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Research Article

Tide Management in the Elbe River and Changes in Ecosystem Services

H. O. Mangi

College of Social Science and Humanities, Department of Development Studies, Sokoine University of Agriculture, P. O. Box 3024, Morogoro, Tanzania

Correspondence should be addressed to H.O. Mangi; halima.mangi@suanet.ac.tz

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Flood currents (tidal pumping) have led to the increase of transportation of sediments to the river's upper estuary. In the tidal section of the Elbe River, more sediment is transported to the upper estuary with flood currents (tidal pumping) related to tidal asymmetry. This process contributes, amongst others, to dredging in order to obtain the water depth required for navigation safety. Cognizant of the above problems, construction of shallow water area is planned in order to reduce tidal asymmetry while improving ecological integrity at the tidal Elbe areas. The study on which this paper is based was conducted to assess ecological integrity and ecosystem services before and after the shallow water creation. Habitat identification and quality ranking were conducted for current habitat, while model habitats representing future state (after shallow water creation) were designed using HEC-RAS model simulation. The assessment matrix was used to assess ecological integrity and ecosystem services provisioning of the study area's habitats before and after the shallow water creation, using potential indicators. Results indicate that there is increase in the ecological integrity after the project implementation. Based on the above explanation, it can be concluded that the measure will increase the flow of ecosystem services after its implementation.

1. Introduction

Ecosystem goods and services are vital for human well-being [1]. By definition, ecosystem services are the benefits that human obtain from the ecosystem [2, 3]. They provide human with necessities as food, fresh water, and less obvious services such as flood protection and spiritual and recreational services [4–6]. The services have supported growth and progress of the human population [4]. Recent findings by MA show that around 60% (15 out of 24) of the ecosystem services are being degraded [2, 3]. Although there are some arguments that the degradation has resulted in an overall gain of human well-being at the present, the damage made may bring costs to the future generation [2]. Estuaries and the associated services are among the degraded ecosystems worldwide. Estuaries and Coastal areas are the most productive areas on Earth, providing many development opportunities [7]. Among the degraded ecosystems and the associated services worldwide are the estuaries and coastal estuaries, which are the most productive areas on Earth, providing many development opportunities [7]. They are influenced by marine and freshwater conditions that make them biologically critical areas providing high biological niches to biodiversity [8–10]. Since historical times, estuaries have been attractive for settlements to people. Currently, they are reported to be the most populated areas, accommodating most of the largest cities in the world [11–13]. They have been used for port building since industrial periods to allow communication between human settlements for trading purposes including transport of raw materials and finished goods [14]. It was recently reported that degradation on the estuaries ecosystems has significantly increased in the last 150–300 years [15, 16]. Analysis further indicates that 65% of wetlands and sea grass habitats have been destroyed, and 90% of marine species have disappeared due to human disturbances [2, 17]. The rate of ecosystem and services degradation and their impact on development strategies have culminated for the need to integrate ecosystem services management with economic development strategies. The best way to make decisions about development that explicitly considers ecosystem services and reduces trade-offs across services is required [17]. Therefore, decision makers need to reconcile development goals and ecosystem services through building on existing experience with multiple use of ecosystem [4]. The ecosystem services approach has recently emerged as a new scientific approach, which seems to promise prevention of the ecological problems caused by human land uses [3]. It is a practical approach, which allows assessment of the connections between ecosystem services and economic development on a project basis [5]. While suggesting indicators and metrics that could increase chances of no group suffers a welfare loss, at least one group experiences a gain [18–20]. It emphasizes the role of a healthy ecosystem in the sustainable provisioning of human welfare, economic development, and poverty alleviation [18, 21]. The ecosystem services approach interprets human in relationship with the ecosystem and encourages decision processes that integrate and balance ecosystem protection with land use goals [17, 22–24]. This approach also encourages conservation of the ecosystem by providing services for people's livelihood sustenance [22]. According to Boumans et al. [25], the approach is suitable for management of estuaries because it helps researchers and managers to synthesize important ecological and economic concepts; it uses the latest available economic methods for economic valuation and allows scientists and policy makers to use the concept to assess social and political trade-offs between development uses of the estuary and conservation.

The study on which the paper is based used the ecosystem services approach to determine changes in ecosystem services, following the creation of shallow water area as tide management measure along Elbe Estuary. The Elbe Estuary and the port are facing high tidal energy and tidal asymmetry causing tidal pumping and accelerated sedimentation, which in turn interferes with the shipping safety [26]. High tidal energy erodes sediments from the sea/coast and transports them to the upper estuary whereas weak ebb tidal currents take less sediment back to the sea/coast [27]. This phenomenon creates a tidal pumping effect [26], hence causing more sediment transport upstream, amongst which is the port basin. Therefore, sedimentation in the port basin is the net sediment transport from the North Sea [28, 29]. Among the causes of the high tidal energy reported are the widening of the funnel shaped Elbe River mouth, deepening of the river channel, river banks straightening, and loss of the flood plains [26, 30]. These problems are partly due to the biogeophysical modification of the river/estuary [2]. Modifications occurred at different stages during which at the early days convention of estuaries wetlands to agricultural farms through filling took place [5, 31]. Later, river deepening and widening were necessary in order to accommodate the ever-increasing oversea going ships [14].

The above-mentioned modifications seem to have been necessary and will continue to be so in the future following the importance of the estuary for economic development and shipping requirements. In addition, their use is more likely to increase in the future [14]. These issues present enormous challenges to the port management and the society, because of consequences of all of these modifications. In particular when they are purely engineering they lead to changes in ecological structures and functions of the estuary/river hence leading to changes in its capacity to provide ecosystem services. Dredging is currently used as a measure to control sediments at the port basin [32]. However, it is ecologically and economically costly. Objectives of the study on which the paper is based included, first, assessing the ecological integrity of the ecosystem before and after the planned management measure implementation and, secondly, assessing the relevant capacity of the study area's habitat to provide ecosystem services before and after the shallow water creation (see Figure 2).

