

Influence of Salinity Intrusion on Groundwater Quality along Diamond Harbour Road, South 24 Parganas, West Bengal

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Abstract

The present study evaluates twenty four physicochemical and microbiological characteristics of groundwater at Amtola, Diamond Harbour Road, South 24 Parganas, over a period of six-year (2020–2025). Microbial contamination, particularly fecal and total coliforms, showed a progressive increase over time, rendering the groundwater unsuitable for direct consumption. Although organic pollution levels remained low, the combined effects of salinity and microbial contamination highlight serious public health concerns. The year 2021 showed severe salinity intrusion, as highest TDS (6070 mg/l) and conductivity (7356 $\mu\text{S}/\text{cm}$) were recorded in 2021. Also the year showed very high level of chloride (3576.84 mg/l). The value indicates a very strong coastal/seawater intrusion. Throughout the study period very hard water was observed, in 2021 the total hardness peaked to 980 mg/l, along with very high calcium and magnesium levels. Microbial contamination increased in successive years fecal coliform increased from 0 in 2020 to 23 in 2025, and the total coliforms raised to 33 in 2025, suggesting sewage infiltration. Reason for observe in rising trend in sodium 490 mg/l in 2025, could be attributed to possible ion exchange processes and advancing saline front. Organic pollution was found to decrease and pH was within acceptable range throughout the study. Results indicate significant fluctuations in groundwater quality, suggesting strong saline intrusion and mineral dissolution processes. Although partial improvement was observed during 2022–2023, increasing sodium, chloride, and microbial contamination trends in 2024–2025 raise concerns regarding groundwater sustainability and potability. Elevated coliform counts in recent years indicate possible anthropogenic contamination and inadequate sanitation

infrastructure. Overall, the groundwater in the study area is characterized as moderate to highly mineralized, very hard, and periodically bacteriologically unsafe for direct consumption without treatment. The findings highlight the influence of coastal dynamics, over-extraction, and recharge variability on aquifer chemistry. The study emphasizes the need for continuous monitoring, effective groundwater management, and appropriate treatment strategies to ensure sustainable use of groundwater resources in coastal regions. Future scope of work lies in comparing with surface water quality parameters and applying machine learning for same.

Keywords: Groundwater quality, Coastal aquifer, Salinity intrusion, Hydrochemistry, South 24 Parganas, West Bengal.

Introduction

Groundwater, a vital component of the Earth's hydrological cycle, plays a crucial role in sustaining ecosystems, agriculture, and human communities.[1] It is a crucial source of drinking and domestic water in coastal regions of West Bengal, however, rapid urbanization, population pressure, and saline water intrusion pose serious threats to its quality.[2]. Ground water is increasingly being sought as a source of drinking water due to the scarcity, nonavailability and bacteriological pollution of surface water. Ground water is a major source for all purposes of water requirements in India and it plays a vital role to human life and economic activity.[3] Groundwater serves as a primary source of potable water in many parts of India, particularly in semi-urban and rural coastal regions. The groundwater quality of West Bengal, a state located in Eastern India, is a subject of critical importance due to its direct impact on public health, agriculture, and various ecosystems.[4] This diversity contributes to a wide range of groundwater characteristics and quality issues across the state. Day by day, a number of intrusive toxic pollutants are polluting groundwater from various sources whether natural (through mineralization) or anthropogenic (through agricultural and industrial activities), which causes a serious threat to health .[5] Hence, it is essential to pay a full consideration to understand the hydrochemical characteristics and groundwater quality for proper planning and management of groundwater resources to ascertain its sustainable safe use for drinking, agricultural and industrial purposes of the state. Therefore, the present report focuses on the hydrochemical study of the groundwater quality chemistry refers to the chemical composition of water that is found beneath the Earth's surface in saturated zones of soil and rock. This water originates from precipitation that infiltrates the ground and moves downward through the soil until it reaches the saturated zone, where all the pores in the soil or rock are filled with water.[6] Groundwater chemistry is influenced by various factors, and understanding it is crucial for managing water resources and addressing environmental concerns.

