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Groundwater and Aquifer Usage for Human Consumption and Irrigation in the Southwestern Coastal Region of Bangladesh: A Review

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Abstract

This review examines the use of groundwater and aquifers for human consumption and agriculture in the southwestern coastal region of Bangladesh, which faces particular hydrological and environmental issues. Groundwater is a significant source for drinking water and irrigation, with thousands of people relying on it. Due to increase of population pressure, expansion of agricultural and commercial activities, the aquifer systems in this region have been significantly stressed. The study explores the trends of groundwater and aquifer, highlighting significant issues including arsenic contamination, saline intrusion, and overextraction. Moreover, it analyzes the present management techniques and policies to reduce groundwater consumption in the region. This review reveals limitations in existing approaches and provides recommendations for management strategies that balance the demands of human consumption, agriculture, and environmental sustainability.

Keywords: Groundwater, aquifer, irrigation, human consumption, southwestern coast.

Introduction

Groundwater is one of the most crucial natural resources in Bangladesh, particularly in its southwestern coastal region, where approximately 35 million people live, representing about 29% of the country's total population[1,2]. This area includes three districts likes Khulna, Satkhira, and Bagerhat (Figure 1), faces seasonal surface water shortages and topographical challenges that make groundwater essential for agricultural use as well as drinking purposes[3]. Historically, groundwater extraction has been regarded as a consistent way to satisfy the rising water needs of the population[4]. Recent studies indicate a significant change in groundwater usage for irrigation with its contribution increasing from 41% in 1982-1983 to over 77% by 2006-2007. It reflects a change in water resource management policies in response to changing climatic conditions and agricultural practices[3,5,6]. However, the sustainability of these groundwater resources has become a big issue due to rising population demands, agricultural development, and the impacts of climate change[7].

In addition to concerns about the quantity of groundwater, the quality is also a major issue in this region. Contaminants like arsenic that face serious public health risks are present insignificant concentrations due to natural and human activities[8]. Numerous researches shows that higher arsenic levels in shallow aquifers are an inconsistent issue in the southwest coastal area of Bangladesh affecting both groundwater for human consumption and irrigation[9]. Focusing on its importance in human consumption and irrigation, this review attempts to integrate current data and research on groundwater utilization in the southwestern coastal region. Climate change and over-extraction continue to threaten the sustainability of groundwater resources[10]. Additionally, sustainable irrigation techniques, particularly for crops like Boro rice have shown significant declines in groundwater levels, therefore worsening the risk of water shortage[11].

This study highlights the primary challenges caused by over-extraction, arsenic contamination, salinity intrusion, and possible long-term effects of climate change. It also explores government regulations and policies aimed to protect groundwater resource for future generations and promote sustainable groundwater management strategies.

Materials and Methods

This study used a systematic literature analysis on groundwater and aquifer use for human and agricultural purposes on southwest coast of Bangladesh (Figure 1). Rigorous and scientific data collected from various secondary sources like published journal, conference

proceedings, reports, books and reputable websites. Metadata were created, examined, and presented in a logical sequence. Qualitative research applied to find out the trends in groundwater use, management practices, emerging problems, and recent studies. Mentioned term such as "groundwater use in Bangladesh", "aquifer depletion", "irrigation in coastal Bangladesh", and "water management", incorporated (focused on 2000–2024) from specific, Google Scholar, Scopus, Web of Science, and PubMed. Boolean operators were used to narrow the search to papers addressing this review's geographic area. Included and excluded criteria guaranteed relevance and quality of research. Particularly in Bangladesh's southwest coastal area, groundwater and aquifer utilization for human consumption or irrigation covers.

Data extraction focused on groundwater availability and recharge rates, aquifer features, the impact of groundwater extraction on human consumption and irrigation, salinity intrusion and pollution, and management and sustainability. Narrative analysis and theme classification revealed tendencies and literature gaps. Numerous literatures were critically evaluated for relevance to review goals, methodological consistency, credibility, and geographic specificity. This technique is consistent with recent Bangladeshi groundwater studies, which highlight coastal groundwater depletion, contamination, and salinity intrusion.

