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Sustainable Management of Aquaculture and Water Footprint Analysis in Sunderban

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Abstract: India is the world's second-largest producer of fish, where the state of West Bengal is leading in fish production. The Sundarbans, located in the southern part of India's West Bengal state, is a UNESCO-designated world heritage site. The Indian Sundarbans is a tide-dominated region in the southern part of deltaic West Bengal, and is home to 4.43 million people. Even though it is traversed by numerous creeks and rivulets and receives a significant amount of precipitation during the monsoon season, freshwater is a scarce resource in the Sundarbans. During the dry season, there is a lack of fresh water above and below the ground, increasing siltation results in shallower channels, high salinity of the water and soil, and congestion in drainage making it difficult for people to make a living. During the dry season, most blocks experience water scarcity as a result of the ever-increasing population's demand for water. According to this study, Sundarbans' current annual domestic and drinking water demands are 105.1 mcm and 8.08 mcm, respectively. By combining the area under various crops and their lifecycle water requirements, the water demand for agriculture has been calculated to be 2782.83 mcm. The rainfall-runoff modelling aims to get a general idea of how much fresh water is available each year through surface runoff. It has also been estimated how much water is available from different sources in each block. It is estimated that deep and shallow bore wells contribute approximately 400 mcm, whereas surface water sources like tanks and canals contribute approximately 50 mcm. The communities that live in the Sundarbans eco-region benefit greatly from aquaculture's contribution to their socio-economic development. For the sustainable development of aquaculture in the Sundarbans Delta, strong technical, financial and extension services from government organisations and research institutions are urgently required to meet these obstacles. Additionally, this study emphasises that roof-top rainwater harvesting in this region has the potential to supply 45 mcm more water, which could be used to partially satisfy the region's domestic water demand. Future major policy options for meeting the Sundarbans ecoregion's water demand include large-scale rainwater harvesting, rejuvenation and reconnection of disconnected river channels, artificial recharge of shallow aquifers to lower their salinity, and de-salination of shallow groundwater.

Keywords: Monsoon; Siltation; Dry-season; Aquaculture.

Introduction

According to Rudra (2009), the world's water supply is constrained, and its demand is rising. The world's rivers are highly variable and erratic. Rainwater is the most unpredictable over time, and groundwater is also vulnerable to overexploitation (Bhadra, 2013). The water situation of the "critically vulnerable" Indian Sundarbans (ISD) eco-region, more commonly referred to as Sundarbans Biosphere Reserves (Govt. of India, 2011a) is a region on the Ganges-Brahmaputra delta's tidally active western edge. Despite its numerous creeks and rivulets, Sundarbans does not have a lot of fresh water. Sundarbans receive a significant amount of

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precipitation, but it is not properly utilised to meet the water needs of the Biosphere Reserve's 4.43 million inhabitants, who live in 19 administrative blocks. The goal of this study is to determine how much freshwater is needed and how much is available for wise and long-term water resource management. The Sundarbans Biosphere Reserve covers a total of 9630 square kilometers, with a block area of 5367 square kilometers and a reserve forest area of 4263 square kilometers (Hazra et al., 2015). A core area and a buffer area make up the second subdivided portion of the forest area. The habitation area is broken up into 19 community development blocks, 13 of which are in the South 24 Parganas district of West Bengal and 6 of which are in the North 24 Parganas district. The ecosystem services provided by the Sundarbans and its rivers are important to the people who live in the ISD habitation area. The hydrological conditions of its rivers determine the current flow of freshwater into the Sundarbans (Hazra et al., 2015; Mirza, 2006). Due to siltation at off-take, the majority of rivers have lost their connections to their parent rivers, and monsoonal run-off alone now maintains their estuarine character (Bhadra et al., 2014; Cole and Vaidya Raman, 1966; Gopal and Chauhan, 2006). In the ISD, most of the rivers are salty. Except for confined aquifers that are only a few meters thick, the groundwater is also saline. Only at depths, greater than 250 meters is fresh groundwater accessible (CGWB, 2006; Sinha Ray, 2010). River influent discharge frequently causes saltwater intrusion into groundwater (Bhadra et al., 2013). The salinisation of the soil and aquifer makes farming difficult and taints drinking water sources (Hazra et al., 2014). High soil and water salinity, drainage congestion, and a lack of surface or groundwater during the dry season are all contributing factors that make it extremely difficult for the Sundarbans' inhabitants to earn a living (Hazra et al., 2015). The "Indian Sundarbans" in West Bengal state is the world's largest delta. It is made up of two districts in the extreme south, North and South 24 Parganas, consisting of 54 islands, and 19 blocks. The "Indian Sundarbans" span a total of 9629 km^2, of which 4493 km^2 are inhabited by humans and the remainder are reserved forests. The total population is approximately 37.56 lakhs. Only six of the 19 blocks are located close to the river's mouth, and the remaining 13 blocks are considered to be inland. Sundarbans is the result of the Ganga and its tributaries becoming sedimentary.

