2012; Shampa and Paramanik, 2012). In TRM, river water flows enters into *Beel* through one opening twice a day. Simultaneously, it continues 4 to 5 years or more. Unfortunately, Boro

rice[4] production is significantly diminished due to salinity in groundwater aquifers (Adri and Islam, 2012). The installation of village protection dams is essential for safe habitats, home gardens and vegetation (CEGIS, 2003b). It is vital to maintain salinity in TRM for environmental and socio-economic sustainability.

Biodiversity –

Biodiversity is a significant indicator for wetland ecosystem as well as water resource sustainability (Sullivan, 2002). Enriched biodiversity with birds, plants, animals generates more ecological functions and services that provide more livelihood options to the community. The IUCN toolkit (Springate-Baginski et al., 2009) sets out a method for integrated wetland assessment and offers tactics to investigate the linkages between biodiversity, economics and livelihoods as an approach to river and flood plain restoration. Water-logging degrades environments with deteriorating water quality and reducing plants, animals, fishes and birds' biodiversity in flood plain area (Masud et al., 2014b).

Water Quality –

Water quality is comprised as a motive for river restoration project (Wheaton, 2005), which is an important indicator for assessing the sustainability of water resources (Sullivan, 2002; Policy Research Initiative, 2007; Juwana et al., 2009; 2010). For a better environment and good health, it is essential to ensure high water quality. Poor water quality affects the significant aspects of water resource sustainability i.e. social, economic, health and environment (Juwana et al., 2010). Maintaining the minimum standard of water quality is one of the seven essential requirements for water resource sustainability, which is publicized by Mays (2006). The concentration of TSS, pH, Nitrate, Phosphate, salinity etc. and BOD concentration are significant elements to measure water quality (CEGIS, 2003a). National Sanitation Foundation (NSF) developed NSF Water Quality Index (NSFWQI) in 1970 (Chowdhury et al., 2012; Ray et al., 2015; Ichwana et al., 2016) based on water quality parameters like Dissolved Oxygen (DO), Total Dissolved Solid (TDS), pH and Temperature (Islam et al. 2011) to measure the value of WQI. The index value less than 51 indicates bad to very bad and more than 75 indicates good to excellent (Chowdhury et al., 2012).

Migration of climate refugees –

Migration of climate refugees is in itself an indicator of water resource sustainability. An extremely ecological stressful situation is created by undesired climatic events such as rising sea levels, storm surges, flood, cyclone and their consequences such as prolonged water-logging. These climatic events push poor people into becoming climate refugees in their consequent area. It is estimated over 12% of the Bangladeshi population has been displaced (Chu, 2007). The study identifies that prolonged water-logging leads to males' migration to urban areas to search for jobs and to take part in any kind of work, leaving behind their wives and children at home (Ahmed, 2008; Adri, 2009). People are permanently displaced and settlements are reduced due to the consequences of water-logging (Masud et al., 2014a). TRM has the capacity to normalize the ecological stress and reduce prolonged water-logging within short time frames (Kibria, 2011; Uttaran, 2013 and Masud et al., 2014a).

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[4] Boro is a particular rice variety, which needs fresh water for irrigation and cultivated in May to March

3.2.5 Justification for the Component *Human Health* and its Indicators

Human Health is identified for SITRM as the significant component to assess water sustainability. Loucks et al., (2000); the Policy Research Initiative (2007) and Juwana et al., (2010) has accepted the importance of human health as a component for water sustainability frameworks in dealing with water resources. Water sustainability demands a strong management system in allocating water resources for ensuring health quality. The poor supervision of water resources has degraded the quality of health in the community of West Java (Juwana et al., 2010; 2012). There is a negative relationship not only between the accessibility of clean water (tube-well water) and water-borne diseases but also between the sanitation system and water-borne diseases (like diarrhea). Huge numbers of water-borne diseases come from both low accessibility of clean water and poor quality of sanitation systems (like sanitary latrine facilities) Masud et al., (2007-2008). Moreover, the human health component comprises of three indicators as deliberated below.

