

Gross freshwater availability and accessibility in the delta plain of Indian Sundarbans

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Abstract

The Indian Sundarbans Delta is experiencing severe water scarcity that has affected 4.5 million people due to increased salinity levels, restricting access to drinking and irrigation water. Remote sensing data and GIS analyses were used to assess the consumable water availability. The water quality investigation showed variations in pH and salinity levels in surface water post-monsoon season. The central part of the delta had better water quality compared to Sagar Island. Groundwater levels diminished from 3.3 meters BGL in 1996 to 7.67 meters BGL in 2022. Freshwater scarcity and seawater intrusion are affecting agriculture and food security.

Keywords: Water Demand, Ground water availability, water quality, salinity, Green economy

1. Introduction

Groundwater is the largest source of drinking water globally, with half of the world's population relying on it (Chatterjee & Bhadra, 2023). In the Sundarbans region, access to fresh drinking water is a critical issue due to the predominance of brackish water. Despite receiving abundant rainfall, the region fails to adequately utilize it to meet the needs of its 4.43 million residents across 19 administrative blocks (Bhadra & Hazra, 2012). The region's terrain frequently changes due to floods, cyclones, beach erosion, and sea level rise, causing significant disruptions to local livelihoods (Mondal & Bandyopadhyay, 2014).

During the COVID-19 pandemic, surface water quality in rivers improved by 40-50%, with notable decreases in TDS and BOD levels, demonstrating the potential for natural water quality recovery (Chakraborty et al., 2021). The urgent need for a fresh water supply to protect the Sundarbans' landscape and mangrove ecosystem is evident, considering the region's high salinity levels (Noor Islam, 2008). Mangrove forests play a crucial role in providing habitat, preventing erosion, and protecting against natural disasters, making the assessment of surface water quality and temporal changes essential (Rahman et al., 2013).

Studies have modeled the Water-Energy-Food (WEF) nexus in India using various data sources, including the Community Land Model v4.0, to estimate groundwater storage changes and validate satellite-derived groundwater data (Barik et al., 2017). After Cyclone Aila in 2009, water quality measurements at three stations in the Sundarbans showed sharp increases in COD, BOD, nitrate, and phosphate levels (Bhattacharya et al., 2014). Six blocks close to river estuaries (Gosaba, Hinjalganj, Patharpratima, Basanti, Namkhana, and Sagar) face severe water problems in agricultural areas due to high salinity. Despite surface water supply, potable water availability is nearly nonexistent, forcing reliance on groundwater located below 300m (Zaman & Gayen, 2008).

Sagar Island, with its numerous tidal creeks, presents opportunities for large-scale aquaculture. Studies have been conducted to investigate the surface water quality in these creeks, revealing the potential for sustainable aquaculture practices (Basu et al., 2021). Research has also explored nexus modeling of water, energy, and food subsystems, considering variables such as agricultural water withdrawal and electricity consumption. This approach underscores the importance of integrated resource management to ensure sustainable development (Ravar et al., 2020). Given the high population pressure in the Sundarbans, it is crucial to assess water availability and production for aquaculture and agriculture, alongside addressing the knowledge gap regarding dry season irrigation (Humphreys et al., 2014).

In low-lying areas like Sagar and Basanti blocks, fish farming ponds are vulnerable to saltwater flooding, prompting farmers to raise the height of pond dikes to reduce salinity intrusion (Chand et al., 2012). Global climate patterns such as the El Niño Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD) significantly affect water quality and recharge patterns. Continuous monitoring and adaptation strategies are necessary to mitigate these impacts (Das, Mukherjee, et al., 2021).

Despite these efforts, the Sundarbans region continues to face significant challenges in managing its water resources. Freshwater scarcity remains a critical issue, exacerbated by seawater intrusion and limited infrastructure for rainwater harvesting and storage. The region's high salinity levels not only affect drinking water availability but also have profound implications for agriculture and aquaculture, which are vital for the local economy and food security.

The urgent need to improve water management practices in the Sundarbans is clear. This includes enhancing rainwater harvesting, developing sustainable aquaculture practices, and implementing integrated water resource management (IWRM) approaches. Addressing these challenges requires a comprehensive understanding of the region's hydrology, climate impacts, and socio-economic conditions.

Identifying research gaps is essential for guiding future studies and interventions. Key areas include the availability and accessibility of potable water, water for domestic and irrigation purposes, and the feasibility of dry season irrigation. Additionally, there is a need to explore innovative solutions to enhance water quality and availability, such as advanced filtration technologies, desalination, and the use of alternative water sources.

The Sundarbans region's water scarcity issues are multifaceted and require a holistic approach to address. By leveraging scientific research, technological advancements, and community engagement, it is possible to develop sustainable solutions that ensure water security for the region's residents. This will not only improve their quality of life but also contribute to the resilience and sustainability of the Sundarbans' unique ecosystem.

2. Study area

The Sundarban Tiger Reserve is located in the South 24 Parganas district of the Indian state of West Bengal (9630 km²). It is a part of the Gangetic delta and is associated with the Sundarbans reserve forest of Bangladesh. It is located in the south-west of Bangladesh. The area is located at the intersection of buffer(2563 km²), core(1700 km²) and habitation area (5367 km²) divided into 19 CD Blocks. Entire area is covered by mangroves and the Bengal tiger is its largest reserve. A variety of birds and animal habitats including crocodiles can be found here in the salt water. The area was inscribed as a UNESCO World Heritage Site in 1987 and has been designated as a Ramsar site since 2019(Das, Mishra, et al., 2021). It can be called a global network of WEF. Sundarban region is located between the 21°43'N to 21°55' N and 88°42'E to 89°04' E. Seven major rivers and numerous watercourses from a