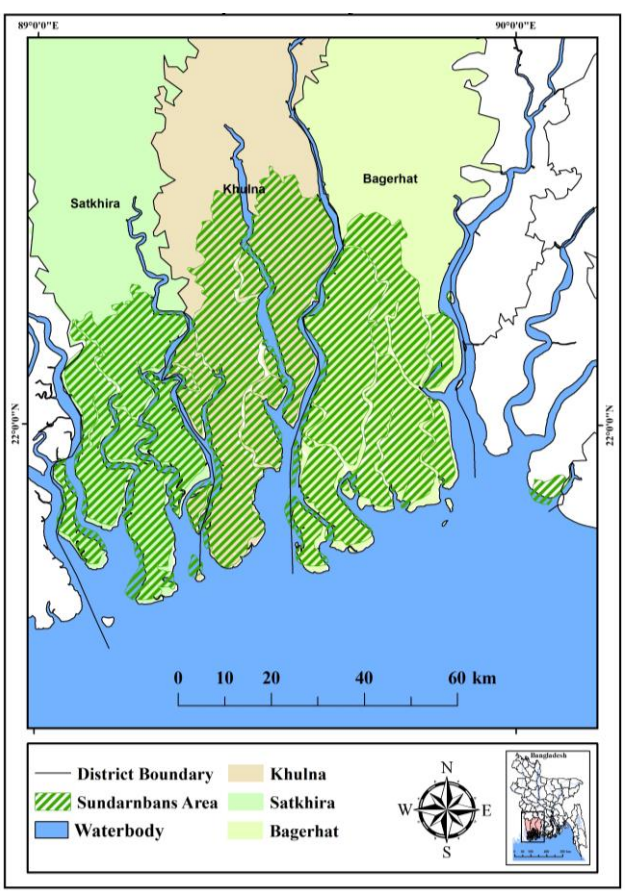

Figure 1. Map of the southwest coastal region of Bangladesh.

Results and Discussion

Groundwater Availability and Usage in Southwestern Bangladesh

Groundwater is an essential resource that is used mostly for industrial, agricultural, and drinking water in Bangladesh. Despite being plentiful, its quality and availability differ across the nation due to factors like seasonal variations, over-extraction in cities, and arsenic contamination.

Hydrogeological Context of Southwestern Bangladesh

Bangladesh's southwest coastline area is distinguished by a complicated hydrogeological system mostly consisting of alluvial aquifers[2]. Usually, split into

shallow, intermediate, and deep strata, these aquifers are within the vast Bengal Basin part. This area, easily accessible, shallow aquifers, found at depths ranging from 10 to 100 meters, as well as intermediate aquifers, found between 100 and 300 meters, are extensively exploited for irrigation[3,5]. On the other hand, since deep aquifers found beyond 300 meters are less likely to be contaminated by surface pollution and saltwater intrusion, they constitute the main supply of drinking water[3]. Seasonal rainfall determines the recharge of these aquifers; so, the rates of recharge highly depending on where one is living human being[6]. Their proximity to the Bay of Bengal, coastal districts such as Bagerhat, Satkhira, and Khulna are especially vulnerable to saltwater intrusion; inland areas struggle with seasonal water scarcity[11]. Extensive deltaic and alluvial deposits define Bangladesh's southwestern coastline area[2]. Mostly laid over the Quaternary period, the last 2.58 million years, these sediments gathered gravel, silt, clay, and sand[12]. Depth divides the region's aquifers into shallow, intermediate, and deep levels[11].

Shallow and intermediate aquifers are unconfined to semi-confined, whereas deeper ones are confined in southwestern coastal area of Bangladesh. The shallow aquifers, mostly Holocene deposits (less than 10,000 years old), at less than 100 meters, contain fine to medium sands, clay, and silt[13,14]. Deep aquifers may extend into Pleo-Pleistocene and Miocene deposits (5.33 million to 2.58 million years ago) at depths of more than 300 meters. Many limited aquifers include well-sorted, fine to coarse sands with clay interbeds. Due to overburden pressure and geologic age, these sediments are more compacted[13,14]. Salinity intrusion and groundwater contamination are threats in this region. Sea-level rise (SLR), tidal surges, reduced freshwater flow from upstream rivers, and shrimp farming, which often introduces saline water, are major causes of salinity intrusion, especially in coastal areas. The Bengal Basin sediments naturally contain arsenic, which pollutes shallow aquifers[15,16].