Sanitation –

This indicator indicates how many people enjoy basic sanitation facilities in a community. GOs and NGOs take initiatives to facilitate 100% sanitation coverage to people. People are not aware about proper solid waste management. They often throw waste from households and market places into the river that lead to deterioration of the rivers water quality. Safe sanitation, clean water and hygienic environments are essential to human life and its survival (Masud et al., 2007-2008). Sedimentation affects irrigation that can put pressure on ground water. Safe drinking water is now at risk due to arsenic contamination with continuously depleting ground water. Water-logging worsens sanitation and safe drinking water on a large scale (Kibria, 2011; Adri and Islam, 2012). Therefore, the inclusion of *sanitation* as an indicator of water sustainability is highly important. At this stage, no specific threshold values are available for a *sanitation* indicator.

Health Impact –

Waterborne diseases are most common in Bangladesh. At the time of Flood, surface water is contaminated by both organic and inorganic substances and this creates shortages of pure drinking water. Water-logged situations deteriorate the environment that results in health impacts such as spreading diarrhea, dysentery and skin diseases (Adri, 2009). Health impact can be measured by the number of cases affected with water-borne diseases of a community. The decline of human health will affect the efforts of achieving sustainability of water resources.

3.2.6 Justification for the component Community Participation and its Indicators

The Community Participation component is a serious demand for Sustainability Index of TRM. An indigenous practice, TRM is evolved by people in the community to tackle the vulnerability of water-logging caused by environmental hazards (Tutu, 2005) and climatic events (Sterrett, 2011). It includes five indicators: *awareness and co-ordination, compensation, land use changes, employment, rotation of TRM Beel* and *water governance.* It measures a coping capacity (Adger, 2006; Oliver-Smith, 2009) that deals with socio-economic strains and environmental events. Community people have contributed to policy change and made its

environments at a level which is fit for the system to move to the less vulnerable conditions (Nazari et al., 2015). Ramsar Handbook- 5 (2007), the Dublin Statement (1992) on water and environment and WMO (2012) have given importance to the inclusion of the communities' participation as a key component for water resource sustainability.

Awareness and Co-ordination –
Awareness and co-ordination is believed to play an important role in the sustainability of water resources. TRM is an indigenous practice of local community for river management. The communities' population who were aware of the sedimentation of river and water-logging vulnerability had taken initiatives for co-ordination in local CBOs and NGOs to apply TRM to remove water-logging crisis. TRM in *Beel* Dakatia and *Beel* Bhaina are good examples for local people's strong participation (CEGIS, 1998; PDO-ICZM, 2002; Tutu, 2005). Growing awareness and the active participation of people within the community as well as strong co-ordination among GOs, CBOs and NGOs are important issues in TRM. People with higher education levels are believed to have a better water sustainability awareness, compared to those with lower education levels (Sullivan, 2002; Juwana et al., 2009).

Compensation-
Community people sacrifice their land in a TRM *Beel* for sediment management of the tidal river for 3 or more years. Governments have paid compensation to the land owners for their crops in *Beel* Khukshia. The procedure of compensation was not effective and friendly to the poor farmers (Paul et al., 2013). Most of them did not get compensated properly and they were displeased with their Government. For this reason, at *Beel* Kopalia people did not allow TRM in proper time. Hence, an easy and effective method of compensation is essential for SITRM.

Land Use Changes –
Land use changes in the floodplain and tidal river has a great influence on water resources management. Coastal embankment and polder system in the downstream make coastal people more vulnerable by introducing water-logging than previous free tidal movement time. To cut forests for the settlement of an area provides more soil erosion in tidal river than the area which is covered with forest. In addition, water construction (dam, bridge, and regulator) leads further sedimentation in tidal river. The area of forest and vegetation begets more rainfall and permits it to infiltrate and raise the groundwater levels; besides the area of without forest has less rainfall. Nevertheless, the area is subjected by impermeable materials preventing rainfall from penetrating the ground, and increasing the volume of run off (Juwana et al., 2010). TRM removes water-logging from *Beel* with sediment deposition. Most of the fallow land of *Beels* is going under paddy, vegetable and fish production (Khadim et al., 2013). It provides grassland and fodder to cattle, and increases vegetation with continuous progress in biodiversity.