network of channels in this estuarine delta and all have a southerly course towards the sea. Sundarban has achieved his name from the Sundari tree. Today it has become an important tourist place. A lot of people are crowding there. Many launch facilities have come and gone. But this region is still affected by natural and human factors. Future climate change is expected to cause further ecosystem degradation. The surface air temperature in the Bay of Bengal is increased at the rate of $0.019^{\circ}\text{C}/\text{year}$. According to ISD this temperature will increase by 1°C in 2050 (Ghosh, 2015). Between 1980 and 2007, the water temperature increased by 0.06°C , resulting in severe impacts on aquatic life in the region (Abul & Mallik, 2016). Sea level rise has doubled in the past few years, about 65% of mangrove saplings have been submerged in most places and saline water has entered agricultural land in many places. Sidr in November 2007, Aila in May 2009 and Amphan in May 2020 have caused about 60% damage to the Sundarbans due to these devastating cyclones (Ghosh, 2015). According to the WWF report (2010), the salinity level in this region is increased day by day; northern part of this Sundarban region is relatively less compared to the southern region, while the amount of fresh water is decreasing. Fresh groundwater is only available at a depth of 160 to 400 meters; as a result water consumption is decreased day by day. Freshwater fish species have declined drastically. From 1990 to 2000 the amount of fish caught per unit has steadily declined (Abul & Mallik, 2016). Sundarban is a large area under the two coastal districts of West Bengal, North and South 24 Parganas. Where 74% of the population is South 24 Parganas and the remaining 26% is in the North 24 Parganas. There is severe food shortage in this vast region especially in some parts of South 24 Parganas. The pattern of cultivated land along the river has changed; much of the land has been lost due to various natural causes, resulting in 45% of paddy cultivation in the region being stopped due to intrusion of saline water from the river (Ghosh, 2015). Plantation of mangroves in the region has started in some places over the past few months. The soils of the delta region are very fertile due to the deposition of sediments throughout the year.

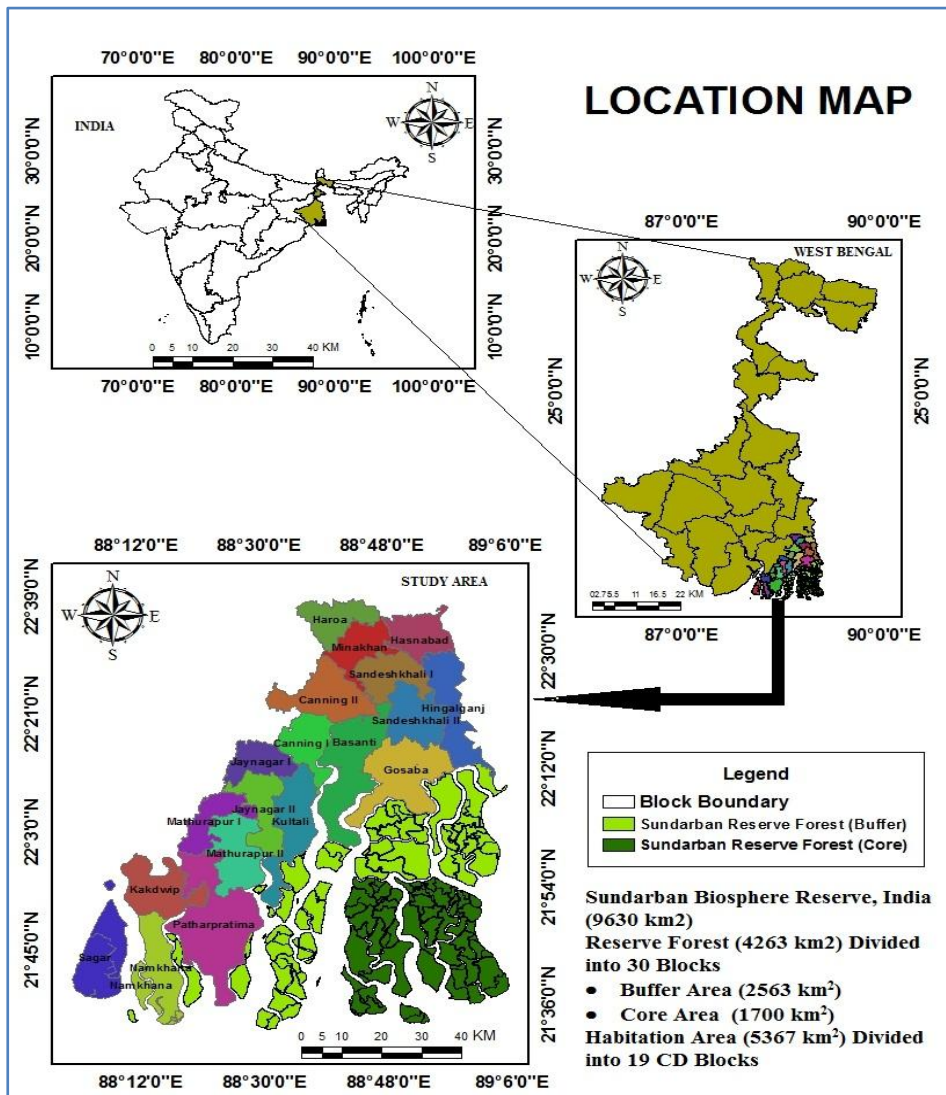


Fig1: Study area of Indian Sundarban (West Bengal)

3. Methodology

The assessment of surface and groundwater availability and accessibility involves evaluating surface water quality, surface water coverage and quantity, groundwater levels from the surface, and groundwater quality. Surface water, which includes rivers, canals, ponds, wetlands, and other bodies, is assessed and quantified using the Modified Normalized Difference Water Index (MNDWI). The MNDWI formula is $(Green - SWIR)/(Green + SWIR)$ (Xu, 2006). MNDWI values greater than zero indicate the presence of water, while negative values denote non-water features in the Sundarban region. Surface water quality is evaluated by computing the Water Quality Index using a weighted averaging method that includes parameters such as pH, salinity, dissolved oxygen (DO), turbidity, and chlorophyll (CHL). Groundwater quality and level data are

obtained from the Central Ground Water Board report and the Global Groundwater Information System (GGIS) developed by the International Groundwater Resources Assessment Centre. Parameters for groundwater quality assessment include pH, electrical conductivity (EC), carbonate (CO₃), bicarbonate (HCO₃), chloride (Cl), sulfate (SO₄), nitrate (NO₃), phosphate (PO₄), total hardness (TH), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), fluoride (F), and total dissolved solids (TDS). Continuous surface maps for both surface water and groundwater quality and levels are generated using spatial interpolation techniques, specifically the Empirical Bayesian Kriging method and the Inverse Distance Weighting (IDW) method, selected based on their accuracy reports. These spatial continuous surfaces are then used to assess water availability and accessibility on a zonal or block-wise basis. Finally, a Consumable Water Availability and Accessibility Map has been produced using the weighted overlay method, incorporating all four previously mentioned parameters of water availability and accessibility.