Groundwater for Human Consumption

The majority of the population in the southwestern coastal region of Bangladesh depends on groundwater for drinking purposes. Groundwater provides nearly 90% of the drinking water supply in rural areas, where access to treated surface water is limited[17]. However, the safety of groundwater for human consumption has been compromised in recent years due to widespread contamination by arsenic, iron, and salinity. Affecting millions of people and causing serious health consequences like skin lesions and cancer, arsenic contamination has become a huge public health concern[8,9]. Saline intrusion aggravates the issue in southwest coastal areas by making groundwater progressively brackish and unfit for drinking without appropriate treatment. Nonetheless, certain areas, such as portions of the Bengal Delta, have shown promise for freshwater availability in shallow aquifers during the rainy season, therefore highlighting variances in salinity problems[18].

Figure 2 shows the fast-rising groundwater withdrawal and the number of deep tubewells, highlighting important challenges in the context of groundwater use for human consumption. Primarily led by agricultural and domestic needs, the rising number of tubewells corresponds with growing demand for groundwater. But depending too much on groundwater extraction brings major risks like aquifer depletion, lower water quality, and long-term sustainability issues[19].

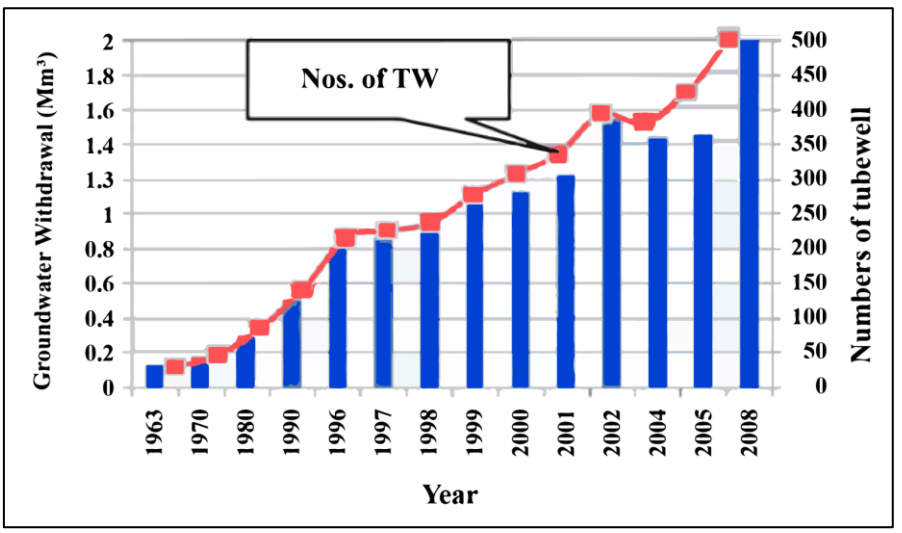

Figure 2. A rapid increase in groundwater abstraction rate and the number of Deep tubewells[18].

Groundwater for Irrigation

Groundwater is also the primary source of water for irrigation in the southwestern coastal region of Bangladesh. Agriculture, particularly rice cultivation, which requires significant water input heavily reliant on groundwater. The region's shrimp farming industry, which has expanded rapidly in coastal districts, has further intensified the demand for groundwater[20]. Irrigation practices in this region predominantly use shallow tube wells to extract water for farmlands, contributing to the depletion of the shallow aquifer systems. A study conducted in 2023 revealed that groundwater extraction for irrigation purposes accounted for approximately 70% of the total water usage in the region[21]. Many areas of the region have seen notable drops in the water table as a result of over-extraction of groundwater during the dry season.

Figure 3. depicts the differences in groundwater recharge and irrigation abstraction between boreholes and other Bangladesh locations. Agriculture depends on groundwater, particularly in dry seasons, but too great abstraction creates sustainability issues. Groundwater availability is influenced by climate elements like precipitation, flooding, and droughts raise irrigation demand and over-extraction causes overabundance of these elements[22].