Since the late 1980s, aquaculture has experienced significant growth in global fish production, from 32.4 million tons in 2000 to 66.6 million tons in 2012, a compound annual growth rate of 8.8% (FAO, 2014). India is the second largest fish producer in the world after China. In 2012, landlocked India produced 3.8 million tonnes of farmed fish and fish products (FAO, 2014). The spread of aquaculture as a viable and cost-effective alternative to capture fisheries has been driven by the steady decline of stocks, the energy crisis, and the high cost of fishing (Ayyappan et al., 2000; Ayyappan and Jena, 2001; Pillai et al., 2004). India's domestic production increased from 5.7 million tons in 2000-2001 to 6.2 million tons in 2013-2014. Aquaculture accounts for about 70% of domestic production. West Bengal accounts for about 30% of inland fish production in India. Inland aquaculture production in West Bengal increased from 0.88 million tons in 2000-2001 to 1.39 million tons in 2013-2014 (Government of India, 2014). The main objective of this study is to identify different methods of development of aquatic resources in the estuaries and coastal areas of Sundarbans to demonstrate the significant impacts of this development and to develop appropriate Environmental Management Plans (E.M.P.) to ensure the future with the sustainable environment for development. This study highlights possible solutions that can be implemented to find alternative ways to provide drinking water to the average person. This study also recommends some suitable methods to improve freshwater availability through sustainable water management and to maintain ecosystems and livelihoods in changing climate scenarios.

Literature Review

According to Bandyopadhyay and Basu (2017), a major issue that arises when freshwater supplies are insufficient is water scarcity. Surface water bodies including rivers, lakes and other bodies of water provide freshwater that can be used by humans (TWAS, 2002). Also, from aquifers freshwater, resources are being exploited worldwide due to an expanding population. Because it is easier to access, surface water is utilised more frequently than groundwater. However, in areas without access to clean surface water, groundwater becomes the only source of potable water. According to UNESCO (2015), at least half of the world's population requires potable water from groundwater. According to Bhat (2014), India's domestic water demand is anticipated to rise by 40% over the next 10 years, from 41 to 55 trillion liters. According to Bhat (2014), India's per capita water supply will decrease by almost 36% in 2025 and 60% in 2050 compared to the level in 2001 (The Ministry of Water Resources, Govt. of India).