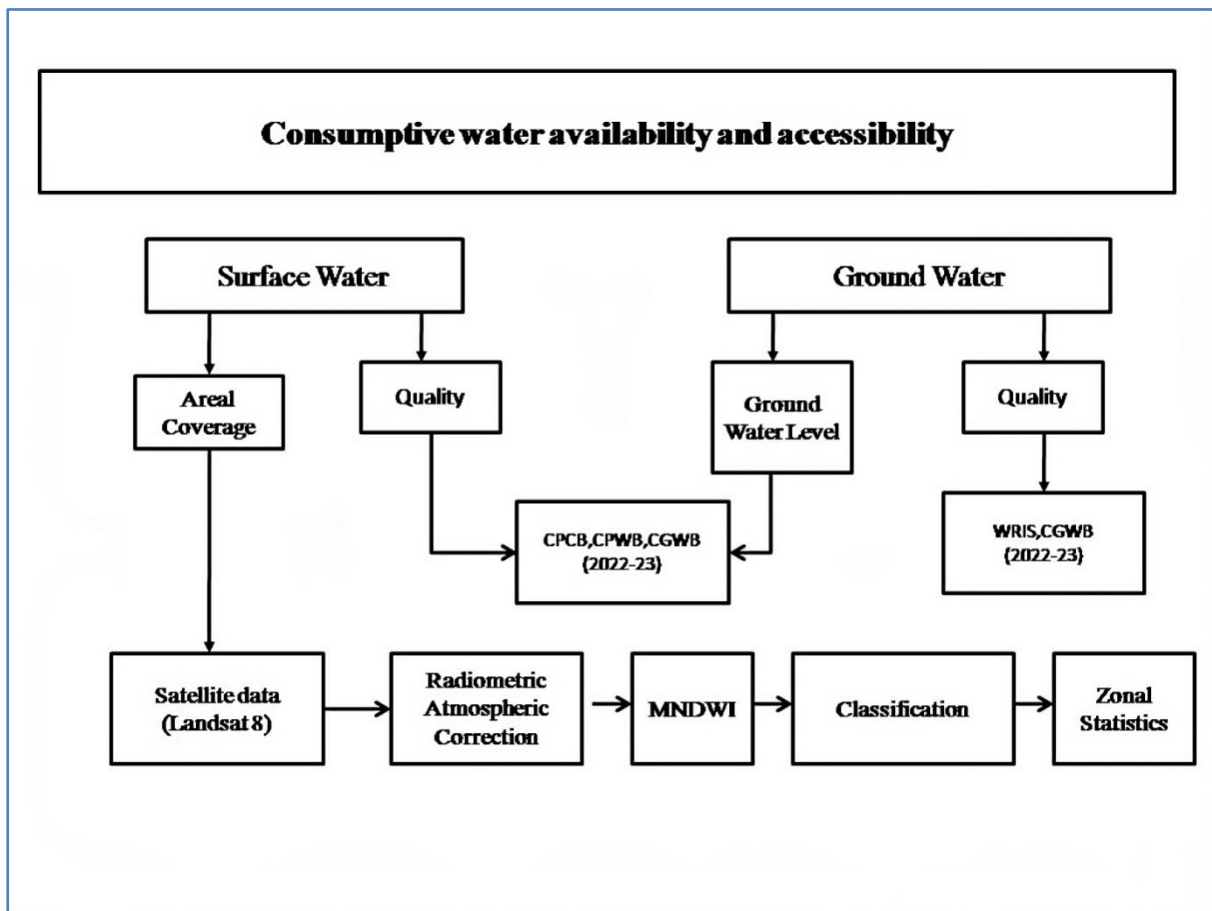


Fig2: Methodological framework

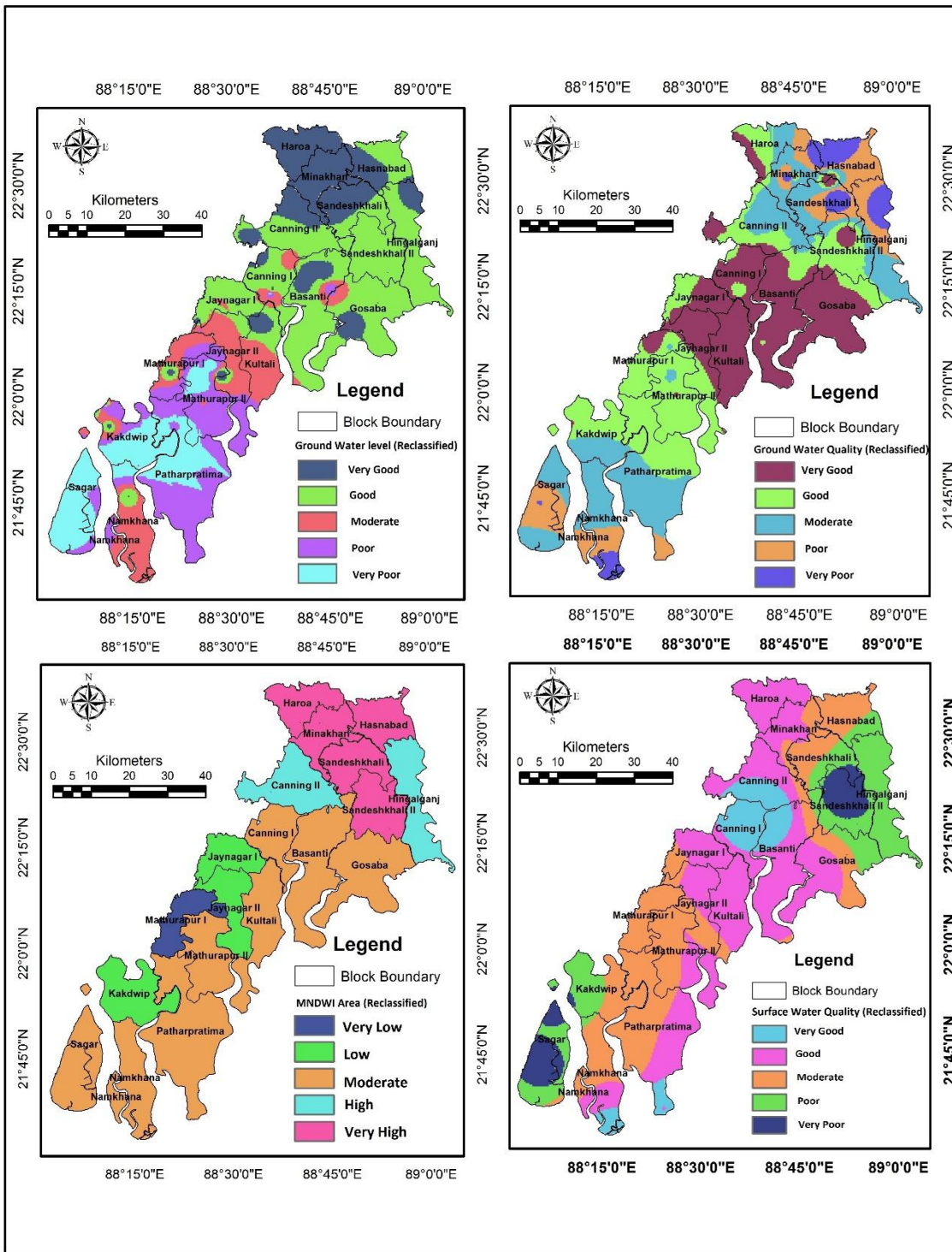


Fig3: Reclassified Parameters of Consumable Water availability and accessibility Map

4. Result and Discussion: The result and discussion section is presented in three main segments: the assessment of surface water, the assessment of groundwater and Consumable Water availability and accessibility mapping.

a. Assessment of surface water:

A comprehensive study of surface water quality was conducted across 19 blocks in the Sundarbans region during pre-monsoon, monsoon, and post-monsoon periods (Figure 4). The analysis focused on ten parameters, of which five—pH, Salinity, Dissolved Oxygen (DO), Turbidity, and Chlorophyll (CHL)—showed continuous variation. Data primarily from the post-monsoon period (August) were utilized for consistency. The pH levels ranged from neutral to alkaline (pH > 7.0) during the post-monsoon period. Salinity in the Sundarbans varied, with the highest recorded at 29.7 ppm and the lowest at 7.4 ppm. The region's ambient temperature during this time (28°C - 31°C) influenced salinity, which generally increased post-monsoon.