In South 24 Parganas district of West Bengal, increasing population density, unplanned urban development, and proximity to the Bay of Bengal have placed significant stress on groundwater resources. Coastal aquifers are especially vulnerable

to seawater intrusion, over-extraction, and contamination from domestic sewage and agricultural run off Amtola, Diamond Harbour Road, South 24 Parganas, West Bengal, India is located in the lower Gangetic delta near tidal creeks and estuarine systems. The region is hydrogeologically sensitive due to proximity to coastal and estuarine water bodies, low elevation and deltaic alluvium, high groundwater extraction, cyclonic and storm surge events.[7] Groundwater quality assessment in coastal and deltaic regions has been a major focus of hydrogeological research due to the complex interplay of natural processes and anthropogenic pressures. Coastal aquifers are highly susceptible to saline intrusion, which alters hydrochemical characteristics and impacts water usability.[8] Studies have shown that over-extraction of groundwater lowers the freshwater table, facilitating the inland movement of saline water and deteriorating water quality.[9][10][11] In India, extensive research has been conducted on coastal groundwater quality, particularly in regions such as the **Ganges–Brahmaputra delta, Sundarbans, and Coromandel Coast**. [12][13][14] The deltaic system of West Bengal is influenced by tidal processes, seasonal monsoonal recharge, and cyclonic storm surges, all of which affect aquifer chemistry and salinity profiles.[15]

Several studies have applied hydrochemical indicators such as **Electrical Conductivity (EC), Total Dissolved Solids (TDS)**, and ionic ratios (Na/Cl, Mg/Ca) for seawater intrusion analysis. Many studies in past have shown that, high chloride and sodium concentrations are reliable markers of saline water influence, while **cation exchange processes** further modify groundwater chemistry during saline–freshwater interaction. Groundwater hardness and mineralization patterns have also been widely explored in coastal regions. Hardness parameters (Ca^{2+} , Mg^{2+}) and alkalinity serve as indicators of rock–water interaction and anthropogenic influences, showed that groundwater in the lower Gangetic basin exhibited increased hardness due to agricultural activities coupled with tidal effects.[16] Microbiological contamination is another critical concern in coastal belts with inadequate sanitation infrastructure. Many previous researchers[17][18] identified elevated coliform counts as an outcome of inadequate sewerage systems and surface–groundwater connectivity during monsoon flooding events. Recent research also highlights the application of multivariate statistical techniques for groundwater quality classification, enabling more robust interpretation of complex datasets. Despite considerable research [19][20] on coastal groundwater salinity, studies focusing on long-term temporal variation in peri-urban coastal settings—such as Amtola in South 24 Parganas—remain limited. This gap underscores the need for multi-year hydrochemical monitoring integrating both physicochemical and microbiological parameters.

Even in today's time more than 70% rural people, directly rely on groundwater for drinking and irrigation. As a result, groundwater not only plays a crucial role in human life but is also responsible for healthy ecosystems and agro-economic activity. Overusing pesticides and fertilizers in agricultural practices is the major concern regarding the deterioration of groundwater quality. In the coastal areas, one of the major problems is the infiltration of salt water into drinking water resources. In recent decades, excessive groundwater extraction for irrigation purposes via multiple deep wells has been a key cause of the rise of artificial salt levels and associated

degradation of groundwater quality. It is also a fact that, because of their toxicity and carcinogenic nature, pollutants provide a substantial health danger to a large number of people, these pollutants carry water, So, safe and clean water is a basic need for long-term human health that every government in the world should meet in the best way possible. Literature survey identified that there is very limited long term study investigating multichanges in coastal groundwater quality. Very few studies on peri urban expansion zones like Amtola, where urban pressure intersects coastal hydrogeology.

Many studies have already been done on assessing water quality in a specific region, but very little research has been conducted on assessment based on hydrochemical parameters of groundwater. Considering the above facts, the current study area of the South 24 Parganas district of the Bengal basin has been selected to assess groundwater vulnerability and related health risks. The coastal districts are the low-lying areas that are bordering or are close to the coastline of the Bay of Bengal. In West Bengal, three districts fall under coastal regions such as Purba Medinipur, South 24 Parganas, and North 24 Parganas. In the west of this district, the Hooghly River flows, Calcutta city, and North 24 Parganas are in the North, the Bay of Bengal surrounds the South and, in the east, there are Matla and Bidya Rivers and Bangladesh. The Ganga and Brahmaputra River systems, which create a major intertidal deltaic mass, as well as coast sand linked with estuaries and tidal creeks, are also part of the study region. The geological characteristics of the South 24 Parganas district of the Bengal basin are dominantly composed of alluvial and marine sediment of the quaternary age.