2. Materials and Method

2.1. Study Area. The Elbe River is one of the largest rivers in Central Europe. It has a length of about 1.100 km and a catchment area of almost 148,268 km [33]. The river catchment is shared between Germany, Czech Republic, Austria, and Poland. One-third of its length falls within Czech territory while two-thirds of its length is found within Germany. Some small catchment areas fall within Austria and Poland [34]. The river source is in the Riesengebirge (Krkonoše) mountains, in the Czech Republic. The river discharges its water in the North Sea, near Cuxhaven. As it flows through the Czech Republic, to the northern and central part of Germany, it passes through some major cities, like Prague, Dresden, and Hamburg that form part of the river catchment. Despite human influence, the Elbe River cape still has many near-natural parts [35]. Along the river from the Riesengebirge to the North Sea, there are more than 200 areas under different protection status including some, which are protected for international significance (biosphere reserves) [34, 35]. The last 140 kilometers of the river are tidal influences, forming the Elbe Estuary. In this section of the river, there are about 30 nature-protected areas under the national law. The National Park, Hamburgisches Wattenmeer, is one of these areas [33]. The tidal condition makes unique wetland habitats and biodiversity with unique flora and fauna, including some species that are endemic to the area [36]. The alluvial forests, mudflats, and reed areas of the estuary provide habitats for resident and migratory birds. Populations of seals and Porpoises (*Phocoena phocoena*) also occasionally forage on some parts of the estuary. The study site is located in the freshwater part of the tidal section of the Elbe River, Kreetsand's area in the southwest of Hamburg City at the eastern edge of the Wilhelmsburg Island [37]. This space was used as spoil field in the past, and it was behind the dike until 1999 when the flood protection dike was shifted further to the west. The site includes the riparian flood plain forest, which is one of the rare habitats of the Elbe Estuary [27]. The planned tidal shallow water area has recently been included in the Nature Protection Area with expectations of its implementation.

2.2. Methodology

2.2.1. Habitat Identifications. Status of current habitats were identified from the Environmental Impact Assessment Report, which was conducted by the authorized agency (BBS Office Greuner-Pönicke). Further habitats identifications and classification were done through surveys. Information about the habitats was supplemented by using relevant habitat maps, for instance, Hamburg habitats maps and species distribution maps of Germany and Europe. Species field guides, available literatures, and interviews to the experts in the field were utilized to gather information about the status of the habitats. Biodiversity (fauna groups) and species activities level for the present habitats also were determined from Environmental Impact Assessment Report and field survey in the study area. Future habitats were obtained from the model habitats designed after the Hydrologic Engineering Centers and River Analysis System (HEC-RAS) model simulation. Model simulation was carried out to determine hydrology, sediments transport, and depositional characteristics in both the Elbe River and the shallow water [38]. Model simulations were carried out for different shallow water area designs, involving different inlet diameters and shallow water features depth. Numbers of inlets and outlets were also varied ranging from one to three. The aim was to determine a design which will bring best outcomes regarding the primary target of the shallow water area.

2.2.2. Habitats Quality Assessment and Ranking. Both the present state and the future habitat were assessed for their quality using combination of criteria. The criteria used for the present habitats quality assessment were level of habitat deterioration by human, biodiversity, presence of species with high protection status, and the extent of the use of the habitat by the major fauna groups. These major fauna groups were birds, bats, mammals, insects, fish, reptiles, and amphibians. Criteria used for future habitats quality assessment were the predicted level of disturbance on the habitat through management activities, number of the benefiting species, and the conservation significance of the benefiting species (including their protection status). The combination of the above criteria was used to develop habitat quality ranks. For present states, the habitats with a high level of deterioration, no detectable biodiversity, and no fauna activities were ranked 1: very inhabitable. The habitats correspondent to a high level of deterioration, a low biodiversity level, and no fauna activities were ranked 2: inhabitable. The habitats with a medium level of deterioration, a relatively medium biodiversity, and a medium activities level were ranked 3: less habitable. The habitats with a medium level of deterioration, relatively high biodiversity, and medium activity level were ranked 4: habitable, and habitats with low level of deterioration, relatively high level of biodiversity, and high level of fauna activities were ranked 5: very habitable. Similar combinations were applied for the future habitats. Finally, habitats five ranks were obtained for both present and future state habitats.

2.2.3. Identification of Potential Indicators for Assessment of Ecological Integrity and Ecosystem Services. A set of potential indicators for assessment of habitat ecological integrity and the relevant capacity for the provision of the ecosystem services were derived based on the features that show ecosystem health status and ecosystem services supplied to the people [39]. At least one indicator was derived for each ecological integrity component or the ecosystem service.

2.2.4. Assessment of Habitats Ecological Integrity and Relevant Capacity for the Ecosystem Services Provision. The ecological integrity and the ecosystem services provisioning relevant capacity of Kreetsand's habitats were assessed using the assessment matrix. The assessment matrix used was adopted from [3, 23, 24]. This matrix is a two-dimensional matrix that consists of columns and rows, which together forms grids into which information was entered. The matrix in this case is served as a platform for gathering essential information about habitat's relevant capacity to provide ecosystem services. The ecological integrity components and the ecosystem services were placed on the first top raw of the matrix grids and habitats on the first column of the matrix grids. The ecological integrity of the habitat and relevant capacity of the habitat to provide corresponding ecosystem services were assigned based on the experts judgments. The expertise judgment referred to the utilization of the expertise knowledge on the ecosystem, to assess the relevant capacity of the habitats to provide ecosystem services in association with the functions and structures of that ecosystem. The judgment was supported by some relevant data about the ecosystem services in the study area. Some of these data obtained from the HEC-RAS (model) are simulation results, the Environmental Impact Assessment, the Elbe River water quality monitoring data, the historical maps for the study area, the habitat quality information, and Some of these data obtained from the HEC-RAS (model) are simulation results, the Environmental Impact Assessment, the Elbe River water quality monitoring data, the historical maps for the study area, and the habitat quality information. In addition, potentiality of the habitat to provide ecosystem service compared to other habitats found in the study area such as the potential of a deep zone habitat to prevent floods through floodwater storage was obtained through expert judgment and benefit transfer method [40].

Values from 0 to 5 were assigned; 0 represented no relevant capacity on provisioning of the ecosystem service; 1 represented a very low relevant capacity; 2 represented a low relevant capacity; 3 represented a moderate relevant capacity; 4 represented a high relevant capacity; and 5 represented a very high relevant capacity. The same range of values was applied to the assessment of the ecological integrity. Initially 9 assessment matrices for habitats before and after creation of shallow water area were generated through consultations of expertise from different background. The aim of the consultation of expertise with different background was to benefit from professional experiences regarding ecosystem services. For instance, habitat relevant capacity to provide services related to hydrology, for example, nutrient retention and sediment regulation, was assessed better by the experts with hydrological background. Results of these matrices were used to produce the final assessment matrices for both present and future state habitats.