Employment–
Employment is an important indicator of economic sustainability as well as sustainable water resources management. The sustainable TRM will generate employment in agricultural,

fisheries and other sectors that reduce poverty of the community. Sullivan (2002) has proved that sustainability of water resources can effectively be achieved by reducing poverty within the community. Uttaran (2013) states TRM and inter-linking rivers will increase better agricultural and fishery practices that would ensure more jobs and employment figures. Considering TRM in *Beel* Bhaina, poverty situation has been improved as a result of the improvement in the drainage situation (Tutu, 2005; Khadim et al., 2013). Therefore, employment is an essential indicator that needs to be taken into account in developing the SITRM.

Rotation of TRM Beel –
Rotation of TRM *Beel* is also assumed to have an important role in the sustainability of water resources of coastal regions. For achieving the best results from TRM, it is essential to develop a networking system among coastal rivers with their selective TRM *Beels* (Uttaran, 2013)*.* The application of TRM will be continued rotation wise according to selective TRM *Beels* (Khadim et al., 2013; Paul et al., 2013; Uttaran, 2013). Moreover, 8 to 10 *Beels* with their connecting rivers will be identified by consultation of stakeholders to go on rotational TRM. Otherwise, the benefits of TRM will be fruitless due to huge siltation yet again after closing TRM.

Water Governance –
In the first Water Development Report, the United Nations strongly stated that the "water crisis is essentially a crisis of governance and societies are facing a number of social, economic and political challenges on how to govern water more effectively" (UN, 2003). The situation of water governance can define the management capacity of water resources that addresses numerous water related problems (Gain et al., 2012a; 2012b). Therefore, water governance is important for water resource sustainability.

3.3 Applicability of the components and indicators of Sustainability Index of Tidal River Management (SITRM)

There is no framework available to measure the sustainability of TRM because it should gradually be developed and acknowledged as an accepted technique in the Southwest region. Therefore, the SITRM as a conceptual framework is being introduced in this paper for the first time, which should be improved and implemented after incorporating experts' opinion. The study goes along with the following chronological steps illustrated in Figure 5 for making relevant the components and indicators with social, economic and environmental characteristics of Southwest region. The initial set of components and indicators should be finalized through discussion with stakeholders and water experts (Juwana et al., 2012; Chaves and Alipaz, 2007; Sullivan and Meghi, 2007). Moreover, it is significant to consider experts' opinion by involving stakeholders and experts at local and national levels for measuring the applicability of SITRM. Their positive feedbacks and insights will make the indicators and components in the step- 3 and 4 of the flowchart to be accepted fully. Figure 5 describes that step-1 has been initiated by reviewing sustainability concepts, water resource