Study Area

The study area, Amtola, is located along Diamond Harbour Road in South 24 Parganas district, West Bengal. The absolute location of South 24 Parganas is from $22^{\circ} 30' 45''$ to $20^{\circ} 29' N$ latitude and $89^{\circ} 4' 56''$ to $88^{\circ} 3' 45'' E$ longitude, and it is the southern-most district of West Bengal. The region lies within a coastal alluvial plain characterized by shallow aquifers composed of sand, silt, and clay. The area experiences a tropical monsoon climate with high humidity and seasonal rainfall.



Figure 1: (Amtola, Diamond Harbour Road), South 24 Parganas, West Bengal, India.

Materials and Methods

West Bengal Pollution Control Board (WBPCB) has its monitoring station at Diamond Harbour, and it regularly monitors quality of water for the stretch of River Ganga, in the state of West Bengal, India. The physio-chemical data of monitoring for the period 2020 to 2025, was obtained from the database of WBPCB. Yearly data was tabulated, correlation analysis was done to find the correlation between the physiochemical parameters. Groundwater samples were collected annually from the same source at Amtola during the period 2020–2025. Parameters analyzed included pH, temperature, electrical conductivity, total dissolved solids (TDS), total suspended solids (TSS), total fixed solids (TFS), total hardness, calcium, magnesium, sodium, potassium, chloride, sulphate, fluoride, nitrate-N, ammonia-N, phosphate-P, iron, alkalinity, biochemical oxygen demand (BOD), chemical oxygen demand (COD), turbidity, total coliform, and fecal coliform tabulated in Table 1.

Results and Discussions

A total of twenty four water quality parameters were analysed over a period of 2020 to 2025, as presented in Table 1. Their temporal trends were evaluated through comparative analysis across years (2020- 2025).

Table 1: Ground Water at Amtola on Diamond Harbour Road, 24 parganas (S)

Year	2020	2021	2022	2023	2024	2025
Parameter	Test Result	Test Result	Test Result	Test Result	Test Result	Test Result
Ammonia-N	0	0.18	0.24	0	0	0
BOD	2.60	0.75	0.5	0.51	0.73	0
Conductivity	6042	7356	2738	1135	3420	3058
Fecal Coliform	0	1.7	1.7	6.8	7.8	23
Nitrate-N	1.35	1.26	0.46	0.5	0.58	0.23
pH	7.02	7.35	7.48	7.78	7.13	7.15
Temperature(Water)	29.0	28	29	30	32	26
Total Coliform	0	4.5	11	22	23	33
Calcium	105.88	200	76	68	136	152
Total Hardness as CaCO ₃	450.98	980	490	250	550	650
Total Suspended Solids(TSS)	8.00	20	82	38	60	20
Turbidity	24.20	24	2.64	2.37	1.68	13
Iron	1.52	0	0.15	0.12	0	0.17
Chloride	449.86	3576.84	504.84	224.93	629.8	684
COD	15.00	18	9	9.44	9.36	4.76
Fluoride	0.70	0.6	0	0.28	0.33	0.21

Magnesium	45.26	116.6	72.9	19.44	51.03	65.6
Phosphate-P	0.06	0.06	0.11	0.03	0.07	0.04
Potassium	6.50	40.42	2.5	4.5	3	4
Sodium	174.82	103.8	126	153	270	490
Sulphate	23.67	50.17	43	64.47	70	47.9
Total Alkalinity	620.00	840	800	170	860	490
Total Dissolved Solids(TDS)	4012.00	6070	1652	670	2010	1954
Total Fixed Solids(TFS)	4306.00	5220	1626	574	1836	1766

Note : All values are in mg/l, except pH which is a constant, Turbidity in NTU, Conductivity in $\mu\text{S}/\text{cm}$, Temperature $^{\circ}\text{C}$