(1) Ecosystem Services Assessment Framework. Ecosystem services assessment strategy is the analysis of landscape

information to determine its capacity to provide ecosystem services [23, 24]. This assessment usually focuses on human being as beneficial exploiting agent. Ecosystem services assessment has an extensive literature on diverse aspects. Assessment methodologies and techniques used also vary widely; however they are mostly conducted in multidisciplinary approach [41]. Some frameworks have developed to suggest approaches for ecosystem services assessment but there is none which stands alone as a complete set to follow during ecosystem services assessment. Nevertheless, each of these frameworks provides guidelines, which can be used to assist in the assessment strategies. A system-oriented framework (DPSIR; drivers, pressure, state, impact, and response) is one of the best-known structured frameworks, which summarize the interaction between ecosystem, socioeconomic activities, and human decisions on land uses [42, 43]. DPSIR is a powerful framework for implementing the ecosystem services approach since it communicates the interactive link between human-wellbeing and ecosystem services; ecosystem processes and structures [14, 44] interpreted the DPSIR framework for applying ecosystem services concept to natural resource management in Australia. They started with stakeholder driven ecosystem services inventory and linked them with ecological, social, and economical factors through utilization of multidisciplinary knowledge and techniques. Bauman's et al. [14] interpreted DPSIR framework to develop integrated conceptual framework for the assessment of ecosystem services in coastal areas. This conceptual framework shows structured link between drivers on the land and their consequences on the ecosystem services provisioning and the society responses [45]. Drivers on the land like human activities and natural phenomena put pressure on ecosystem functions and structures, which leads to changes in the states of ecosystem [45]. The new state of ecosystem may have impacts on human welfare, which can be taken to mean reduced ecosystem services provisioning. The impacts trigger the society responses to the impacts either through formulation of policies, which change land use or technology [25]. This framework uses indicators to communicate feedback at every point; hence it can be used to derive indicators for ecosystem services assessment. From this framework, important steps for ecosystem services assessment can be deduced. The land where human activities take place (pressures) can be identified as a starting point, and its state (ecological integrity) is assessed to determine the capacity to supply ecosystem services (impacts). Management measures implemented to improve services or to provide an alternative to ecosystem services are the societies' responses at different levels. The assessment strategy employed in this study utilizes the structure- oriented framework (DPSIR).

(2) Ecosystem Services Assessment Matrix. Ecosystem services assessment matrix is one of the tools used together with large information and presents it in a summarized manner that is communicable to users in various backgrounds. It links land cover information with ecosystem services while allowing the use of potential indicators for assessment [3, 23, 24, 45]. Burkhard et al. [23, 24] used ecosystem services assessment matrix to apply multiple techniques for assessment of the land cover capacity to provide ecosystem services in Halle-Leipzig region. A set of defined ecosystem services was connected to the Corine land cover information through potential indicators to assess their provisioning. They used 2-dimensional matrix, with ecosystem services arranged on the first top raw and the Corine land cover on the first column. The relative capacity of the land cover to provide ecosystem services was assigned in the corresponding cell. The relative capacity values were assigned based on the expert judgment.

In the millennium ecosystem services (2005), a similar assessment matrix was used to assess relative magnitude of ecosystem services derived from various wetland ecosystems. Cell size was used to represent the magnitude of the service provided per unit area of the wetland (2005). Abel et al. [46] used similar assessment matrix method to decide whether different land uses scenarios based on impacts bring ecosystem services in the Goulburn broken catchment in Australia. Multidisciplinary stakeholders using multicriteria performed judgment on the level of impacts. A choice preferred land use scenario for the catchment was made based on the assessment scores. Meas et al. [45] also used assessment matrix to assess impacts of trade-off between ecosystem services. Prioritized ecosystem services were put on the columns and other potential ecosystem services provided by the flood plain on the rows. Color was used to represent the trade-off impact level. Green color represented positive impact and red color represented negative impact. The color intensity implied the strength of the impact. Multistakeholder options were used to assess impacts level between trade-offs.

3. Results and Discussions

3.1. Habitats' Identification and Quality Ranking

3.1.1. Present State Habitats and Quality. Fourteen habitats were identified in the present state of land cover and ranked accordingly as presented below.

(a) *Tide Riparian Forest*. The willow floodplain marsh with tidal influence; it includes the floodplain 30 areas within the study area and 100 m wide from riparian forest which extends through the riprap in the southern section where it is bound by the Elbe River. This habitat ranked 5 and is considered very habitable.

(b) *Willows of the Wetlands, Shores, and Moist Site*. This represents the seminatural thickets found in the narrow and wet places. The habitat occurs along the water-edge and forms part of the riparian forests and consisted of mainly willow bushes and wickers; it ranked five, hence very habitable.

(c) *Modified River Section (Straightened and Its Banks Reinforced with Riprap)*. This habitat is found at the north of the Elbe River. This habitat ranked 2, that is, inhabitable.

(d) *River Mudflats*. They are muddy to sandy areas with tidal influence. Periodically dries up, found at the lower reaches of the river. The area was frequently flooded and its vegetation was limited to algae; the habitat ranked 5, thus very habitable.

(e) *Tide Reeds (Reed Flats)*. They are areas dominated by tidal reeds community protected from wind and waves and relatively undisturbed. Tidal influenced by reed bed in the study area was about half covered with closed reed plants and marsh marigold (*Caltha palustris*). This habitat was interlocked with tidal floodplain forest areas. In the study areas, this habitat was found at the lower laying area alongside the Elbe River mainstream. The wetlands species weevil grass (*Notaris bimaculatus*) was also present. The habitat ranked 5, that is, very habitable.

(f) *Tidal Ditches/Channels*. They are the excavated artificial tidal channels with silt and no vegetation on it. They occurred at different angles joining the river stream. Tidal influenced habitat was dominated by reed bed. About half of its area was covered with closed reed plants and marsh marigold. This habitat ranked 2: inhabitable.

(g) *Paved Areas*. They represented areas paved by brick, concrete, or stones; these were of less significance as habitats for animals and plants. The area included the slightly hardened roads on the dike embankment within the project area. Others included access routes, passages for walking, cycling, and slightly paved paths crossing dike and the slopes alongside the river. This habitat ranked one, thus very inhabitable.

(h) *High Moisture Nutrient, Rich Herbaceous Sites*. Moist tall herbaceous vegetation is found on nutrient rich sites, humid, moist to wet clay soils or on more mineralized peats in wetlands and low-bog areas. This habitat type occurred only on small areas near the NSG Rhee, which seemed to receive high nutrient loading. Species found were nitrophytes and semiruder. It ranked 5, that is, very habitable habitat.