guidelines, and sustainability indices, followed by deriving a conceptual framework. On the basis of that, the list of potential components and indicators of SITRM has been developed in step- 2, which will be used in assessing sustainability of TRM in the Southwest region of Bangladesh. A comparison with the existing social, economic and environmental characteristics of Southwest region of Bangladesh will be made to finalize the potential components and indicators in step- 3. If the components and indicators are applicable, they will be used for assessment in the next step. Further scanning will be run in step- 4 to assure sufficient data for the corresponding component/indicator. Eventually, a final list of components and indicators for SITRM will be developed in step- 5. Therefore, if the data regarding those components and indicators are sufficient, these will be accepted for the final list of SITRM. On the other hand, if the data is not sufficient for the corresponding component and indicator, it will be removed from the final list of SITRM. Construction of these components and indicators are still going on and has not been implemented yet.
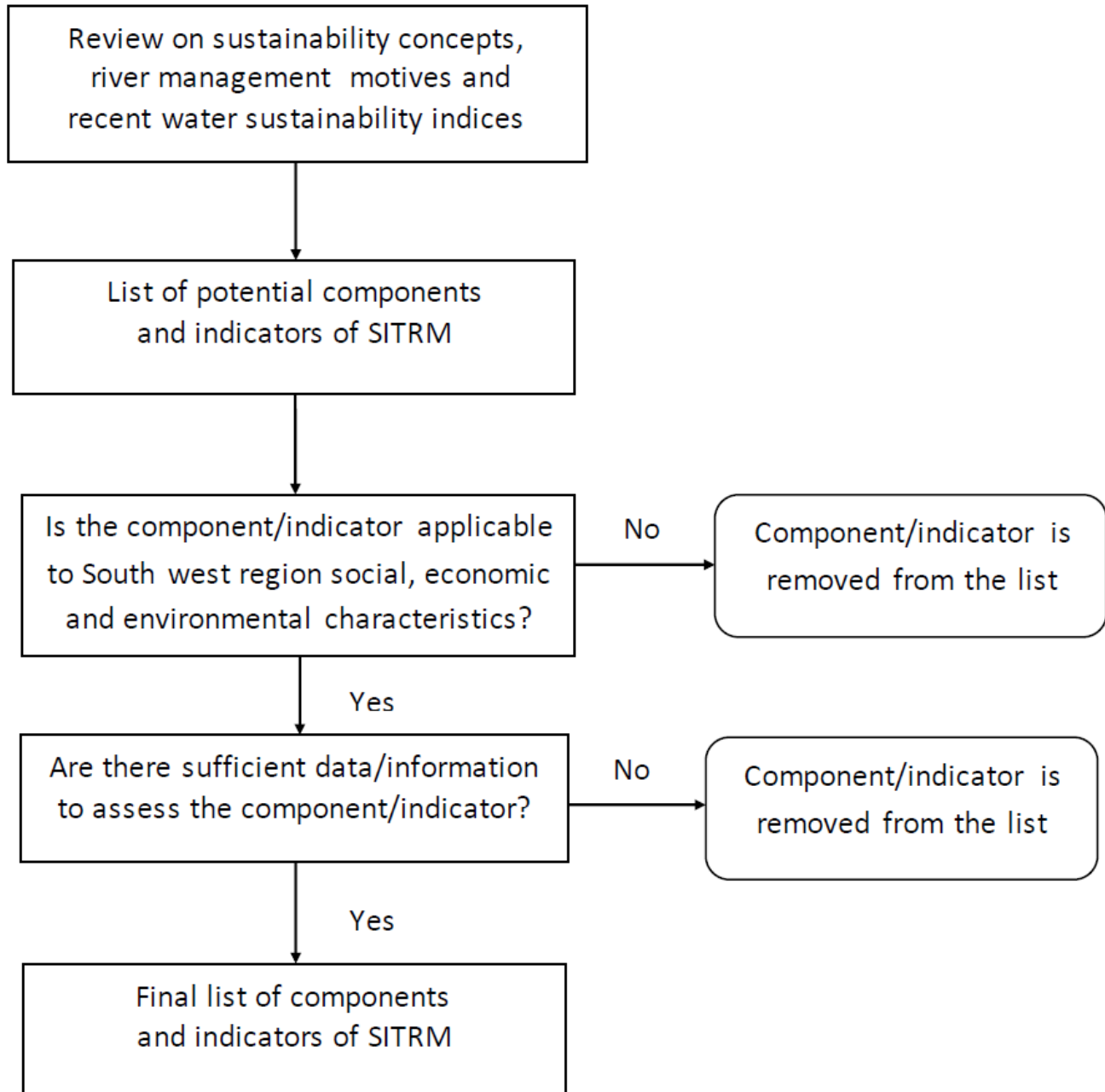
Figure 5: A Flowchart to finalize the components and indicators of SITRM (adapted from Juwana et al., 2010).

4. Discussion

This study has taken into consideration the environmental, social and economic impacts for assessing the sustainability of TRM. It discusses sustainability principles, guidelines and motives for a sustainable water resources management regarding TRM as well as the recent water sustainability indices. Moreover, for a sustainable river management, it is essential to better integrate ecosystem services and economic valuation into a superior decision-making

process. Finally, the conceptual framework for sustainability impact assessment of TRM is developed based on the Ramsar Convention Secretariat (2007) guidelines and sustainable river management strategy.

