Environ Res Tec, Vol. 7, Issue. 1, pp. 41–60, March 2024

Environmental Research and Technology
https://ert.yildiz.edu.tr - https://dergipark.org.tr/tr/pub/ert
DOI: https://doi.org/10.35208/ert.1362577

Environmental Research & Technology

Research Article

Assessment of tube well water quality in selected residential areas in Khulna

Sumaya TABASSUM*[1], Jinat Tasnim DRISTY[2], Asif AHMED[2], Riyadul Hashem RIYAD[3]

[1]Khulna University, Soil, Water and Environment Discipline, Khulna, Bangladesh
[2]Department of Civil Engineering, Ahsanullah University of Science and Technology, Dhaka, Bangladesh
[3]Department of Civil Engineering and Construction, Georgia Southern University, Statesboro, USA

ARTICLE INFO

Article history
Received: 18 September 2023
Revised: 29 October 2023
Accepted: 14 November 2023

Key words:
Khulna residential areas; Physico-chemical and biological parameter; Standard limits; Tube well water quality

ABSTRACT

Clean water is vital for sustainable development, fostering socio-economic growth, ecological stability, and human survival. The study aimed to evaluate the quality of tube well water in specific residential areas of Khulna for drinking purposes, comparing it with the standards of World Health Organization (WHO) and Bangladesh (BD). Twenty tube well water samples were collected from residential areas at depths of 700–1500 ft. The samples were tasted with about 20 parameters, including physical: color, taste, odor, total dissolved solids (TDS) and total suspended solids (TSS); chemical: acidity/alkalinity (pH), arsenic (As), electrical conductivity (EC), dissolved oxygen (DO), bicarbonate (HCO_3^-), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), chloride (Cl^-), iron (Fe), phosphate (PO_4^{3-}), sulfate (SO_4^{2-}), potassium (K^+); and bacteriological parameters: total coliforms and *E. coli* bacteria. Most of the samples were found to have higher TDS (avg. 1380 mg/L), TSS (avg. 620 mg/L), Fe (avg. 20.2 mg/L), K^+ (avg. 194.1 mg/L), and Na^+ (avg. 439 mg/L) concentrations compared to the WHO and BD Standards. 90 to 95% of samples exhibited acceptable levels of EC, pH, DO, Mg^{2+}, Ca^{2+}, Cl^-, and SO_4^{3-}. The salinity levels in most of the samples were excessive to be used for drinking, and the levels were especially very high in samples S-01(Na^+ 820 and Cl^- 3195 mg/L) and S-04 (Na^+ 660 and Cl^- 2946 mg/L). The arsenic levels were found to be higher than acceptable limit in S-01 (0.086 mg/L) and S-04 (0.091 mg/L) as well. *E. coli* and other bacteria in a few samples (S-01, 04, 13, 16, 17, 19) were detected.

Cite this article as: Tabassum S, Dristy JT, Ahmed A, Riyad RH. Assessment of tube well water quality in selected residential areas in Khulna. Environ Res Tec 2024;7(1)41–60.

INTRODUCTION

Water plays a crucial role in the natural environment [1, 2], as it supports economic growth, guarantees food security, alleviates poverty, maintains ecological functions, and acts as a potentially limiting resource for both humans and other organisms [3–7]. The provision of a sufficient quantity and quality of water is essential in order to meet the growing needs of households, industries, and agriculture [8, 9]. Water can exhibit characteristics of both a renewable and nonrenewable resource, depending on its usage and rate of depletion. Therefore, it is imperative to prioritize the resolution of water quality issues and the exploration of efficient management approaches in different nations [10–14]. Groundwater serves as the predominant freshwater resource, with a fraction of it originating from rainfall [15],

***Corresponding author.**
*E-mail address: sumaritu.ku@gmail.com

Published by Yıldız Technical University Press, İstanbul, Türkiye
This is an open access article under the CC BY-NC license (http://creativecommons.org/licenses/by-nc/4.0/).

[16–18]. On a global scale, the extraction of groundwater for various purposes has had a substantial impact on socio-economic conditions. Approximately one-third of the global population is dependent on groundwater as a primary source of drinking water [19–21].