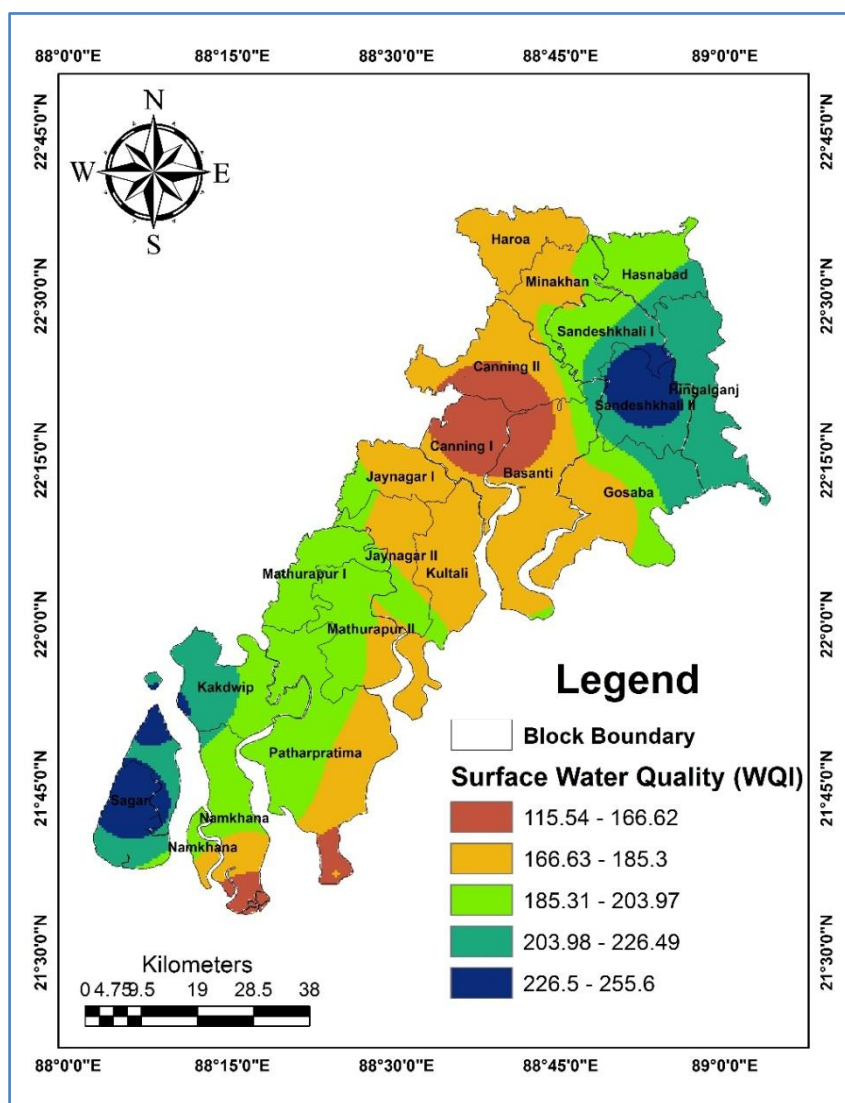


Fig4: Surface water Quality

Spatially central parts of the region exhibited better surface water quality compared to the northern and southern parts. Areas such as Sagar Island, Kachuberia, Bhagabatpur, and Namkhana showed lower water quality. Moderate water quality was observed in Gosaba, Hemnagar, Sandeshkhali, Lebukhali, Malancha, and Bakkhali. The areas around Canning and Basanti had relatively good water quality. The analysis of surface water availability used the Modified Normalized Difference Water Index (MNDWI) to assess changes across different blocks. Haroa, Meenakha, and Sandeshkhali exhibited high accessibility with MNDWI values ranging from 0.03 to 0.21. Hasanabad, Basanti, Canning, Gosaba, Patharpratima, and Namkhana had moderate accessibility with MNDWI values between -0.17 and 0.02. Mathurapur I block had low accessibility with MNDWI values between -0.4 and -0.18 (Figure 5).

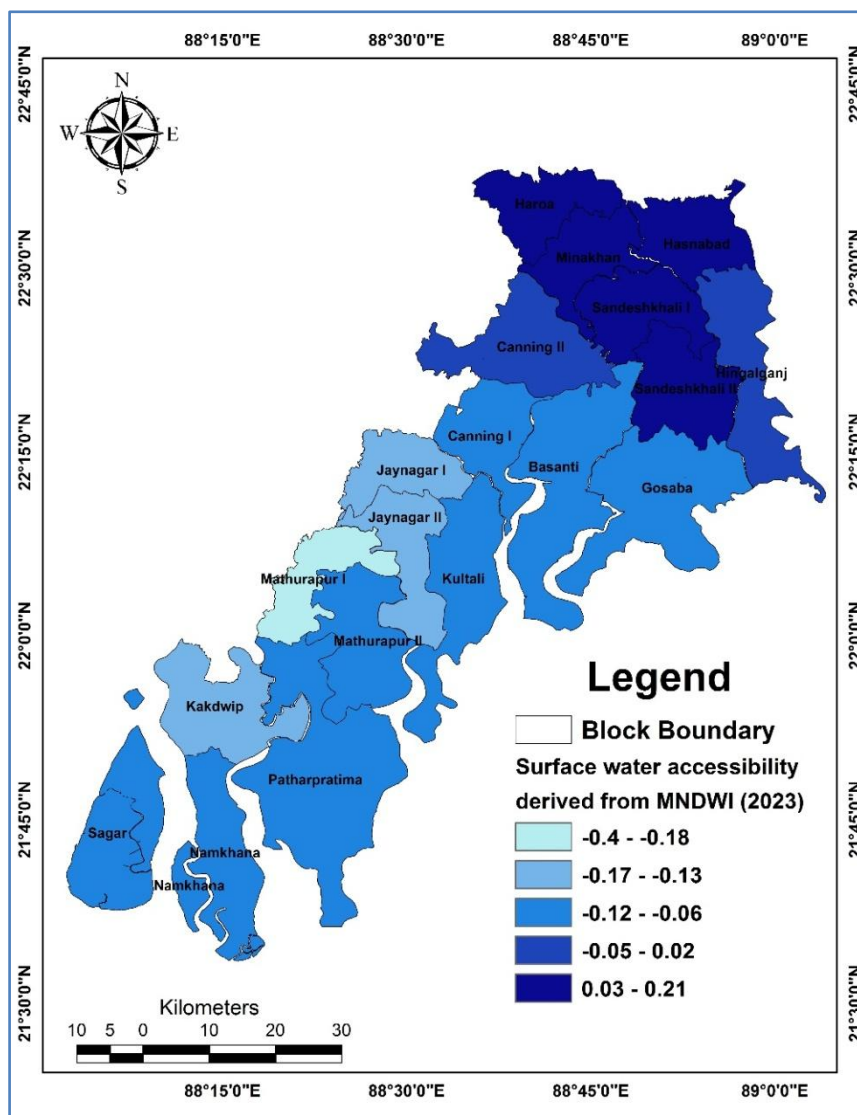


Fig5: Spatial Distribution of Surface water

Zonal statistics calculated minimum, maximum, and range values, providing a detailed overview of surface water availability. The mean values and standard deviations were used to summarize the data, offering insights into the spatial distribution and accessibility of surface water in the region.

b. Assessment of Groundwater

The groundwater quality assessment focused on both deep and shallow water during the post-monsoon period, considering various parameters (pH, EC, CO₃, HCO₃, Cl, SO₃, NO₃, PO₃, TH, Ca, Mg, Na, K, F, and TDS). Shallow water exhibited higher salinity compared to deep water due to significant sea water intrusion. Deep water was more alkaline (pH > 7.0) due to higher bicarbonate concentrations. These values indicated that shallow water, affected by seawater intrusion, was unsuitable for drinking. Some deeper groundwater sources were found suitable for drinking.