(i) *Species Poor Intensively Cultivated Willows*. This habitat was observed to be continuously grazed and dominated by ryegrass (*Lolium perenne*) which has an economic importance and was regarded highly productive in terms of pasture for grazing. Intensive use of fertilizer and herbicide in the past favored Lolio-Cynosuretum species survival; the species is therefore dominant in the area. This habitat type is found at the basement of the new dike. Though the habitat provides pasture, it was poor and inhabitable and ranked 2.

(j) *Semiruderal Grass and Shrub*. A semiruder grass at older stages of succession on fallow and mesospheric area, which was formerly disturbed through human activities, dominated the habitat. It was found on the slopes and lateral areas of roads. The vegetation was dominated by mixed stands of ruderal mugwort (*Jacobaea vulgaris*), flat meadows, and pastures species such as hawthorns (*Arrhenatherum natheretalia*). This habitat ranked 2, that is, inhabitable.

(k) *Moist Ground Semiruder Grass and Shrub*. Habitat with mostly vigorous growing perennial ruder and related matting herbs (*Galio-Urticetea*) represents moisture plants like *Phragmitetalia australis* and *Molinia caerulea*. This habitat ranked three corresponding to less habitable.

(l) *Riprap*. Bundles of coarse material covered the land. These were found at the embankment of the Elbe River and the junction areas of channels and at some places near the old dike. This habitat is found to be very inhabitable with rank of 1.

(m) *Dike*. It is embankment near the paved area made for controlling water during high tides. In the study area, dike is found along the river channel. The dike was found very inhabitable ranking 1.

(n) *Individual Tree*. The outstanding trees represent the species traits by size and age; there were three older multistemmed poplars trees standing in a line at the north of the area. Significant species of this habitat was *Populus canadensis*. The habitat is found inhabitable with a rank of 2.

3.1.2. Future Habitats Model. Eleven habitats (11) were identified from the model habitat generated by HEC-RAS. The future model habitats were divided into vegetated and nonvegetated aquatic habitats. Vegetated habitats will be formed from the extension of the presented vegetation, for example, the tidal forest and tidal reeds. Nonvegetated habitats including mudflats and deep water zone are tidal dependent habitats. Some habitats will appear and disappear depending on the high tides and low tides. Location of the habitat at high tides is presented in Figure 1.

(a) *Tidal Riparian Forest*. It will be found between +2.2 m and +2.5 m asl. It will form an extension of the existing riparian forest along the Elbe River. It will be a functional habitat within tidal floodplain and priority habitat of low land tidal forest habitat type. It will be a valuable habitat for the key species such as aspenduline (*Auriparus flaviceps*), holes breeder species (e.g., Woodpeckers (family *Picidae*)), and bats, for example, Nathusius bat (*Pipistrellus nathusii*). This habitat will rank 5 that is very habitable the same as adjacent riparian forest.

(b) *Tidal Reeds*. Marshes are covered by reed plants; this will form an extension of the existing tidal reed habitat. It will be found at the altitude of +2.5 m above sea level right from the riverbanks towards the tidal, shallow water area. Reed plant species are reported to be tolerant to frequent and relatively long duration flooding. Hence, they are suitable for this new transformation of the site. This habitat will be an essential habitat for breeding birds such as reed warblers a migrant bird between Africa and Europe. This habitat was designed to provide a habitat for the Hemlock (*Conium maculatum*) and fennel (*Foeniculum vulgare)* (priority species) plants and reed breeder bird species such as reed bunting

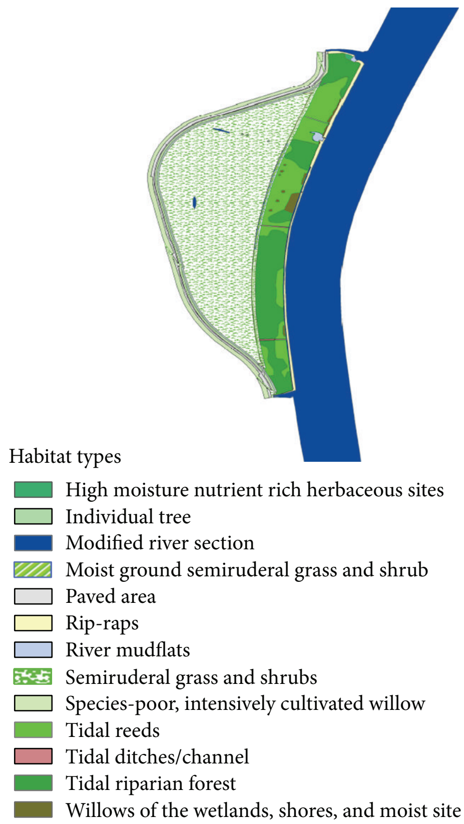

Figure 1: Map of Kreetsand's area showing habitat types before the shallow water area construction.

(*Emberiza schoeniclus*). It will also be a momentous habitat for beetles and black butterflies species. This habitat will rank 5 that is very habitable.

(c) *Deep Zone Creek*. This habitat will be formed at mean water level of 3 m below sea level at shallow water area. It depends on the rise and fall of water level. During high tide flow, the depth of 3 m below sea level will be attained, and hence this habitat was formed. It will provide a habitat for indicator species such as sea lamprey (*Petromyzon marinus*), river lamprey (*Lampetra fluviatilis*), and salmon (*Salmo salar*) [7]. It will also provide habitat for young fish of bream and associated species (*Abramis brama* and *White bream*), asp (*Aspius aspius*), and feint (*Alosa fallax*) [47]. This habitat will be found at the center of the study area, replacing half- ruder grass and shrubs. This habitat ranked 3, thus less habitable.

(d) *Shallow Water Area*. This habitat will depend on tides. It will be formed at water level of 2.5 m below sea level at the shallow water area. It will be adjacent to the deep zone. Shallow water habitats will be highly productive, anticipated to function as nursery areas for nekton like sea lamprey (*Petromyzon marinus*), river lamprey (*Lampetra fluviatilis*), salmon (*Salmo salar*), shellfish, and crustacean species [47]. It will provide habitat for foraging and protection from predators. It ranked 5, thus very habitable habitat.

(e) *Tidal Creeks*. It is a tide dependent habitat, which will be formed when the mean water level at the shallow water area reaches 0.2 m above sea level. It will provide a habitat for lamprey species (*Petromyzon marinus and Lampetra fluviatilis*) and Salmon (*Salmo salar*) [47]. Habitat ranks 5, that is, very habitable habitat.