After evaluation of temporal trends across the years, it was found that, the pH values ranged from 7.02 to 7.78, indicating neutral to slightly alkaline groundwater, which falls within acceptable

drinking water limits. Water temperature varied between 26°C and 32°C , reflecting seasonal and climatic influences. Electrical conductivity was found high (1135–7356 $\mu\text{S}/\text{cm}$), indicating elevated ionic concentration. TDS values ranged from 670 to 6070 mg/l, exceeding permissible limits in most years. The exceptionally high TDS recorded in 2021 suggests severe salinity intrusion or excessive mineral dissolution, rendering the water unsuitable for drinking. Total hardness ranged from 250 to 980 mg/l, classifying that the groundwater as very hard. Elevated calcium and magnesium concentrations indicate carbonate and silicate weathering, along with possible seawater mixing. Such hardness levels may cause scaling of pipes and adverse health effects upon prolonged consumption.

Chloride concentrations were alarmingly high, particularly in 2021 (3576.84 mg/l), strongly suggesting saline water intrusion. Sodium levels increased steadily from 174.82 mg/l in 2020 to 490 mg/l in 2025, raising concerns related to hypertension and irrigation suitability. Sulphate remained within acceptable limits but showed a rising trend in recent years. Nitrate-N, ammonia-N, and phosphate-P concentrations remained relatively low, indicating limited agricultural influence. Low BOD and declining COD values suggest minimal organic pollution and absence of major industrial effluent discharge in the study area.

High turbidity values were observed during 2020–2021, followed by notable improvement in later years. Iron concentration exceeded permissible limits in 2020 but decreased significantly thereafter, indicating geogenic influence and possible aquifer flushing. A gradual increase in total coliform and fecal coliform counts was observed from 2021 to 2025. The presence of fecal coliforms indicates contamination from sewage or septic systems, making the groundwater microbiologically unsafe for direct consumption without treatment. The combined assessment of physicochemical and microbiological parameters reveals that the groundwater at Amtola is severely affected by salinity, hardness, and microbial contamination. Although organic

pollution is low, elevated TDS, chloride, sodium, and coliform counts significantly compromise water quality and public health safety. The groundwater shows moderate to severe mineralization, with high TDS, hardness, conductivity, chloride, sodium, and alkalinity in most years. Microbial contamination has increased steadily, raising concerns for potable use.

pH (7.02–7.78) remains neutral to slightly alkaline, within BIS/WHO acceptable limits.

Water temperature varies seasonally (26–32°C), typical of shallow aquifers. Very high conductivity (1135–7356 $\mu\text{S}/\text{cm}$) indicates salinity intrusion or anthropogenic influence.

TDS exceeds permissible limits (500 mg/L) in all years except 2023. Peak TDS: 2021 (6070 mg/L) unsuitable for drinking. Slight improvement observed after 2021, but still non-potable without treatment. Total hardness (250–980 mg/l) classifies water as very hard. High Ca^{2+} and Mg^{2+} suggest carbonate weathering and possible seawater mixing. Persistent hardness may cause scaling and gastrointestinal issues.

Extremely high chloride, especially in 2021 (3576 mg/l), strongly indicates saline water intrusion. Rising sodium (174 \rightarrow 490 mg/l) by 2025 raises concerns for hypertension risks, Soil sodicity if used for irrigation. Sulphate levels remain within limits but show gradual increase. High alkalinity (up to 860 mg/l) indicates strong buffering capacity and carbonate dominance. Organic & Nutrient Load, Low BOD (≤ 2.6 mg/L) and declining COD indicate limited organic pollution. Suggests no major industrial organic discharge. Nutrients (Nitrate, Ammonia, Phosphate). Nitrate-N remains low (< 1.35 mg/L), below health limits. Slight presence of ammonia and phosphate points to localized domestic or agricultural inputs. Suspended Solids, Turbidity & Iron

High turbidity in 2020–2021, followed by improvement. Iron exceeded limits in 2020 (1.52 mg/L), likely from geogenic sources. Later years show improvement, suggesting aquifer flushing or dilution. Microbiological Quality (Major Concern), Coliforms Fecal and Total Coliform counts increase continuously (2021–2025). Indicates progressive microbial contamination, likely from. Leaking septic systems poor sanitation shallow well vulnerability. Water is microbiologically unsafe for direct consumption.