Trace amounts of soluble salts can always be found in groundwater. However, groundwater is unfit for agricultural use due to the lack of treatment in municipal sewage generated from decomposable solid waste [22–24], medical waste [25], and other sources, as well as unregulated industrial and agricultural practices. When this sewage infiltrates the ground, it can introduce harmful substances into the groundwater, making it unsuitable for irrigation. Degradation of the drinking water supply can occur if a combination of landfill leachate and wastewater contaminates groundwater sources [26, 27] and introduces harmful pollutants [28–31]. Further, people have reason to be concerned about the safety of groundwater due to the presence of harmful contaminants like pesticides, arsenic, nitrate, fluoride [32], mineral hardness, and iron [33]. In developing countries, 80% of illnesses and 30% of infant mortality rates have been linked to contaminated groundwater [34]. Modifications in the quality of groundwater arise from the interactions between water and rock, along with oxidation-reduction reactions that take place as water infiltrates through the aquifer system [35]. Shallow aquifers are deteriorating as a result of increased population density, extensive human endeavors, insufficient resource utilization, and a lack of efficient management protocols. Deeper aquifers generally have less arsenic contamination. Protecting them from biological and physico-chemical pollutants can be challenging due to their depth and location. Reduced chemical use [36], source protection [37], proper monitoring of contaminants, sustainable farming [38], waste diversion (e.g., biogas production from organic waste [39, 40]), and other measures can prevent groundwater contamination. These reasons may have limited effect on deep aquifers. Contaminants move slowly from the surface to deep aquifers. But persistent environmental contaminants can leach into deep aquifers over time.

Tube well water is generally believed to be devoid of microbial pollution owing to the inherent natural filtration capabilities of the underground environment [41–44]. In the context of Bangladesh, it is observed that a significant proportion of tube wells are situated in suboptimal locations, and their upkeep does not adhere to the sanitary inspection guidelines prescribed by United Nations International Children's Emergency Fund (UNICEF) and WHO [43], [45–48]. A considerable proportion of tube well water in Bangladesh is contaminated with microorganisms, specifically fecal organisms, thereby indicating the presence of contamination [46, 49–55]. Insufficiently constructed sanitary latrines are believed to be among the potential sources of contamination. Waterborne diseases constitute a prominent global health issue [54, 56–59]. The presence of impurities in drinking water possesses the capacity to engender a variety of illnesses, such as cholera, dysentery, typhoid, hepatitis, and diarrhea. Diarrhea occupies a prominent position within the realm of waterborne illnesses [59, 60–62], as it stands as a primary factor in the mortality of children, it is also estimated that the annual death toll of approximately 25 million individuals by consuming contaminated water [63]. The United Nations (UN) estimates that 2.5 billion people in developing nations lack adequate sanitation, and over half of this population lacks safe drinking water [63]. Groundwater is often referred to as the "hidden sea" due to its vast quantity and concealed nature [64–66]. This obscurity makes groundwater pollution pathways and processes difficult to see. The prioritization of microbial quality control in drinking water should be regarded as a matter of utmost importance for all nations [21, 50, 67–71]. Groundwater holds considerable socioeconomic importance due to its reduced treatment requirements, rendering it a financially viable alternative in comparison to surface water [71].

Coastal areas exhibit a vulnerability to increased levels of salinity in both surface and groundwater [72–76], which is distinguished by the occurrence of total dissolved solids (TDS) [75, 77] and specific chemical components: Cl^-, Na^+, Mg^{2+} and SO_4^{2-}. The Khulna Division is located in the southwestern coastal region of Bangladesh, where it faces notable difficulties such as salinity in the surrounding area and contamination of shallow aquifers with arsenic. The increase in salinity levels in Khulna can be attributed to the commencement of the Farrakka Barrage operation by India in 1975. The aforementioned development significantly reduced the water discharge of the Ganges River in the surrounding area [78–84]. The Ganges River, known as the Padma in Bangladesh, is situated to the northeast of Khulna city. Currently, the Khulna water supply system is exclusively dependent on groundwater as its primary source. The urban population of Khulna city is experiencing a consistent increase, resulting in an escalating need for water resources. Due to drought, river levels dropping, seawater intrusion during high tides, groundwater contamination, and natural arsenic, Khulna faces severe water scarcity [85, 86]. The evaluation of the origin and quality of groundwater is a vital obligation for the Khulna City Corporation, as the residents of this urban area heavily depend on this resource for their diverse needs.