(f) *Mudflats*. This will also be a tide dependent habitat. At low water level bigger area of mudflat will be exposed, and vice versa. It will be nonvegetated wetlands with varying productivity determined by the adjacent habitats. Adjacent marshes may provide organic matter to mudflat microbial populations [48]. The organic matter from marshes is essential for nutrient cycling in the mudflat and shallow water area in general. It is expected to be functional habitat for crabs, snails, and mud tubeworms. It will also function as foraging habitat for ducks (family *Anseranatidae*), sayer, gulls (family *Laridae*), and plover (one of the species, golden plover (*Pluvialis apricaria*)). However, during high water it will be a foraging space for fish (especially for indicator species and associated species of bream). The habitat ranked 5 that is very habitable.

(g) *Thin Sand Area*. This habitat will occur together with the mudflat. It will sustain high abundance of invertebrate prey and will be a critical foraging area for migrating shorebirds. It ranked 5, very habitable.

(h) *Modified River Section*. This habitat currently exists and will exist after project implementation at the study area. However, its rank will shift from 2 to 3 after shallow water creation, due to anticipated habitat quality improvement. These will include water quality improvement and tidal energy reduction.

(i) *Paved Areas*. This feature/habitat currently exists and will exist after the project implementation. Its quality will not change after project implementation as well.

3.2. Changes in the Ecological Integrity of Kreetsand's Area

Biodiversity. At present state, a large area has low biodiversity because it comprises high proportion of poor habitat quality [49]. Large area of Kreetsand ranks 1-2 (very inhabitable to inhabitable). Species distribution correlates with resource availability; present habitats have few resources for food and shelter, and they are often used by few species of birds and mammals described as the guest users of the area mainly for a short time foraging or hunting. Birds and other animals with a high-developed foraging and energy budget strategies are not willing to risk their energy to forage in this area [50]. There are few nesting or breeding activities in the area compared to the high quality neighboring habitats such as the tidal forest, the willow bushes, and the tidal reeds [51]. Future habitats will be thoroughly managed for high quality; hence they will accommodate high diversity of species. At present, habitats are highly altered and lack naturality, which is important for many species. River channelization, for

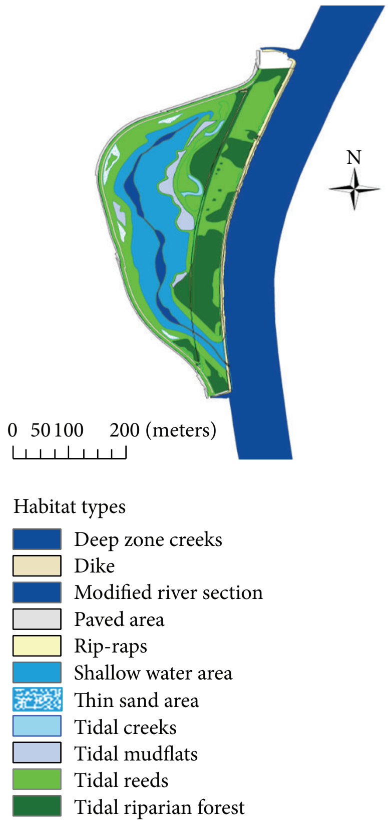

Figure 2: Map of Kreetsand's area showing model habitat types to be formed after the shallow water area construction.

instance, removed river backs naturality and habitat diversity. The channelization combined with riprap revetment keeps the riverbanks isolated from its riparian wetlands, hence reducing the exchange of water, sediments, nutrients, and the organisms between the main channel and the riparian habitats. Cooper et al. [52] reported that the juvenile salmon preferred the natural riverbanks to the riverbanks reinforced with the riprap despite the high abundance of the invertebrates on the riprap side. The channelization also reduces the ecological niches of the river through increased water flow and reduces nutrient uptake by the macrophytes over the riverbanks [52]. A study by Cordell et al. [31], which covered the habitats restoration in the Snohomish River estuary, where the floodplain was reconnected to the river through dike breaching, found that the physical and biological conditions at the site were improved soon after the tidal reestablishment.

Abiotic Heterogeneity. Microclimate elements associated with the shallow water area establishment will potentially increase biotic heterogeneity of the area. The soil moisture content rise, plants, and the temperature regulation at the tidal shallow water area improve and increases niches for a variety of species [53]. Biological processes of the tidal shallow water area will provide a rich foundation for the food chains that lead to an increase in a variety and abundance of the organisms [53].

Energy Capture. Some of the habitats in the present state such as the tidal reeds/reed flats, tidal riparian forest, modified river section, high rich moisture nutrients, herbaceous sites, moist ground, semiruder grass, and shrub have high to very high relevant capacity for energy capture (Figures 3 and 4). Modified river section relevant capacity for energy capture was assessed based on the chlorophyll concentration measured at Zollenspieker (kilometer 598) between 2004 and 2009. It was assessed to a high relevant capacity, which suggested that primary production was high in the river section and it was related to microphytes production (green algae). However, high microphytes production (green algae) is the indication of eutrophication. According to Verney et al. [29], high concentration of chlorophyll and organic matter promotes diatom bloom. Verney et al. [29] reported diatom blooms at average chlorophyll, concentration of 100 μg/L, and particulate organic carbon concentrations of 3 mg/L in the Seine Estuary in France. The concentration of organic matter in which algae bloom occurred in the Seine River which is at the same range with chlorophyll-a concentration was measured in the modified river section of Kreetsand's area (60–120 μg/L per year). However, organic matter concentration at the Kreetsand's area was three times higher (9.5 per year) than that of Seine River. The shallow water area construction provides space for organic matter uptakes (reduction) hence reducing the risk of eutrophy in this section of the river. The high energy measured at the modified river section therefore is due to high concentration of chlorophyll which is also due to high concentration of organic matter. This suggests that energy is not a good indicator of ecological integrity improvement after the construction of the shallow water area because it seems that there will still be organic matter input from upstream.

3.3. Kreetsand's Habitats Ecosystem Services Provisioning Capacity Changes. From the HEC-RAS model habitats, results indicated the increase in the ecosystem services provisioning capacity after construction of the shallow water area. However, changes vary from one group of the ecosystem services to the other. Details are discussed per ecosystem service group as follows.