The proposed framework is supposed to enable investigators and policymakers to find out the impacts of TRM on environmental issues (water availability, water quality, salinity, sedimentation and drainage capacity of tidal rivers, new land formation, forest, biodiversity); socio-economic issues (crop production, employment, removal of water-logging, land use changes, sanitation, health impacts, migration of climate refugees); and institutional issues (rotation of TRM *Beel,* compensation, water governance) in the Southwest region of Bangladesh. Mitigating the effects of climate change is another important issue to be addressed while discussing the framework. Rising sea levels along the Southwest coast is currently 2 mm per year (Quadir, 2009). Most of the land of the Southwest region is near the Bay of Bengal. On average, it is 80 to 90 km away from the sea. The average land elevation in this region is 2 to 3 m (Mohal et al., 2006; Khadim et al., 2013). People of this region are particularly concerned about the geographic issues of this region. The framework can address this concern.

Notwithstanding the fact, this study does not incorporate few important parameters, which do not address the socio-economic and environmental issues properly in the Southwest region. Less considered parameters may be poverty, education and water demand. The present study measures the impacts by employment and crop production as a proxy of poverty as poverty is expected to be greatly reduced by ensuring employment opportunity in the region. Again, multi-dimensionality of poverty is a complex issue, which is beyond the scope of this study. Education has a positive feedback on the awareness level of people, which is linked to community participation in case of water resource management. Hence, the study selects awareness of community people instead of education. In addition to this, water demand cannot be fulfilled unless the proper justification for the drainage capacity of the river is made. Therefore, instead of water demand, drainage capacity has been chosen as an indicator in this study. But regarding the active natural and anthropogenic forces in this region, the authors have chosen the present set of parameters, rationale of which has been justified in more detail in subsection 3.2.

Firstly, the SITRM framework like the WPI has strongly linked water resources to the poor. This demonstrates that the SITRM will reduce poverty by creating job facilities and intensifying agriculture due to removal of water-logging to achieve water resource sustainability. Secondly, like the CWSI framework, the SITRM is evolved by following the principle of water sustainability, and is capable to provide benefits among coastal communities. Thirdly, the SITRM follows the WSI to integrate hydrological, environmental, life supporting and policy oriented issues for basin water management and to remove water-logging induced sewage pollution, to promote irrigation, and to increase forest's productivity by advancing freshwater flow. Fourthly, the SITRM framework can be applied in several catchments in the Southwest region to understand the current status (risks and opportunities) of water resources and to take decision for sustainable use of water resources. Fifthly, the SITRM unlikely the WPI, CWSI, WSI, WJWSI can address the water-logging, siltation, drainage congestion problems (Gain et al., 2017) and climate change issues (Sullivan and Meigh, 2005; Sterret, 2011; Paul, 2013) properly. Besides, this proposed framework includes