The purpose of this study is to determine the groundwater (tube well) quality status in terms of various physical, chemical, and bacteriological parameters in different residential areas of Khulna. This research is emphasized because groundwater quality profoundly affects public health and the environment, making it essential for socioeconomic development, effective resource management, and sustainable use. The current research is undertaken due to the limitations of prior studies, which may have had a limited scope, outdated data, insufficient sampling, inadequate assessment of parameters, inconsistent data availability, and changing contamination sources, necessitating a comprehensive and up-to-date evaluation of groundwater quality's multifaceted significance for public health, environmental preservation, socioeconomic development, and resource management.

The primary goals of this study are to conduct a comprehensive evaluation of the deep tube well water quality in different residential regions of Khulna. The ultimate goal is to ensure the provision of safe and sustainable drinking water, while simultaneously protecting public health, the environment, and promoting socioeconomic development. The specific objectives of this study are:

- To evaluate the physical and chemical attributes of tube well water and compare them to the drinking water standards established by both Bangladesh and the WHO.
- To assess the biological conditions of the studied tube well water.

MATERIALS AND METHODS

Study Area

Khulna is situated in the south-western region of Bangladesh, adjacent to the Rupsha and Bhairab Rivers. The location is positioned within the geographical coordinates of 21.38° to 23.15° north latitude and 89.54° east longitude, with an elevation of approximately 30 feet above mean sea level. The area of the Khulna city corporation is 45.65 km^2. Salinity poses a significant challenge in coastal regions' groundwater [87, 88], while shallow aquifers are additionally burdened by the presence of high levels of arsenic. The Khulna City Corporation (KCC) is currently experiencing a severe shortage of adequate drinking water. To provide an overview of the current drinking water quality in four residential areas within the Khulna division, the following locations were chosen for analysis: Gollamari (including Islam Nagor, Banargati Road, Khorshed Nagor, Bank town, and Khulna University (KU), Sonadanga (covering Sonadanga bus terminal, road no 10, 12, 13, Link road, and M A Bari street), Nirala (encompassing road no 4, 13, 21, 23, and 26), and Moylapota (including Ikbal Nagor, Moilapota mor, Sandhya bazaar, Moilapota bypass road, and Basupara road). These areas are depicted in Figure 1.

A total of twenty tube well water samples were collected from various locations, with the sampling points selected in a random manner.

Sample Collection

A total of 20 high density polyethylene (HDPE) bottles with a capacity of 500 mL were purchased from a local market and subsequently utilized for the purpose of sample collection. The sample bottles went through a thorough washing process, consisting of four rinses with deionized water, followed by two rinses with the sample water. Subsequently, the samples were collected. A total of 20 water samples were collected from 20 tube wells within the designated area. Table 1 displays the depth of each sampling tube well and the corresponding duration of its installation.

To maintain a consistent water flow from the tube wells, they were subjected to continuous pumping for a duration of approximately one to two minutes before sampling. The sample bottles were carefully labeled with distinct sample identifiers, and thorough documentation regarding the sampling locations was diligently recorded for each drinking water source in a dedicated notebook. The provided information encompasses various specifics, such as the identities of the owners, depths of the wells, dates and times of installation, any documented concerns pertaining to the quality of drinking water, and additional relevant details. The HDPE bottles underwent a preliminary cleaning procedure involving rinsing with deionized water three times, followed by triple rinsing with tube well water prior to sample collection [89]. Subsequently, the collected samples were promptly preserved in a cooler with ice to keep them free from external contamination. The samples were expeditiously conveyed to the laboratory for experimental investigation and were preserved under freezing conditions, typically at approximately 4 °C.

Table 1. The depth of each sampling tube-well and its installation time

Sampling area	Sample ID	About depth of tube well water (in ft)	Installation duration (in year)
Islam Nagar	S-01	700	12
Banrgati road	S-02	900	8
Bank town	S-03	1100	15
Khorshed Nagar	S-04	980	26
Khulna university	S-05	1300	22
Nirala, road no 4	S-06	1200	7
Nirala, road no 13	S-07	1250	15
Nirala, road no 21	S-08	1400	17
Nirala, road no 23	S-09	1500	13
Nirala, road no 26	S-10	1050	5
Sonadanga bus terminal	S-11	1100	16
Sonadanga, road no 10	S-12	900	40
Sonadanga, road no 12	S-13	850	29
Sonadanga, road no 13	S-14	1000	12
Link road, M A Bari Street	S-15	850	17
Ikbal Nagar	S-16	650	9
Moilapota mor	S-17	700	13
Sandhya bazar	S-18	750	18
Moilapota bypass road	S-19	800	18
Basupara road	S-20	950	12

Source: Owners of each respective tube well.