3.3.1. Provisioning Services. Provisioning services differ slightly between the two phases. Water for navigation measured by total cargo handled per year remained unchanged between the two phases. The river section is providing water for navigation and service is already very high. Creation of shallow water will have some positive impacts on the navigation service (e.g., sediment reduction) but will not influence the increase of the navigation activities. The increase of navigation activities in the future is independent of the management measure implementation because there is already an increasing trend of the navigation activities with time each year This service is accessed by some of the regions in Germany and the Czech Republic

Land cover	Ecological integrity	Biodiversity	Energy capture	Biotic heterogeneity	Provisioning services	Food: animals	Water for industrial use	Water for navigation	Regulation services	Climate regulation: carbon sequestration and burial	Regulation extreme events or disturbance: flood water storage	Regulation extreme events or disturbance: wave reduction	Water quantity regulation: drainage of river water	Water quantity regulation: dissipation of tidal and river energy	Water quantity regulation: landscape maintenance	Water quantity regulation: transportation	Water quality regulation: reduction of excess nutrients coming from the catchment	Erosion prevention	Sedimentation regulation; maintenance of the river channel depth	Cultural services	Aesthetic values	Opportunities for recreation & tourism	Inspiration for culture, art, and design	Information for cognitive development
Tidal riparian forest	4	5	5	3	0	0	0	0	2	4	0	4	2	4	0	0	2	4	2	3	4	3	3	3
Willows of the wetlands and moist site	4	4	4	4	0	0	0	0	3	4	3	4	3	4	4	1	0	4	4	3	2	3	3	3
Tidal reeds (reed flats)	4	4	4	4	0	0	0	0	3	4	3	4	3	4	4	1	0	4	4	3	2	3	3	3
Individual tree	2	1	4	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	2	3	2	2	2
Modified river section	2	1	4	1	2	0	0	5	2	1	5	1	0	1	4	5	3	0	0	2	1	4	1	3
Rip-raps	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	1	5	0	1	0	0	0	3
Mudflats	2	2	1	2	0	0	0	0	2	3	2	3	3	3	3	0	3	0	3	2	2	1	3	2
Tidal ditches/channel	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	2	2	1	2	1
High moisture nutrient rich herbaceous sites	2	2	3	2	0	0	0	0	1	0	1	1	0	0	1	0	3	2	0	1	1	1	1	1
Moist ground semiruder grass and shrub	2	2	3	2	0	0	0	0	1	1	2	0	2	0	1	0	1	0	4	2	1	1	2	2
Semiruder grass and shrubs	1	1	2	1	0	0	0	0	0	1	2	0	1	0	0	0	1	0	0	1	2	1	1	1
Species-poor, intensively cultivated willow	1	0	2	1	0	0	0	0	0	1	0	0	0	0	0	0	0	2	0	0	0	0	0	1
Paved areas	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	1	5	0	1
Dike	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	3	0	3

Figure 3: Assessment matrix showing ecological integrity and ecosystem services flow capacity for each habitat type before shallow water area creation.

which is a landlocked country using the Elbe River to access the oversea ports.

3.3.2. Changes in Regulation Services

Climate Regulation: Carbon Sequestration and Burial. The assessment of this ecosystem service was based on three ecological processes governed by the introduction of water in the area. First, it is the rewetting of the area, which lowers carbon dioxide emission due to the principle that water inhibits organic matter decomposition. Second, it is the extension and conservation of the tidal forest with potential of carbon sequestration and, third, it is shallow water volume that forms peat land and stores carbon in the soil [54–57]. Generally, water creates anaerobic condition in the soil due to low oxygen diffusion and low temperature [5, 55]. The large area of Kreetsand at present state (semiruder grassland) is supposed to emit carbon dioxide based on theory that decomposition rate on the top soil is relatively high [58]. According to Förster et al. [57] areas once occupied by peat lands and then converted to agricultural areas are simply transformed from a carbon sink into a carbon emission source. Therefore, they have a potential of emitting up to 20 Mio t CO_2 per year. Moreover, Abberton et al. [59] have reported that carbon loss was high from top soils across England and Wales. Therefore, the shallow water area establishment will reduce chances of carbon emission and has potential of acting as the carbon sink [60].

Water Quality Regulation: Reduction of Excess Nutrients Coming from the Catchment. Shallow water areas habitats (floodplains/wetlands) have relevant capacity for nutrients retention and can thereby enhance water quality of the river [61–63]. Floodplains increase retention capacity due to velocity lowering and hence increase the time for nutrients uptake by plants and nitrogen gas released through denitrification in the sediments [64]. The shallowness of water area allows

Land cover	Ecological integrity	Biodiversity	Exergy capture	Abiotic heterogeneity /contribution to a total area	Provisioning services	Food: animals	Water for industrial use	Water for navigation	Regulation services	Climate regulation: carbon sequestration and burial	Regulation extreme events or disturbance: flood water storage	Regulation extreme events or disturbance: wave reduction	Water quantity regulation: drainage of river water	Water quantity regulation: dissipation of tidal and river energy	Water quantity regulation: landscape maintenance	Water quantity regulation: transportation	Water quality regulation: reduction of excess nutrients coming from the catchment	Erosion prevention	Sedimentation regulation/river channel depth maintenance	Cultural services	Aesthetic information	Opportunities for recreation & tourism	Inspiration for culture, art, and design	Information for cognitive development
Tidal riparian forest	4	5	5	3	0	0	0	0	2	4	2	4	2	4	2	0	0	4	2	4	4	3	3	4
Tide reeds (reed flats)	4	4	4	4	0	0	0	0	4	4	4	5	4	5	4	4	5	4	4	3	2	3	3	3
Deep zone creeks	3	3	3	3	2	0	0	5	4	0	5	5	5	5	5	5	4	0	3	3	3	3	1	3
Shallow water area	4	4	4	4	2	0	0	5	4	2	5	5	5	4	5	5	5	0	3	3	3	3	1	3
Tidal creeks	4	4	3	4	0	0	0	0	4	2	5	5	5	5	5	5	5	0	3	3	3	3	1	3
Thin sand area	2	3	0	4	0	0	0	0	1	2	3	2	0	2	2	0	3	0	0	3	3	3	1	3
Modified river section	3	2	4	2	2	0	0	5	2	1	2	2	0	0	4	5	4	0	0	2	1	4	1	3
Rip-raps	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	1	5	0	1	0	0	0	3
Mudflats	2	2	1	2	0	0	0	0	2	1	3	3	3	3	3	0	3	0	3	2	2	1	3	3
Paved areas	1	0	2	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	1	5	0	3
Dike	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	4	0	3

Figure 4: Assessment matrix showing ecological integrity and ecosystem services flow capacity for each habitat type before showing water creation.

light penetration that will be sufficient for aquatic plants photosynthesis. Photosynthesis produces oxygen, required by microorganism for organic matter decomposition, hence reduction of nutrients in the water [61–63]. Therefore, implementation of Spadenlander Busch/Kreetsand's project will increase water quality through increased surface area (shallow water area) for nutrients removed.