Seawater Intrusion is clearly visible in our study, extremely high chloride content was observed in 2021, (3576.84mg/l), elevated TDS 6070mg/l, was also observed in 2021, along with high electrical conductivity 7356 $\mu\text{S}/\text{cm}$. Chloride is a conservative ion and a strong indicator of marine water mixing. The spike in 2021 suggests saline water encroachment into freshwater aquifers, likely due to, excess groundwater pumping, Reduced freshwater recharge, Tidal backwater effect, Cyclonic storm surge events. Rising sodium levels (490 mg/L in 2025) indicate, Base exchange reactions where Na^+ replaces Ca^{2+} and Mg^{2+} in aquifer sediments. Progressive salinization of groundwater. This is typical of coastal aquifers under saline stress.

Very high **total hardness (980 mg/L in 2021)**, elevated calcium and magnesium indicates, dissolution of marine-derived sediments evaporation concentration in shallow aquifers interaction between saline and freshwater zones tidal influence and fluctuating trends, the patterns observed are a peak salinity in 2021, 2022 -2023 showed a dilution phase and 2024 – 2025 witnessed a rising salinity again. Data set over a period of 6 years witnesses seasonal recharge impact, monsoon dilution, tidal pumping effect and microbial contamination in coastal lowlands, increasing coliform counts may be influenced by Floodwater intrusion, Surface–groundwater interaction, poor drainage in low-lying coastal terrain. The data set shows typical trends of coastal indicator with high chloride, TDS, Sodium and Hard water. These collectively confirm **coastal influence on groundwater chemistry**. Mechanism of Coastal Impact Over-pumping lowers freshwater table, Saline water moves inland, Ion exchange alters water chemistry, Monsoon recharge temporarily restores balance, Repeated stress leads to long-term salinization

Major findings of the study are, freshwater saltwater interaction strongly influences aquifer chemistry in coastal deltaic regions, the piper diagram helps in diagnosing water types and intrusion intensity excessive pumping and land use changes exacerbate groundwater degradation at sampling site. Monsoon recharge plays a critical role in temporal fluctuations of salinity level, poor sanitation and surface runoff contribute to coliform contamination. Statistical techniques enhance understanding of controlling factors in groundwater quality.

2020 samples cluster toward **Ca–Mg dominated facies**. 2021 shifts strongly toward **Na–Cl facies**, indicating saline intrusion. 2022–2023 show transitional mixed water type. 2024–2025 trend again toward **Na–Cl dominance**, confirming increasing coastal influence. Temporal Recovery Phase (2022–2023) Sharp decline in TDS and Chloride. Likely due to **monsoonal recharge and dilution effect**. Groundwater quality shows **strong temporal variability**. Evidence of **coastal influence and anthropogenic contamination**. Water is **not suitable for direct drinking** due to high salinity, hardness, and microbial contamination. Requires **treatment and sustainable groundwater management practices**.

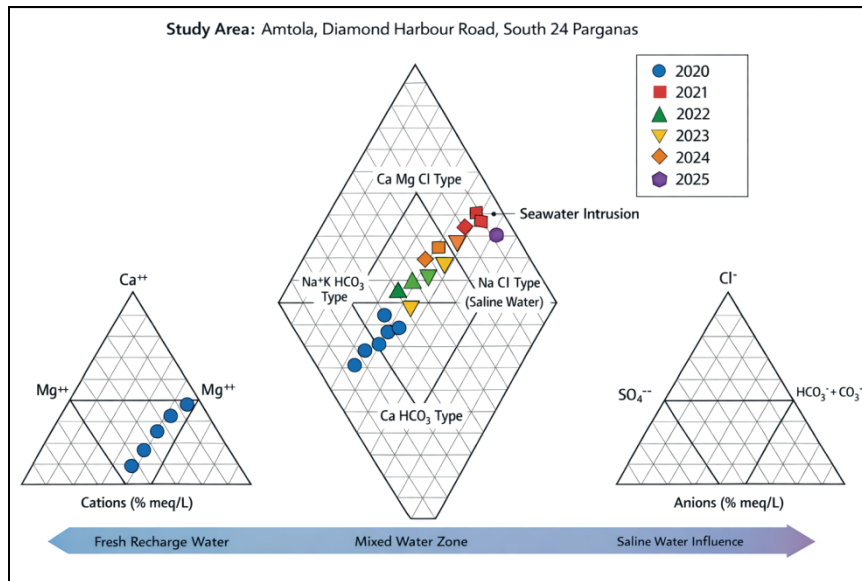


Figure 2: Piper Trilinear Diagram for your groundwater dataset (2020–2025) for Amtola, Diamond Harbour Road, South 24 Parganas, West Bengal, India.