Sample Analysis

Various methods were employed to evaluate a variety of physical, chemical, and bacteriological parameters at both sampling locations and in the laboratory, as outlined in Table 2.

Heavy metals such as manganese (Mn), cadmium (Cd), lead (Pb), chromium (Cr), etc. were not tested due to the limitations of the laboratory.

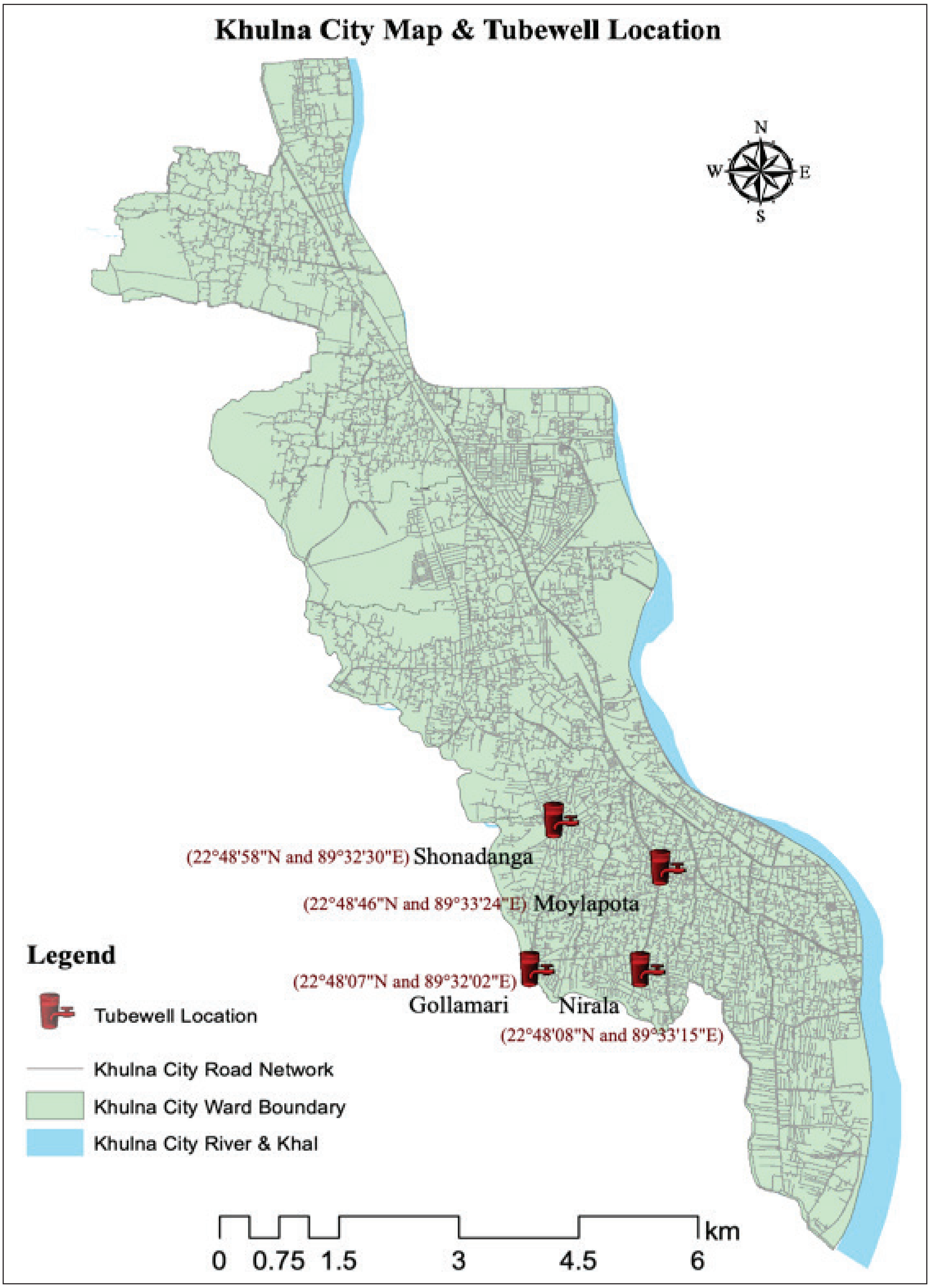

Figure 1. The map of the studied area (17, 23, 24, 25 no. wards were covered out of 31 in Khulna city corporation).