Regulation Extreme Events or Disturbance: Water Current Reduction and Regulation of Water Quantity and Dissipation of Tidal and River Energy. These services are influenced by estuarine hydraulic forces originating from the coast/sea (leading to horizontal and vertical water movement patterns), morphology of the river and its riparian features, and vegetation of the river floodplain. Currently, riparian forest, reed bed, willow of moist ground, tidal channels/ditches, and mudflats habitats have high relevant capacity to dissipate river energy and reduce wave's length and tide amplitude [65]. Vegetated habitats create roughness that provide resistance to high energy tidal waves with high wavelength and speed. They also slow down speed and reduce wavelength [54]. Vegetation increases sediment settling on floodplains through reducing flow velocity by increasing surface roughness where water currents flow [66, 67]. Nonvegetated habitats such as mudflats and tidal channels also provide space for the tidal energy dissipation [54]. However, currently the contact between river water and these potential habitats for reduction of tidal energy is limited because these habitats are spatially small and isolated from the river channel. Future habitats have more potential to dissipate tidal energy and reduce tidal currents due to the connection with the river. Future habitats are designed to increase roughness at the periphery of the shallow water area to increase resistance, reduce tidal energy, and hence dissipate energy. The shallow water, deep water, and tidal creeks also provide space for tide energy dissipation and hence reduce tide-pumping effect [68]. HEC-RAS model results show that the shallow water area has potential to dissipate tide energy for about 286170 meters. Shallow water area also has the potential to reduce wavelength by 2.6 cm. This value is relatively low compared to the 3.63 m tidal range in the river channel, but the fact that this small unit of the area has showed this potential is a sign that tidal floodplains have relevant capacity to regulate tidal energy and hence reduce tide-pumping effect.

Regulation Extreme Events or Disturbance: Floodwater Storage. Based on data from the HEC-RAS model, the shallow water area has the capacity to store 880,000 cubic meters of water. Therefore, the assessment indicates the potential of the shallow water area to take excess water in case of an extreme flood event. The shallow water area will increase water infiltration in the soil and hence increases soil water retention capacity [65, 69, 70]. Like other wetlands, shallow water will prevent flooding by holding water in its soil and vegetation [70]. During high water levels and storms, shallow water area will capture and store water and slowly release it back when water level is low thereby reducing the impact of flood [69–71]. Studies have indicated that flood peaks of areas without wetlands can be as much as 80 percent higher compared to similar areas with wetlands [72]. A study by Reinhardt et al. [73] reported that 65,000 m^3 wetland reduces peak flow by 48% and delayed the flood peak for 6 to 10 hours. The water retention ability of the wetland also facilitates groundwater recharge (aquifer recharge) [68]. In addition, shallow water area vegetation, emergent aquatic vegetation, reed vegetation, and tidal forests act as flood defense by slowing down the downstream passage of flood peak by increasing surface roughness [65, 66, 74].

Sedimentation Regulation: Maintenance of the River Channel Depth. Shallow water areas have the relative potential to reduce sediment transportation through the reduction of tidal energy. Shallow water area provides space for energy dissipation and hence reduces forces that could push sediments to the upper estuary. Reduced tidal energy allows sediment settling downstream. Tidal energy dissipation on the shallow water area will lower the deference between tidal flow and ebb flow and hence will reduce tidal asymmetry. The reduction of the tidal asymmetry will reduce tidal pumping effects and hence reduction of the upstream sediment transportation. Some of the sediment will be collected in the shallow water area, for instance, deep zone area, since tidal flood velocity at the deep zone will be low. Therefore, settling velocity of sediment this zone will be high. However, sediment accumulation in the deep zone will cause management constraint in the shallow water area, since it will require being removed. On the other hand, vegetated habitats of the shallow water area will have potential for sediment trapping [69, 75]. Despite the potential of the shallow water area to regulate sediments, the contribution to the overall sediment transport problem is very small due to the small size of the planned shallow water area.

Water Quantity Regulation: Landscape Maintenance. This ecosystem service is indicated by proportion of modified river features versus possible natural river features of river network [42]. The study based its assessment on the availability of the floodplains as one of the natural features of the river. Therefore, all features that increase moisture transfer from the river channel to the periphery contribute to landscape maintenance. The shallow water will provide space for water from the river to the periphery, thereby transferring moisture to the landscape.

3.3.3. Changes in Cultural Services. The Elbe River and the coast of the North Sea are of great cultural significance; hence, communities around the area wish to protect it for heritage. The significance covers both the fantastic landscapes and organisms. Tidal freshwater is one of unique habitats of the Elbe River basin with high biodiversity. Protection of these areas is protecting cultural heritage of the Elbe River basin for present and future generation. As mentioned earlier, the project area will be part of the Rhee Nature Reserve with the expectation of its ecological improvement after the shallow water creation. The area will be reserved for cultural heritage and recreational activities as part of the Rhee Nature Reserve. The following are cultural services changes expected in the study area as per assessment.

Aesthetic Information. This cultural service is attached to biodiversity and the beauty of the landscape. The assessment indicates that there will be improvement of aesthetic value of the study area after the creation of shallow water because the shallow water creation is associated with habitats improvement. Most of these habitats are important for the survival of endangered species that are culturally significant. The new habitats that will be created are also important for indication of species of the Elbe Estuary. Generally, the future state of Kreetsand area will have a better landscape and more biodiversity hence more aesthetic information for recreation, culture, and studies.

Opportunity for Recreation and Tourism. The tidal section of the Elbe River is used for recreation activities by local people including cycling and quiet recreation activities as were recorded during EIA exercise. These activities have potential of increasing in the future due to potential additional attraction of bird diversity, butterflies, fish, and the beauty of the landscape. Wetlands are biological supermarkets. They provide food to many animal species. These animals use wetlands as part of their life cycle. When wetland plants die leaves and stems break down in the water and form small particles of organic materials. The organic materials feed many small aquatic insects, shellfish, and small fish that are food for larger predatory fish, reptiles, amphibians, birds, and mammals. Ultimately, animals increase biodiversity and attraction for recreation and tourism activities to the site.