the integration of SWOT analysis, livelihood analysis and trade-offs analysis to measure a complete impact assessment (Hester and Little, 2013) of the sustainability of TRM, and a holistic approach will be useful for water managers and policy makers (Plummer et al., 2012) but such type of integration is not present in the Ramsar Convention framework (2007), the WMO framework (2012) and the Water Vulnerability Index (WVI) framework (Gain et al., 2012). Therefore, the proposed impact assessment framework will be more effective by evaluating livelihood assets of community people (Scoones, 1998; Ellis, 1999; DFID, 2000), the performance of TRM operation and its institutional set up. By providing strengths and opportunities or weaknesses and threats information (Nazer, 2009; Beckanov, 2010), the benefits will come from a group of ecosystem services by trade-offs (Falkenmark, 2003; Tallis et al., 2008) and by properly monetarising an ecosystem service (Springate-Baginski et al., 2009; WMO, 2012; Schagner et al., 2013; Hossain et al., 2016) with both economic and environmental value to understand risks or opportunities than those of mentioned frameworks. Sixthly, the framework will project the future vulnerability focus on water supply, ecological assessment and disaster risk reduction (Sullivan, 2010; Gain et al., 2012a; Doczi, 2014; Vollmer et al., 2016) by rainfall and weather forecast (Wu et al., 2010; Chau et al., 2010; Pallavi and Singh, 2016; Vivekanandan, 2016) as well as rainfall runoff predictions (Walker et al, 2014; Sarkar and Kumar, 2012; Mittal et al., 2012) for water-logging in the floodplain area, sediment and water flow forecast (Mostafa et al., 2012; Krishna et al., 2010; Shabani and Shabani, 2012) for drainage congestion of the tidal river and rising sea levels projections (Pashova and Popova, 2011; Rafiean and Aliei, 2013; Goharnejad, et al., 2013) for the floodplain community, tidal river and Tidal Basin. However, this type of projections are absent in the Ramsar Convention and WMO mentioned frameworks. Seventhly, the study provides significant information to understand both societal (Wheaton, 2005) and environmental motives of coastal people to address socio-economic and environmental issues for setting up TRM objectives and choosing SITRM indicators by considering of ecosystem services. Moreover, the SITRM framework follows the Ramsar Convention framework (2007) to achieve water sustainability; likely the WMO framework (2012), and the SITRM framework emphasizes the consideration of ecosystem services (Van Leeuwen et al., 2012; Dodds, 2013) to assess the sustainability impacts and it is capable to project the future vulnerability like the WVI framework (Gain et al., 2012a) by highlighting climate change issues for the coastal community, tidal river and the Tidal Basin.

Therefore, the SITRM index and conceptual framework of TRM have been introduced to solve water related problems in coastal areas. The framework can also ensure the improvement of biodiversity, extend agriculture, fisheries, and create new job facilities and employment that not only reduce poverty but also protect migration of climate caused refugees and encourage coastal people to adapt to the rising sea level in a sound environment for achieving water resource sustainability. Previous environmental and social impact assessment reports already stated that the tidal river management is environmentally pleasant, cost effective and economically feasible, and accepted to the people (EGIS, 1997; EGIS, 1998). TRM intervention as a community-based climate adaptation and the river basin management option can be ascended and simulated to bring water sustainability in the Southwest coastal region of Bangladesh (UNDP, 2011).

5. Conclusions

The conceptual framework SITRM has been developed, by integrating and organizing different sources of information and indicators, to assess the sustainability of TRM regarding societal and environmental motives based on ecosystem services. A comprehensive assessment on biophysical, socio-cultural, and monetary values should be properly integrated into this framework. Moreover, the SITRM opens a new horizon of sustainable tidal river management by involving the most discussable issues such as water-logging, 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.

The framework proposed in this paper emphasized ecosystem services to evaluate the sustainability of TRM that is important in coastal areas. It incorporates trade-offs between alternative strategies of water resources management. This study is not without any limitations. This study is purely theoretical and the proposed framework needs to be tested and validated in the field and improved accordingly. The SITRM, itself is a conceptual framework based on theoretical approach. The study involves reviewing relevant papers, field survey and local stakeholder consultations to select SITRM indicators and components but not to derive skilled opinion from experts. Therefore, the major components, indicators and their threshold values of the SITRM index may be accepted, modified or deleted by experts' opinion. Besides, other components or indicators may be added for the improvements of the SITRM with the skilled knowledge of experts. Furthermore, the study does not set standard threshold values for the *drainage capacity, biodiversity, rotation of TRM Beel* and *water governance* indicators with lack of experts' opinion. It is essential to undertake case studies for the field test. Therefore, the effectiveness of the SITRM for measuring the sustainability of TRM will be evaluated. Moreover, it will make changes in SITRM components and indicators for further improvements of this framework. In addition, the researchers may use the SITRM framework for integrated water resources management, integrated coastal zone management and disaster management regarding tidal river management. Furthermore, the study generates a few new components and indicators that may stimulate researchers to conduct further research towards evaluating the effectiveness of water resource sustainability indices. The SITRM includes rotational TRM, which is mostly implemented and more popular and accepted than fixed TRM or compartmentalizational TRM or clustering TRM (EGIS, 1998). In fact, this framework is applicable only to the management of tidal rivers in the coastal region. Therefore, another research in case of non-tidal river and non-coastal area would need further attention.

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