Physical Parameters

Color: The water samples were visually inspected in the laboratory immediately after collection, utilizing direct observation without the aid of any optical instruments.

Odor: The olfactory perception of the water samples is achieved through direct inhalation, allowing the individual to perceive the various odors through the sense of smell.

Taste: The taste of the water samples was assessed through direct consumption.

Total Solid (TS): 50 mL water samples collected from each tube well were transferred into 100 mL beakers and subjected to a 24-hour drying process in an oven at a temperature of 105 °C. The calculation of total solids involved determining the difference between the weights of empty beakers

Table 2. Methods employed for analyzing collected samples and the corresponding units of measurement for the studied parameters

Parameters	Methods		Units
	Temperature	**Temperature Probe**	**^oC**
Physical	Color	Visualization	–
	Taste	Tongue	–
	Odor	Smelling	–
	Total solids (TS)		mg/L
	Total dissolve solids (TDS)	Filtration, evaporation	mg/L
	Total suspended solids (TSS)	Filtration, evaporation	mg/L
Chemical	Acidity/Alkanity (pH)	Electrometric	–
	Arsenic (As)	Atomic absorption flame spectrometer	mg/L
	Bicarbonates (HCO^{3-})	Titrimetric	mg/L
	Calcium (Ca^{2+})	Titrimetric	mg/L
	Chloride (Cl^-)	Titrimetric	
	Dissolve oxygen (DO)	Electrometric	mg/L
	Electrical conductivity (EC)	Electrometric	μS/cm
	Iron (Fe)	Colorimetric	mg/L
	Magnesium (Mg^{2+})	Titrimetric	mg/L
	Potassium (k^+)	flame emission spectroscopic	mg/L
	Phosphate (PO_4^{3-})	Colorimetric (blue color)	mg/L
	Sodium (Na^+)	Flame emission spectroscopic	mg/L
	Sulfate (SO_4^{3-})	Turbidimetric	mg/L
Bacteriological	Total coliform (TC)	Spread plate	CFU/100 mL
	Fecal coliform (FC)	Spread plate	CFU/100 mL

and the weights of the same beakers containing residual total solids following the removal of water.

Total Dissolved Solids (TDS): A water sample of 50 mL is extracted from each tube well and subsequently subjected to filtration using Whatman 0.45-micron GF/F filter paper. The filtered water is transferred into 100 mL beakers and then undergoes a 24-hour drying process in an oven set at 105 °C. The quantification of TDS is accomplished by calculating the difference in mass between the empty containers and the containers holding the remaining solid substances after the removal of water.

Total Suspended Solids (TSS): After subtracting each sample's TDS value from its TS value, TSS values were recorded.

Chemical Analysis

The samples were subjected to analysis in the laboratories of the Discipline of Soil, Water, and Environment at Khulna University and the Department of Civil Engineering at Khulna University of Engineering and Technology.

pH: The water samples' pH levels are determined by a microprocessor pH meter (Sper Scientific 850051, USA).

Arsenic (As): A Shimadzu AA-7000 atomic absorption flame spectrometer was used to determine the arsenic content of each sample.

Bicarbonate (HCO_3^-): Titrimetric analysis employing a standard 0.086N H_2SO_4 solution is used to determine the concentrations of bicarbonate in the water samples [90].

Calcium (Ca^{2+}): The calcium concentrations in the water samples are determined through the utilization of a titrimetric technique, which involves the application of a standardized 0.01N Ethylenediaminetetraacetic acid (EDTA) solution [91].

Chloride (Cl^-): The concentration of chloride in the water samples is assessed using a titrimetric method involving the utilization of a standardized solution of 0.05N $AgNO_3$ [92].

Dissolved Oxygen (DO): A digital DO meter (Sper Scientific 850045, USA) was used to assess the levels of dissolved oxygen in the samples.

Electrical Conductivity (EC): A conductivity meter (Sper Scientific 850036, USA) was used to measure the electrical conductivity of the water samples.