Inspiration for Culture Art and Design. Elbe Estuary is a part of communities' culture. Therefore, conserving ecosystem contributes to conservation of the culture. Elbe Estuary is a part of the Elbe River; it is a culture and symbol of unit; for instance, recently the Yuhana-Elbe River Project was launched to provide the opportunity for culture and art connecting people of India and Germany; the two rivers are used as symbol of culture and art connection. Ecological improvement of the Elbe River is protection of cultural inspiration, art, and design. Diversity of birds of the Elbe River basin is widely used as cultural inspiration and art in the region.

Information for Cognitive Development. Ecosystems, their components, and processes provide the base for both formal and informal education in many societies. The Elbe River including its estuaries is one of most studied areas. The project will attract studies after its completion. This study is one of the examples. The assessment also relied on the Lippenbroek, a similar project that has attracted many researchers after its implementation [76]. Most researchers speculated on what had happened after the shallow water area was created [77].

4. Conclusion and Recommendation

This study has utilized several methods and techniques together and analyzed and interpreted information about Kreetsand's habitats, ecological integrity, and ecosystem services over two periods, that is, before and after the shallow water area was created. Generally, results show that there will be an increase in the ecological integrity of Kreetsand's area after the creation of the shallow water. The increase is due to the transformation of poor quality inhabitable habitats (rank 2), namely, ruder grass, shrubs species, and poor intensively cultivated willows to the high quality habitats (ranks 4 to 5). High quality future habitats include shallow water area, tidal reeds flats, mudflats, tidal creeks, thin sand areas, tidal reeds extension, and tidal forest that will extend from the existing tidal forest. Based on the hypothesis made concerning the effect of the project on the ecological integrity of the area, the management measure implementation will have positive effects. Moreover, based on the assessment of the relevant capacity of the study areas habitats to provide ecosystem services over two periods it can be concluded that there will be an increase in regulating services and the cultural services after the shallow area creation but there are no significant changes in the provisioning services. Habitat quality provides more useful information for the ecosystem services supply assessment than a habitat type itself. There is a high connection between the ecological integrity of the habitat and its capacity to provide ecosystem services. Therefore, this study concludes that the project will increase the flow of ecosystem services benefit after its implementation.

A follow-up research is recommended some years after shallow water creation to assess if there will be some diversion from the expectation in terms of the ecological integrity and ecosystem services flow. Due to benefits associated with connection of the river to the flood plains, projects of this nature are recommended.

Competing Interests

The author declares no competing interests.

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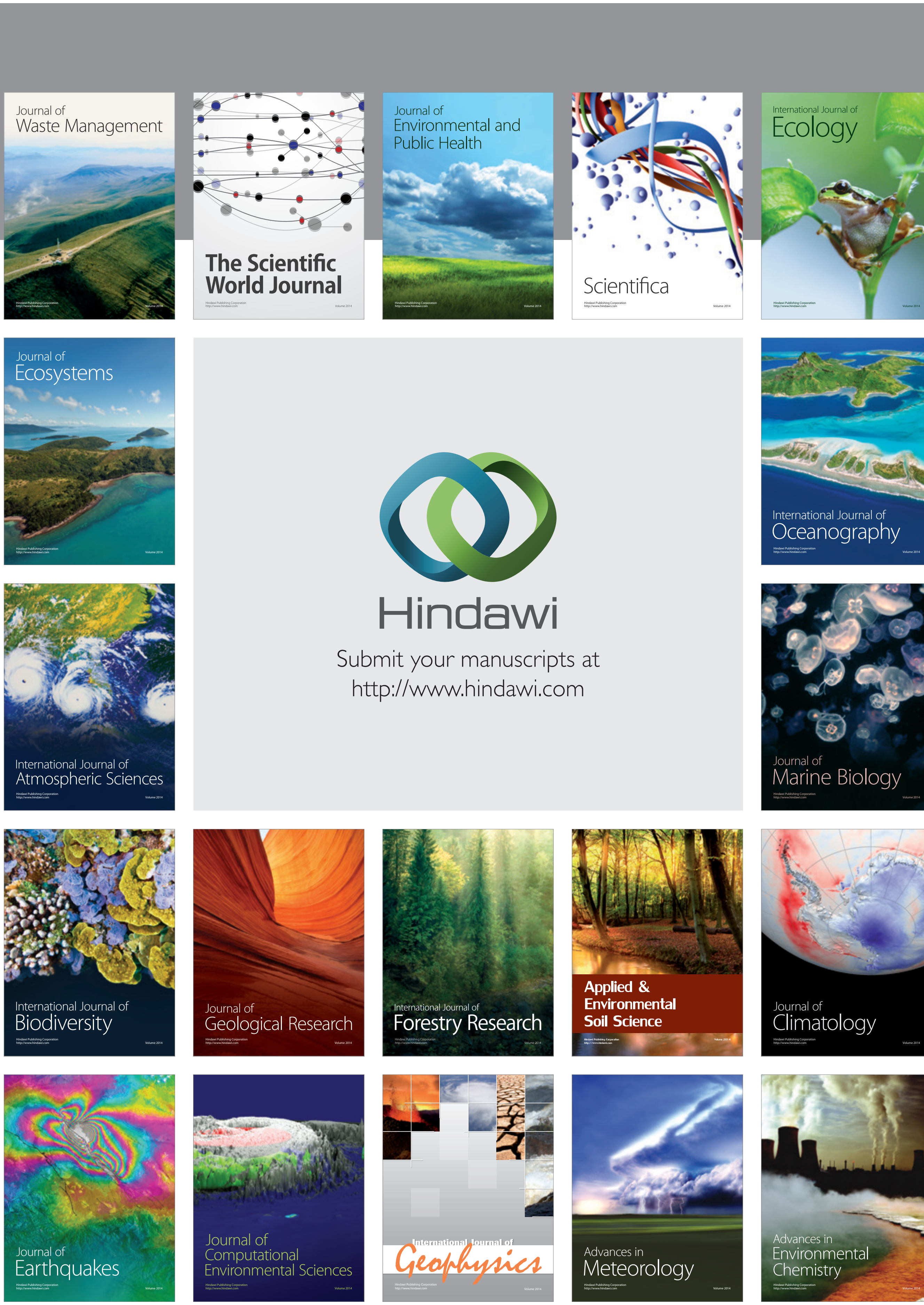
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