The Piper trilinear diagram figure 2, indicates a temporal shift in hydrochemical facies from Ca–Mg dominated freshwater types toward Na–Cl facies, particularly during 2021 and again in 2024–2025. This transition reflects progressive seawater intrusion, ion exchange reactions, and fluctuating recharge conditions in the coastal aquifer system. The groundwater evolution pattern is characteristic of saline mixing processes in deltaic environments. Observed trend for cation triangle Interpretation ($Ca^{2+} - Mg^{2+} - Na^+ + K^+$), 2020–2021: Dominance of $Ca^{2+} + Mg^{2+}$, 2024–2025: Increasing dominance of Na^+ , Early phase water shows **alkaline earth dominance (Ca–Mg type)**. Later years show shift toward **alkali dominance (Na-type water)**. Rising sodium (490 mg/L in 2025) suggests Ion exchange reactions, Seawater mixing, progressive salinization, indicates transition from **fresh recharge water to saline influenced water**. Anion Triangle Interpretation ($Cl^- - SO_4^{2-} - HCO_3^-$). Observed Trend very high **chloride (especially 2021)**, Moderate sulphate, Alkalinity present but chloride dominant in peak years. Chloride dominance confirms **marine or saline intrusion influence**. Temporary reduction (2022–2023) suggests dilution from monsoonal recharge. Based on ionic dominance, groundwater likely falls into mixed freshwater with slight saline influence in 2020, (Ca – Mg – Cl) type water. While the year 2021 witnessed strong saline intrusion, water type was Na-Cl type. The year 2022- 2023 saw the dilution and transitional phase basically the mixed Ca – Na – Cl type. Year 2024- 2025 saw shifting trends again towards Na- Cl facies. The groundwater shows, **Recharge Water (Ca–HCO₃ type), Mixing Zone (Ca–Mg–Cl type)**

Saline Intrusion (Na–Cl type). This evolutionary trend is typical of **coastal deltaic aquifers**.

Statistical Analysis

Correlation Matrix of Selected Groundwater Quality Parameters

Pearson correlation matrix of selected groundwater quality parameters at Amtola (2020–2025) is represented in Table 3.

Table 3 : Correlation Matrix of Selected Groundwater Quality Parameters

Parameter	pH	TDS	Conductivity	Total Hardness	Chloride	Sodium	Total Coliform
pH	1.000	-0.412	-0.546	-0.356	-0.039	-0.450	0.125
TDS	-0.412	1.000	0.984	0.798	0.847	-0.319	-0.683
Conductivity	-0.546	0.984	1.000	0.743	0.747	-0.274	-0.710
Total Hardness	-0.356	0.798	0.743	1.000	0.901	0.041	-0.205
Chloride	-0.039	0.847	0.747	0.901	1.000	-0.306	-0.390
Sodium	-0.450	-0.319	-0.274	0.041	-0.306	1.000	0.780
Total Coliform	0.125	-0.683	-0.710	-0.205	-0.390	0.780	1.000

TDS shows a very strong positive correlation with conductivity ($r = 0.984$), confirming that dissolved ionic species are the major contributors to electrical conductance. Chloride exhibits strong positive correlation with total hardness ($r = 0.901$) and TDS ($r = 0.847$), indicating saline intrusion and mineral dissolution as dominant processes. pH shows weak to moderate negative correlations with most parameters, suggesting limited control over ionic concentration. Total coliform shows strong positive correlation with sodium ($r = 0.780$), implying anthropogenic influence such as domestic wastewater intrusion. Negative correlation of coliforms with TDS and conductivity suggests microbial contamination is influenced more by surface activities than mineral content.

Discussion

The combined assessment of physicochemical and microbiological parameters reveals that the groundwater at Amtola is severely affected by salinity, hardness, and microbial contamination. Although organic pollution is low, elevated TDS, chloride, sodium, and coliform counts significantly compromise water quality and public health safety.