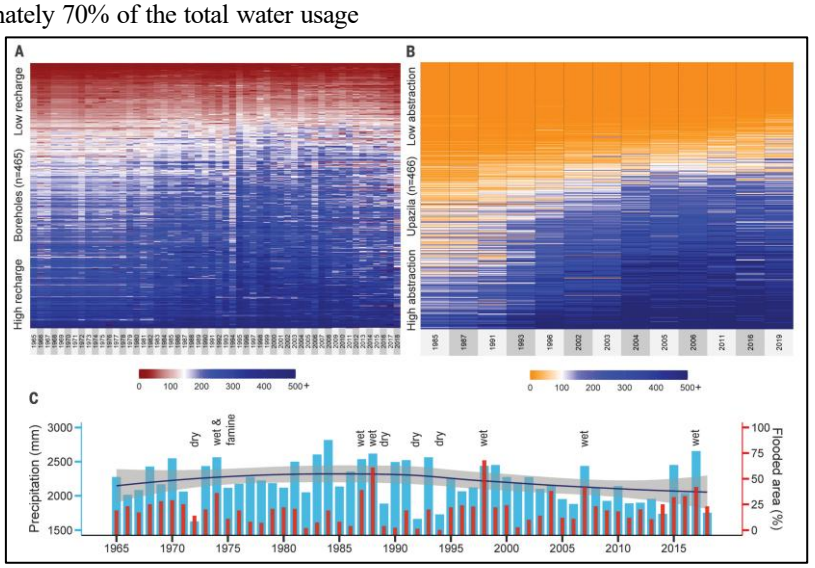

Figure 3. Comparison of estimated groundwater recharge and abstraction for irrigation across Bangladesh. The heatmap in panel (A) illustrates estimated recharge at 465 boreholes in Bangladesh from 1965 to 2017, with missing recharge values for boreholes filled using the Random Forest algorithm

solely for visualization purposes. The heatmap in panel (B) depicts estimated abstraction at 466 Upazilas (sub-districts) based on irrigation surveys conducted during available years between 1985 and 2019. Panel (C) presents a bar plot (blue) of annual rainfall in Bangladesh from 1965 to 2018 (mean = 2211 mm) derived from the CRU (TS4.05) dataset, alongside a bar plot (red) representing flooded areas in Bangladesh, highlighting exceptional dry and wet conditions. The blue line indicates local regression using Loess, while the grey shading delineates the 95% confidence interval of fitted non-linear trends[22].

Over-Extraction and Aquifer Depletion

Over-extraction is one of the most significant issues in agriculture to use groundwater in the southwest coastal area of Bangladesh. Groundwater levels in some regions have shockingly reduced as food production demand rises and agriculture's intensity intense[23]. The groundwater table dropped by an average of 10 meters between 2000 and 2020 in several of the southwestern coastal areas; in certain cases, the drop was much more severe[24]. Additionally, the availability of water for future use, over-extraction raises the risk of aquifer contamination from other contaminants and saline intrusion. Over-extraction of groundwater in southern coastal regions has caused saline water to migrate laterally into freshwater aquifers, therefore compromising the quality of water accessible for cultivation and consumption.

Groundwater use problems in southwest Bangladesh, including over-extraction and aquifer depletion, can be connected to Deep Tube Wells (DTW) increasing depth in the Dhaka metropolis[25]. Figure 4 (a) illustrates how groundwater reliance has throughout time raised the DTW count. Human consumption and agricultural needs have driven groundwater extraction in Bangladesh's Southwest coastal area. The DTW depth rising as water tables drop from over-extraction and aquifer depletion causes concerns of the most serious nature in Figure 4 (b). Similar groundwater use for agriculture and human consumption water supply has decreased water tables in the southern coastal areas of Bangladesh, needing deeper wells to protection supplies. Deeper DTWs show over-extraction and unsustainable groundwater resource management. Problems with water quality, land subsidence, and long-term water shortage brought on by aquifer depletion arise here.