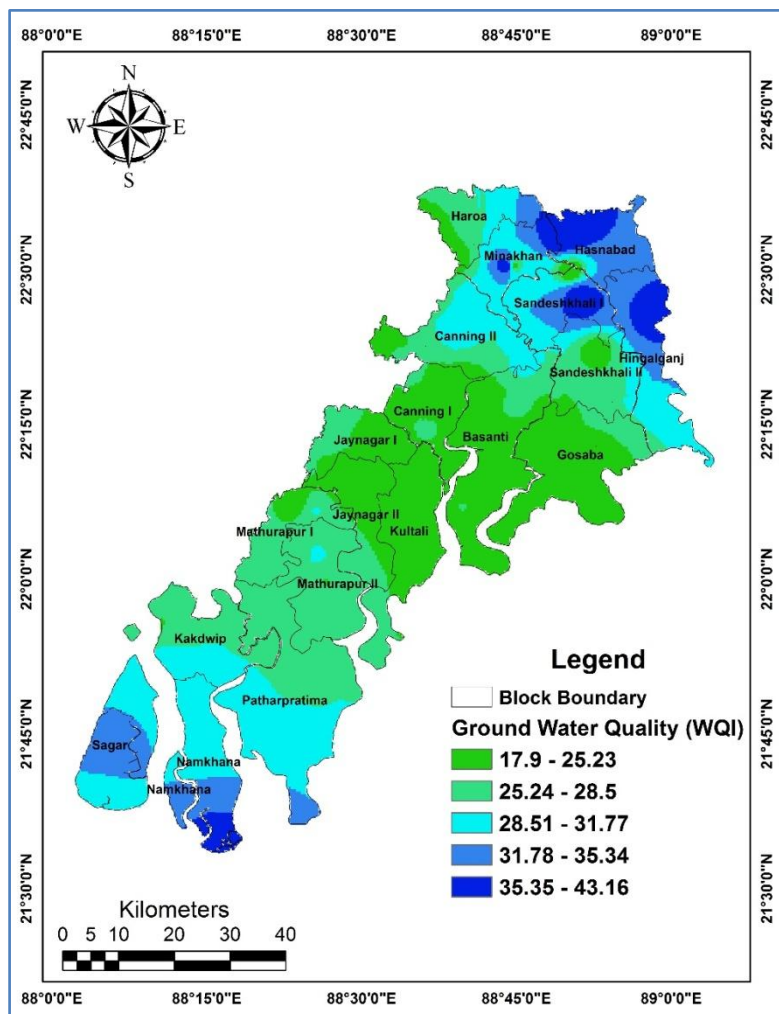


Fig6: Groundwater Quality

In terms of geographical distinctions, the northern and southern portions of Sundarban experienced lower groundwater quality as a result of increased salinity, which was attributed to parameters resulting from seawater intrusion. The central portion of the region did provide deep groundwater, although those areas had shallow groundwater that were unsuitable for consumption. The latter areas demonstrated poor groundwater quality, which included the blocks of Hasnabad, Minakha, Sandeshkhali, Hingalganj, Namkhana, and Sagar Island. The other blocks of Jayanagar, Kultali, Basanti, and Gosaba indicated relatively good groundwater quality, but the quality of water was shallow and difficult to access due to the presence of Vat and the lack of drinking water tube wells. Overall, the number of tube wells sampled during the survey was 69 in total and was comprised of 19 terrestrial blocks in the Sundarban region. The depth of the groundwater sampled in this study indicated the average groundwater depth in each respective year. The year by year average depth of groundwater was 3.3m bgl in 1996 and decreased to 6.5m in 2017 and again down to 7.67m bgl in 2022. (Das, Mishra, et al., 2021). This suggests that the groundwater level decreased by about 3 m between 1996 and 2017 and approached near-normal conditions by 2022. Observations indicate that groundwater levels in the Sundarbans drop markedly during the pre-monsoon period, rise during the monsoon, and stabilize to normal levels in the post-monsoon period. The temporal pattern of groundwater-level (GWL) fluctuations is similar in both shallow (15 mbgl) and deep (115 mbgl) aquifers. The map shows that the northwestern region, with GWL ranging from 0.33 to 4.54 mbgl, is relatively poor in quality and is heavily affected by arsenic pollution. Other blocks display medium to high GWL (4.55 to 13.59 mbgl) but are characterized by saline groundwater. Scarcity of freshwater in both surface and subsurface storages is a major factor influencing agriculture and food security across the region. This situation is especially acute in blocks such as Gosaba, Canning, Patharpratima, Kakdwip, Sagar, and Namkhana. In Gosaba and Basanti, many residents must travel long distances to collect drinking water using the Vat system.