Conclusion

The present study evaluated the temporal variation in groundwater quality from 2020 to 2025 in the coastal region of Amtola, Diamond Harbour Road. The analysis of physicochemical and microbiological parameters reveals significant hydrochemical

fluctuations influenced by both natural coastal processes and anthropogenic activities. The year 2021 recorded peak salinity levels, with extremely high TDS, conductivity, chloride, and hardness, indicating strong saline intrusion into the aquifer system. Although partial recovery was observed during 2022–2023, recent trends (2024–2025) show increasing sodium, chloride, and coliform concentrations, suggesting renewed salinization and growing microbial contamination. The Piper diagram interpretation confirms a temporal shift from Ca–Mg dominated facies toward Na–Cl type water, characteristic of seawater mixing and ion exchange processes in coastal aquifers. Groundwater in the study area is generally classified as very hard and moderately to highly mineralized. While pH, nitrate, and fluoride remain within permissible limits, elevated TDS, chloride, hardness, and coliform counts make the water unsuitable for direct consumption without adequate treatment. Overall, the findings highlight the vulnerability of the coastal aquifer system to seawater intrusion, over-extraction, seasonal recharge variability, and sanitation-related contamination. Continuous monitoring, controlled groundwater abstraction, artificial recharge measures, and integrated coastal aquifer management strategies are essential to prevent further degradation and ensure sustainable groundwater resources in this deltaic region. The groundwater chemistry of Amtola shows clear signatures of **coastal saline intrusion and tidal influence**, intensified by anthropogenic groundwater extraction and climatic variability. The temporal variability between 2020–2025 indicates that the aquifer is dynamically responding to both natural and human-induced stresses. Sustainable aquifer management, artificial recharge, controlled pumping, and periodic hydrochemical monitoring are essential to prevent irreversible salinization. The study area lies within the coastal alluvial plains of South 24 Parganas, where groundwater quality is strongly influenced by proximity to the Bay of Bengal, tidal dynamics of the Hooghly estuary, and intensive groundwater abstraction. The observed variations in groundwater quality parameters from 2020–2025 clearly reflect coastal hydrogeochemical controls. The present study demonstrates that groundwater quality at Amtola, Diamond Harbour Road, is deteriorating due to salinity intrusion and increasing microbial contamination. While pH and nutrient levels remain within acceptable limits, excessive TDS, hardness, chloride, sodium, and coliform presence render the water unsuitable for direct drinking purposes. Immediate implementation of groundwater management strategies, appropriate treatment methods such as desalination and disinfection, and regular monitoring are essential to protect public health and ensure sustainable groundwater use in coastal regions. Future studies should include seasonal sampling, hydrochemical facies analysis, water quality index (WQI) assessment, multivariate statistical analysis, and isotopic studies to better understand contamination sources and aquifer dynamics. Community-based awareness and policy interventions are also recommended. Understanding groundwater chemistry is essential for sustainable water management, especially in the context of drinking water supply, agriculture, and environmental conservation. Regular monitoring and analysis of groundwater chemistry help identify potential issues and guide appropriate remediation efforts when needed. The groundwater chemistry of Amtola shows clear signatures of **coastal saline intrusion and tidal influence**, intensified by anthropogenic groundwater

extraction and climatic variability. The temporal variability between 2020–2025 indicates that the aquifer is dynamically responding to both natural and human-induced stresses. Sustainable aquifer management, artificial recharge, controlled pumping, and periodic hydrochemical monitoring are essential to prevent irreversible salinization. Previous studies have reported elevated salinity, hardness, and microbial contamination in groundwater from coastal West Bengal, raising concerns about its suitability for drinking and irrigation. Despite its importance, long-term groundwater quality data for the Amtola region along Diamond Harbour Road remain limited. Therefore, the present study aims to assess the temporal variations in groundwater quality from 2020 to 2025, identify key contamination sources, and evaluate the overall suitability of groundwater for human consumption

Future Scope of Work

The present study provides a baseline understanding of groundwater quality at Amtola, Diamond Harbour Road, however, further investigations are required to strengthen long-term management and sustainability of groundwater resources in the region. Future investigations integrating hydrogeology, geochemistry, geophysics, and climate modeling will provide a comprehensive understanding of salinization dynamics in this vulnerable deltaic aquifer system. Such studies are crucial for ensuring sustainable water resource management in coastal regions of South 24 Parganas.

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