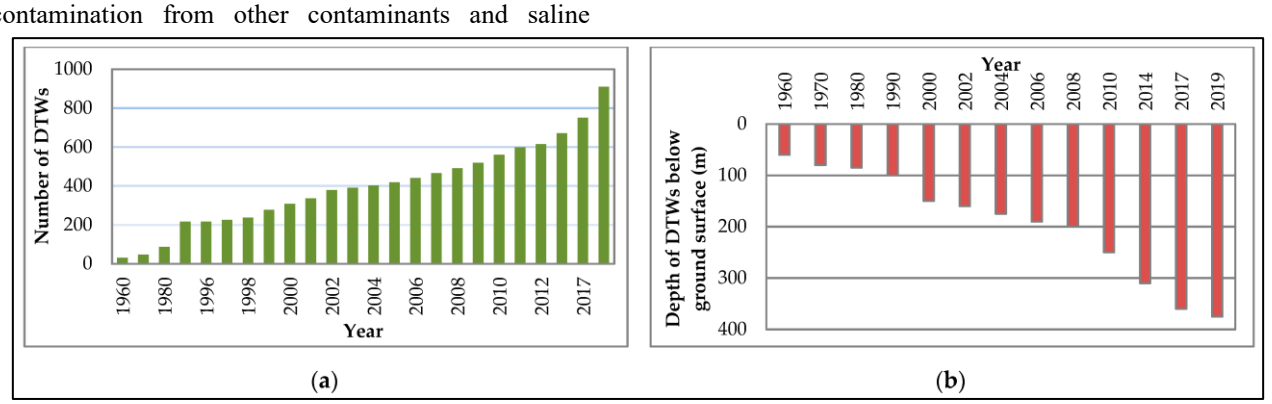

Figure 4. Present Situation of DTWs in Dhaka city: (a) Number of DTWs over the years 1960 to 2019; (b) Depth of DTWs below ground surface over the years 1960 to 2019[29].

Water Contamination: Arsenic and Salinity

Water quality deterioration is also a critical challenge in the management of groundwater resources in this region. Arsenic contamination has been well recorded in the southwest coastal area of Bangladesh[2]. According to the World Health Organization (WHO), more than the 20% of the tubewells have a high presence of arsenic levels in the area[26]. Widespread health problems include arsenicosis, a chronic illness as a result significant skin, cardiovascular, and cancer risks that have come from long-term arsenic-contaminated water intake. Rising sea levels and shifting hydrological patterns brought on climate change are forcing seawater into freshwater aquifers, as well as contamination of groundwater. Crop yields and soil health are reducing day by day due to salinization of groundwater, and it influences drinking water quality and agricultural output[2,27].

Climate Change and Groundwater Sustainability

Climate change is aggravating widespread issues for groundwater management in the southwest coastal area of Bangladesh. Rising sea level and salinity intrusion are increasing in the southwestern coastal area due to climate change. More than half of the shallow aquifers in coastal areas may become too saline for use by 2025[28]. The rapid deterioration of groundwater resources is rising frequency and intensity of extreme weather events, including cyclones and storm surges[29].

Sustainable Groundwater Management Practices

By maintaining the long-term availability and quality of groundwater resources, sustainable groundwater management seeks to strike a balance between the needs of the current and future generations. This entails putting policies in place that guard against pollution and depletion while also taking into account the economic, social, and environmental implications of groundwater use.

Aquifer Recharge and Rainwater Harvesting

Many sustainable management techniques have been suggested to help offset the escalating groundwater depletion crisis. Artificial recharging groundwater aquifers with excess surface water during the monsoon season is Managed Aquifer Recharge (MAR). Successful piloting of this approach in several areas of Bangladesh, particularly the southwest coastal region, where it has shown promise in restoring aquifer levels and increasing water quality, also significant possibility for rainwater collection, especially in places where monsoon rainfall is plentiful[30]. Rainwater collection and storage help communities lessen their reliance on groundwater during the dry season[6]. Rainwater collection has also been encouraged in coastal areas as a means of relieving salt intrusion-induced drinking water shortages.

Government Policies and Institutional Support

Integrated water resource management is a vital issue for over-exploitation of groundwater in this sense, the Bangladesh Government has taken the National Water Policy-2018, emphasizing the preservation of water resources, the National Water Policy (2018) supports a measured approach to surface and groundwater consumption. It also supports water-efficient irrigation technology such as drip irrigation, and lower water waste in agriculture[23]. Furthermore, the government has started the Sustainable Water Management Action Plan (2021), which seeks to lower groundwater use by means of less water-intensive crops and so enhance local water management policies[24]. If the stakeholder properly maintains the policy rules and regulations, it will help to reduce the hazards of groundwater depletion and the long-term viability of aquifer supplies.

Conclusion

The southwestern coastal area of Bangladesh encounters critical challenges in managing its groundwater and aquifer resources. Over-extraction for irrigation has resulted in aquifer depletion and increased contamination with arsenic and salinity. It is essential to adopt management strategies that include policy reforms, rainwater harvesting, and MAR to ensure the sustainability of groundwater. A holistic approach, incorporating community involvement, technological innovation, and good governance, plays a key role in securing clean water for human consumption and agricultural use in the region. Such strategies align with SDG 6 (Clean Water and Sanitation) by endorsing the sustainable management of water resources and SDG 13 (Climate Action) by building resilience to water scarcity and contamination heightened by climate change.

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