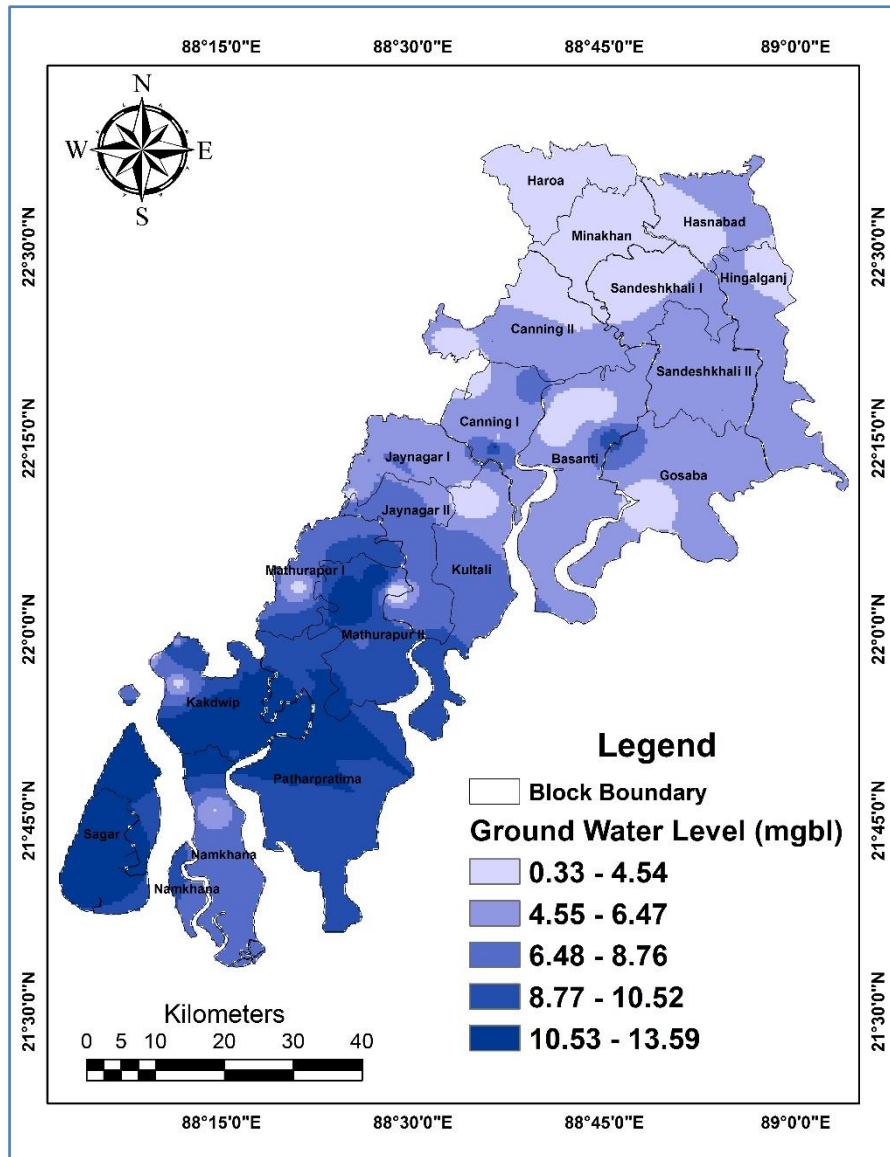


Fig7: Spatial Distribution of Groundwater level

Consumable Water availability and accessibility Mapping

The comprehensive assessment of surface and groundwater quality in the Sundarbans region highlights significant variations in water quality and availability across different periods and locations. The post-monsoon data revealed trends and regional disparities, emphasizing the need for targeted water resource management strategies to address the challenges posed by salinity, alkalinity, and water accessibility in both surface and groundwater sources. The areas with good freshwater availability and accessibility (red) are primarily concentrated in the northern and central parts of the district comprising Canning I, Basanti, Gosaba, Jaynagar I & II, Kultali, Mathurapur I blocks. This suggests that these regions have a better water supply infrastructure and natural resources compared to other areas. A significant portion of the