Rudra (2009) has estimated the water requirements for drinking and domestic use in West Bengal. According to the same study, in 2001, West Bengal needed 0.088 billion cubic meters (bcm) of water for drinking and 1.981 bcm for domestic use. By 2051, the demand for domestic and drinking water would be 0.131 bcm and 3.215 bcm, respectively (ibid.). However, there are no studies on water demand, availability, or accessibility in the SBR region. Therefore, sustainable water resource management in the vulnerable delta necessitates an assessment of the demand, availability, and accessibility of potable water. The majority of the Sundarbans' freshwater comes from rainwater. Sundarbans get most of their rain from the South-West monsoon. It typically begins between the middle of June and the second week of October. According to Dasgupta (2008), the average annual rainfall is 1625 millimeters, but it can reach 2000 millimeters in a high rainfall year and 1300 millimeters in a low rainfall year. The estimation of run-off has been carried out to assess the availability of water in the Sundarbans. Groundwater is the Sundarbans' primary, source of potable water. In the Sundarbans, the quality of the groundwater varies over time. According to Sinha Roy (2014), electrical conductivity (EC) in shallow aquifers ranges from 2960 to 16688 s/cm at 25°C, while chloride (Cl) concentrations range from 1854 to 13581 mg/L, indicating that shallow groundwater is brackish to saline in nature. The pH of the shallow groundwater ranges from 6.73 to 7.64, indicating that it is neutral (Sinha Roy, 2014). Deep groundwater has a pH between 7.4 and 8.1. As a result, the deep groundwater is slightly acidic. According to Sinha Roy (2014), the EC and Cl in the deep aquifer range from 915 to 3960 s/cm at 25°C and 64 to 1255 mg/L, respectively. It demonstrates the relative freshness of the deep groundwater. Sinha Roy (2010, 2014) claims that deep groundwater is drinkable and the quality meets BIS drinking water standards. However, according to Sinha Roy (2014), the quality of shallow groundwater is above the BIS's permissible limits. According to Mukherjee (2009), calcium bicarbonate and sodium chloride are the two most common types of water in deltaic West Bengal. The coastal shallow aquifers of the North and South 24 Parganas undergo significant chemistry alteration as a result of saline water intrusion (Mukherjee et al., 2007b; Mukherjee and Fryar, 2008). The amount of water that is needed for agriculture during Rabi and summer crop cultivation is far less than the amount of water that is available from surface and groundwater sources. The available water holding capacity of the existing tanks is also significantly less than what is required for Rabi cultivation. Food production is hampered when fresh water is scarce, posing a threat to food security. Food insecurity affects 87.5% of Sundarbans residents annually. The significance of biodiversity in the Sundarbans Ecosystems can be found on many different scales throughout the universe (Mather, 1986). In the one-of-a-kind bioclimatic zone of the Sundarbans, the Mangrove Ecosystem is found both on land and in estuarine water. It is made up of extremely diverse plant and animal communities that are closely intertwined in a symbiotic relationship called the Mangrove Food Web. A random collection of prawn seedlings for commercial aquaculture, destruction of other non-commercial seedlings, damage to the fish population and their habitats caused by modern gear, coastal water pollution caused by industries, etc.; indiscriminate removal of mangroves for fuel wood and fishing boats; are gradually reducing this food pyramid's broad base, putting the lives of all top consumers in danger. At the final stage, this human intervention in nature will undoubtedly endanger their very existence.

Discussion

Because the rivers and shallow groundwater in the Sundarbans are saline and fresh groundwater is difficult to extract, the area lacks potable water. Due to siltation at their off-take point, the major rivers in the SBR—Saptamukhi, Thakuran, Matla, Bidyadhari, and Ichhamati—have been cut off from their parent rivers (Bhadra et al., 2017). As a result, the rivers that are disconnected do not receive freshwater flow from the region upstream (ibid). The only source of potable water in the Sundarbans is deep groundwater, which is found at a depth of more than 300 meters below the surface. The Sundarbans people rely on this water for their daily needs. However, groundwater cannot be used for anything other than drinking due to the fragile coastal ecosystem. The government says that groundwater can only be withdrawn manually through an ordinary well between 200 and 500 meters from the high tide line (HTL), which is 200 meters away (Govt. of India, 1991b, 2011c). According to the study, the region's demand for potable water is rapidly rising alongside population growth. When compared to 1991, demand will rise by 2.5 times by 2051. According to CD block-wise estimation, the demand for potable water was highest in Patharpratima in 1991 and will be highest in Canning I by 2051. Sinha Roy (2014) estimates that the deep aquifer's annual groundwater flow of 18.25 mcm would not be sufficient to meet the growing demand for potable water in the future. The wells that draw fresh water from deep aquifers in the Sundarbans' northern and central CD blocks have water levels within 4 meters. The southern Sundarbans blocks have water levels higher than 7 meters. This is because the deep aquifers slope to the south. Arsenic contamination harms the quality of the groundwater in the northern blocks as a result of excessive groundwater use for agriculture and other purposes. The potability of water in SBR is limited by poor water quality.

The majority of the Sundarbans population gets their water from a hand pump. The sources of water aren't always easy to find. To make potable water in SBR more readily available and accessible, the government of West Bengal has begun some groundwater-based piped water supply programs that are intended to eventually serve 2.75 million people. However, these plans are insufficient to meet the anticipated demand for potable water in 2051. As a result, switching to treated surface water, roof-top and large-scale rainwater harvesting, artificially lowering the salinity of the shallow aquifer, and setting up RO plants to desalinate the sediment-free and less saline shallow groundwater (Hazra et al., 2015; World Bank, 2014) might be useful for managing the SBR's supply of potable water.

Although the effects of climate change can be seen all over the world, India is particularly vulnerable due to its large population, excessive demand for natural resources, and relatively weak coping mechanisms. Warmer temperatures, rising sea levels, and possibly more frequent and extreme weather events like tropical cyclones, hurricanes, and heat waves are among the expected effects of global climate change. One of the most vulnerable areas to sudden climate change is the Sundarbans, which are in the southern part of West Bengal, India, and Bangladesh. They are on the delta of the Ganges, Brahmaputra, and Meghna rivers in the Bay of Bengal (Mandal et al., 2019). For adaptation and mitigation strategies to maintain food production in this island's ecosystem, it is important to know the trend of long-term weather variables that affect the climate. According to climate change projections for India, temperatures will rise by 1-4°C and precipitation will change by 9-16 % by the 2050s (Krishna Kumar et al., 2011). The rise in the frequency of extreme events like droughts, floods, and cyclones is another significant aspect of climate change. These normal changes will unfavourably affect the environment's delicate areas like forests, horticulture, and waterfront biological systems and the accessibility of water for various purposes and human well-being (Table 1). WWF-INDIA has extended a rising pattern in surface temperature (0.019°C per year) for the Sundarbans locale and anticipated that more than 1.3 million individuals will be impacted by the ocean-level ascent and super durable submergence of expanses of land, storm floods, and beachfront disintegrations (WWF-India, 2010). Statistical data shows that mean temperature during summer is 28.17°C and during winter is 22°C (Table 2). Even though there are only a few monsoon months when the area gets a lot of rain, most of it ends up in the ocean as runoff, clogging the low-lying agricultural fields and causing widespread waterlogging. Extensive information on environmental changes and related variation procedures through water reaping is urgent for the advancement toward maintainability.

Waste Disposal in Indian Sunderbans due to Festivals

Around 1 million explorers across India combine to wash up at the intersection of the Hooghly estuary and the Bay of Bengal during January every year. Due to this mass-scale bathing, the water quality is negatively impacted by excessive turbidity, low levels of chlorophyll, and low dissolved oxygen. There is a significant decrease in the diversity and abundance of phytoplankton and microzooplankton tintinnids. The celebration goes about as numerous stressors, changing the normal elements of the delta. To keep the protection-use ratio in balance, effective and long-lasting management strategies must be implemented.

Possible Solutions

The sustainable management of this region's water resources may benefit from the combined use of these water sources. The steps that can be taken to guarantee

Table 1: Trend analysis of long-period rainfall distribution and rainy days of Sundarban region

Rainfall (mm)	*Total annual*	*Pre-monsoon (March-May)*	*Monsoon (June-September)*	*Post-monsoon (October-February)*	*Rainy days*	*Extreme rain*
Minimum	1030.8 (1970)	12	803.6	34.3	59	0
Maximum	2461.3 (1979)	663.9	2070.1	604.2	105	4
Mean	1821.2	239.4	1355.0	226.8	84.4	1.4

Table 2: Statistical analysis of temperature trend during Summer months and Winter months at Sunderban

Parameters	*Summer months (April-October)*	*Winter (November-March)*
Minimum Temp. (°C)	24.22	15.85
Maximum Temp. (°C)	31.67	27.46
Mean Temp. (°C)	28.17	22.00

that the water in the Sundarbans is clean are outlined below:

(i) Rainwater Harvesting
During the monsoon season, the Sundarbans receive sufficient rainfall. To meet Sundarbans' water requirements, this rainwater can be conserved. Rainwater that was collected (Gayen, 2013; Mondal, 2014)) can be used for both domestic and recreational purposes with the right treatment. One of the main ways to lessen the problems with water in Sundarbans is to harvest rainwater on a large scale. Additionally, the existing canals must be renovated. This will help store a lot of rainwater, which could be useful for growing crops. Additionally, rainwater harvesting prevents excessive groundwater resource exploitation.