district, particularly in the southern and eastern regions, falls under the category of moderate freshwater availability and accessibility (yellow) comprising Haroa, Minakhan, Canning II, Kakdwip, Mathurapur II, Patharpratima, Namkhana blocks. These areas may face challenges in meeting their water needs during certain periods or for specific uses. The areas with low freshwater availability and accessibility (green) are scattered throughout the district, but they are more prominent in the southern and western regions comprising the Hasnabad, Sandeshkhali I & II, Hingalgunj, And Sagar. These areas may experience water scarcity and have limited access to clean drinking water.

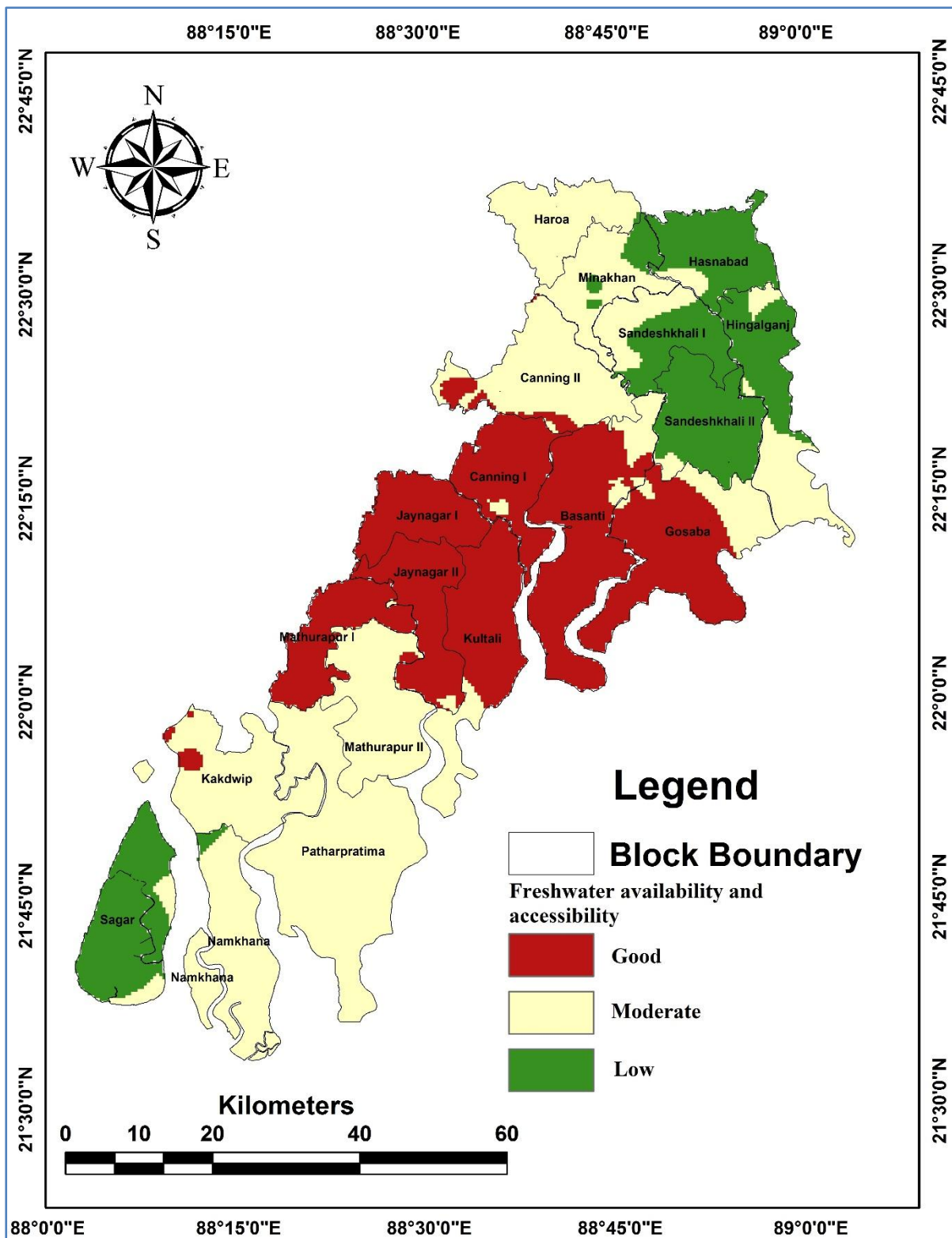


Fig8: Consumable Fresh Water availability and Accessibility Map

5. Discussion

Water scarcity in the Sundarbans region of India is a significant issue primarily due to high salinity levels in surface and groundwater sources along with variability caused

by seasons and climate change. Our research on water quality and availability mapping through remote sensing and GIS approaches was helpful in describing the contemporary situation of water resources in this area.