(ii) De-Salination and Artificial Groundwater Recharge
Excess rainwater in a shallow aquifer can be artificially recharged to lower its salinity. This method may, over time, reduce the salinity of shallow aquifers, allowing them to be used for agriculture and domestic use (Gayen, 2009). The Sundarbans Development Board (SBD) has taken some steps to build infrastructure related to water in the Sundarbans. To provide salt-free water in this region, a few solar pumps and RO plants for desalination were installed (Press release, Government of India, 7.5.2015). The RO plants, on the other hand, were unable to produce potable water because the river water had a high concentration of silt and high salinity (>15 ppt). In the Sundarbans, sustainable water resource management may benefit from combining the use of ground and surface waters. The decayed river channel restoration (Bhadra et al., 2014) is necessary to guarantee the flow of freshwater upstream. Field and remote sensing research have revealed 11 of these significant disconnections (Bhadra et al., 2014) in the Sundarbans' feeder river system. Additionally, large reservoirs can be constructed in several degraded tidal rivers to harvest rainwater. River Research Institute, Government of West Bengal, researched the construction of a closure dam at Saptamukhi's mouth (Delf Hydraulics to GoWB, 1968). The construction of a freshwater reservoir to supply the necessary fresh water for various consumption purposes was one of the project's most important components.

(iii) Commercial fishing has had a significant impact on the Sundarbans' biosphere and caused severe environmental degradation, according to extensive field research (Bhaumik et al., 1992; Banabithi, 1996; Das, 2002).

Conclusion

Drinking water in the Sundarbans is under pressure due to increasing demand and limited supply. Deep groundwater is the only source of drinking water in the region because rivers and shallow groundwater are saline in nature. The estimated drinking water demand in the SBR was 12.93 mcm in 2011 and 22.68 mcm in 2051. Existing water sources and estimated annual groundwater discharge through deep aquifers is 18.25 mcm, which is not enough to meet the water needs of future population growth. Nearly 76% of households in the SBR use hand pumps and about 45.44 households have to walk more than 500 meters to get domestic water. Freshwater springs are not easily accessible in the Sundarbans. Groundwater quality is not always drinkable. In the northern blocks of the Sundarbans, arsenic contamination of freshwater aquifers affects the quality of groundwater present at a depth of 100 meters of water. Shallow groundwater in the SBR is affected by saline intrusion. Deep groundwater may also be affected by saline intrusion in the near future due to the over-exploitation of groundwater in the area. About 164 groundwater-based piped water supply systems have been deployed by the government in the Sundarbans of West Bengal to improve the availability and accessibility of drinking water. However, these initiatives are not enough to meet the drinking water needs of the growing population in the near future. Therefore, to improve the availability and accessibility of drinking water, switch to treated surface water, rainwater harvesting, artificial replenishment of shallow aquifers, and desalination of shallow groundwater, the shared use of surface and groundwater can be useful in the Sundarbans. The Sundarbans region of India has great potential for developing freshwater aquaculture despite some limitations. Freshwater aquaculture development in Sundarbans focusses on carp farming. It is practiced mainly in backyard ponds. Aquaculture is also practiced in large ponds (owned by individuals or several households), earthen ponds (mainly dug for agricultural irrigation purposes), and high-altitude flooded rice fields. The application of modern and scientific technologies will improve fish production and meet the region's need for subsistence. Over-dependence of aquaculture on specific species should be avoided and emphasis should be placed on species diversification. The addition of high-value species should also be considered. The link between seafood production and the weak effective marketing and processing systems in the Sundarbans region needs to be strengthened to provide better returns for farmers. Potential changes in tidal patterns and salinity regimes would have implications for the brackish water aquaculture prevalent in this region. To face these challenges, aquaculture in the Sundarbans needs to be supported by appropriate regulatory and institutional frameworks as well as the active cooperation of various stakeholders. Strong technical, financial, and extension services from government organisations and research institutes are essential for the sustainable development of aquaculture in the Sundarbans Delta.

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