In our evaluation of water surface quality over 19 blocks of the Sundarbans, we found marked seasonal and spatial variability. For pH, salinity, dissolved oxygen (DO), turbidity, and chlorophyll (CHL), there was continuous variability in pre-monsoon, monsoon, and post-monsoon periods. In particular, we saw the pH levels in post-monsoon were neutral to alkaline, so the water should not show an acidic challenge. Salinity was a prominent context with certain pockets of the study area, where salinity ranged from 7.4ppm -29.7ppm. Vacillations with references to ambient temperatures where temperatures varied between 28°C and 31°C during the time of our collection. In general, the central zone of the Sundarbans had a better quality of water than to the northern and southern zones with better management practices and less salt intrusion from the sea.

Specific areas including Sagar Island, Kachuberia, Bhagabatpur, and Namkhana were found to have poorer overall water quality, likely a result of increased salinity and pollution levels. Areas that demonstrated moderate water quality included Gosaba, Hemnagar, Sandeshkhali, Lebukhali, Malancha, and Bakkhali and suggests that localized management of water uses may be more feasible in these locations. Water quality in Canning and Basanti was determined to have better quality water which could be associated with good freshwater management systems or less direct inflow from saline seawater. There is also a clear distinction between shallow vs deep groundwater quality in the Sundarbans with depth being particularly relevant in post monsoon systems. Shallow water sources had elevated salinity level from strong seawater intrusion, which made them unsuitable for consumption. On the other hand, deeper groundwater sources were more alkaline, found higher concentrations of bicarbonate, and some sources were considered suitable for consumption. Still, there are distinct regional differences in the quality of groundwater. Specifically, both northern and southern locations in the Sundarbans faced poorer groundwater quality from increased salinity and seawater intrusion. These areas also had unsafe consumption from shallow and deep groundwater sources. The central parts, though also affected by seawater intrusion, had better deep water quality, making it a more viable option for potable use.

Groundwater quality was not acceptable in certain places, such as Hasnabad, Minakha, Sandeshkhali, Hingaljanj, Namkhana, and Sagar Island, requiring different types of interventions for managing water. Other blocks, like Jayanagar, Kultali, Basanti, and Gosaba, had reasonably good groundwater quality. However, the accessibility of water in these blocks was less than optimal because of the Vat system and fewer drinking water tube wells, making effective distribution difficult. Using the Modified Normalized Difference Water Index (MNDWI), we assessed surface water accessibility between blocks, and there were substantial differences:

- **High Surface Water Accessibility Zones:** Haroa, Meenakha, and Sandeshkhali exhibited high accessibility with MNDWI values ranging from 0.03 to 0.21.
- **Moderate Surface Water Accessibility Zones:** Hasanabad, Basanti, Canning, Gosaba, Patharpratima, and Namkhana had moderate accessibility with MNDWI values between -0.17 and 0.02.
- **Low Surface Water Accessibility Zones:** Mathurapur I block had low accessibility with MNDWI values between -0.4 and -0.18.

These findings are significant for the comprehension of water resources spatial availability and the sustainable use of the water resources. The zonal detailed statistics allow for a better understanding of the area that requires immediate attention and intervention. The analysis has highlighted alarming trends of groundwater levels. The average groundwater levels decreased from 3.3 meters below ground level (mbgl) in the year 1996 to 7.67 mbgl in 2022. The decrease in groundwater levels is sharp and is an indication of over-extraction and insufficient recharge, and seasonal fluctuations have also contributed. There is a rapid decline in groundwater level from pre-monsoon to monsoon, followed by some stabilization of levels post-monsoon. Groundwater levels showed similar fluctuations in shallow (15 mbgl) and deep (115 mbgl) regions in the study area. Importantly, the northwestern slice of Sundarbans with arsenic pollution, has very low groundwater levels. The other blocks have medium to high groundwater levels, although saline groundwater is also present.

The limited availability of freshwater supply both in terms of surface and sub-surface water storage facilities is one of the important determinants of agriculture and food security in the Sundarbans. Blocks like Gosaba, Canning, Patharprotima, Kakdip, Sagar and Namkhana are especially relevant here. For example, residents of blocks such as Gosaba and Basanti sometimes have to travel long distances to collect

drinking water based on the Vat system indicating the need for improved water management and infrastructure.

6. Conclusion

In some blocks of the Sundarbans region, the population is steadily increasing, placing significant pressure on groundwater supplies. Most residents in this area rely heavily on groundwater. However, studies indicate that salinity intrusion rates are much higher in surface water. As previously discussed, salinity levels in the region's rivers are rising daily, harming the people of the Sundarbans and threatening future biodiversity.

Understanding the interrelation between water, energy, and food (WEF) is crucial. We have integrated all relevant WEF parameters and identified both positive and negative relationships. This approach helps clarify which factors are vital for preserving the Sundarbans' biodiversity in the future. To achieve this, support from local communities and the government is essential.

The local population is already seeking small-scale solutions to improve freshwater availability. Initiatives including surface water treatment, rainwater harvesting, artificial recharge of shallow aquifers, and integrated use of groundwater can all be effective in the Sundarbans. Continuing with these initiatives will be useful in the future, for the benefit of the biodiversity of the Sundarbans.

The results of the research show the level of critical water scarcity in the Sundarbans due to high salinity levels, saltwater intrusion, and depletion of groundwater. Water scarcity needs different types of water resource management and development strategies to improve water quality, ensure equity, and promote the sustainability of water use. Only, through varied, coordinated, and collaborative initiatives can the Sundarbans respond to mitigate the impact of water scarcity into the future.

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