Iron (Fe): The iron concentrations in the water samples are analyzed through a colorimetric technique using a spectrophotometer (APEL, PD–303 UV, Japan) set at a wavelength of 510 nm.

Magnesium (Mg^{2+}): Water samples were tested for their total calcium and magnesium content using a titrimetric method with a 0.01N EDTA standard solution [91]. The

Table 3. This table provides a summary of the measured physical parameters of water samples

Sample ID	Color	Odor	Taste	Temperature (°C)	TS (mg/L)	TDS (mg/L)	TSS (mg/L)
S-01	Yellowish	Odorless	Tasteless	27	5600	4000	1600
S-02	Colorless	Odorless	Tasteless	27	2000	1600	400
S-03	Colorless	Odorless	Tasteless	25	1200	800	400
S-04	Yellowish	Odorless	Tasteless	25	6000	4000	2000
S-05	Colorless	Odorless	Tasteless	26	1200	800	400
S-06	Colorless	Odorless	Tasteless	25	1200	800	400
S-07	Colorless	Odorless	Tasteless	27	800	400	400
S-08	Colorless	Odorless	Tasteless	25.4	1600	1200	400
S-09	Colorless	Odorless	Tasteless	25	2800	1600	1200
S-10	Colorless	Odorless	Tasteless	26.1	1200	800	400
S-11	Colorless	Odorless	Tasteless	26	1600	1200	400
S-12	Colorless	Odorless	Tasteless	25	1600	1200	400
S-13	Colorless	Odorless	Tasteless	25.5	2400	1600	800
S-14	Colorless	Odorless	Tasteless	24.8	2000	1200	800
S-15	Colorless	Odorless	Tasteless	25	2400	2000	400
S-16	Yellowish	Odorless	Tasteless	26	1600	1200	400
S-17	Colorless	Odorless	Tasteless	25	1200	800	400
S-18	Colorless	Odorless	Tasteless	25	1200	800	400
S-19	Colorless	Odorless	Tasteless	25	1600	1200	400
S-20	Colorless	Odorless	Tasteless	27	800	400	400

magnesium content was then determined by deducting the calcium content from the combined value.

Phosphate (PO_4^{3-}): The phosphate concentrations in the samples are analyzed using a colorimetric method, specifically the molybdophosphoric blue color technique, conducted with a spectrophotometer (APEL, PD–303 UV, Japan) at a wavelength of 882 nm [93].

Potassium (K^+): A flame photometer (JENWAY, PFP7, UK) was used to determine the potassium concentrations in the water samples.

Sodium (Na^+): A flame photometer (JENWAY, PFP7, UK) was used to determine the sodium concentrations in the collected water samples.

Sulfate (SO_4^{2-}): The turbidimetric method was employed to evaluate the sulfate levels in the water samples [94]. This was done using a spectrophotometer (APEL, PD-303 UV, Japan) configured to a wavelength of 420 nm.

Bacteriological Analysis

Following the guidelines from American Public Health Association (APHA) (2003) [95], the spread plate method was used to find out if the water samples had coliform bacteria or not. Eosin methylene blue agar (EMB) was used as a selective and differentiating medium to find coliform bacteria. It was used to find gram-negative bacteria in particular.

Total Coliform (TC): Labeling each tube with the water sample's source helped count total coliforms. Using a sterilized pipette, each sample's water was spread onto EMB agar plates. Each plate was incubated at 37 °C for 24 hours. In a laminar airflow chamber, the agar plates were placed. Total coliform bacteria in water samples were indicated by red or pink colonies on agar plates.

Fecal coliform (*E. coli* bacteria): After sterilizing a pipette, 1 mL of water from each sample was evenly spread on EMB agar plates to count fecal coliforms. All plates are incubated at 44.5 °C for 24 hours. Agar plates are placed in a laminar airflow chamber after incubation. *E. coli* (fecal coliforms) in water samples is indicated by blue-black colonies with a green metallic sheen on agar plates.

RESULTS AND DISCUSSION

Physical Parameter

Color, odor, taste, temperature, TS, TDS, and TSS are the physical parameters that were used in the experiment. Table 3 displays a summary of the measured physical parameters of the water samples.

TDS and TSS

In the studied area, the values for TS, TDS, and TSS exhibited a range of variability, with TS ranging from 800 to 6000 mg/L, TDS ranging from 400 to 4000 mg/L, and TSS

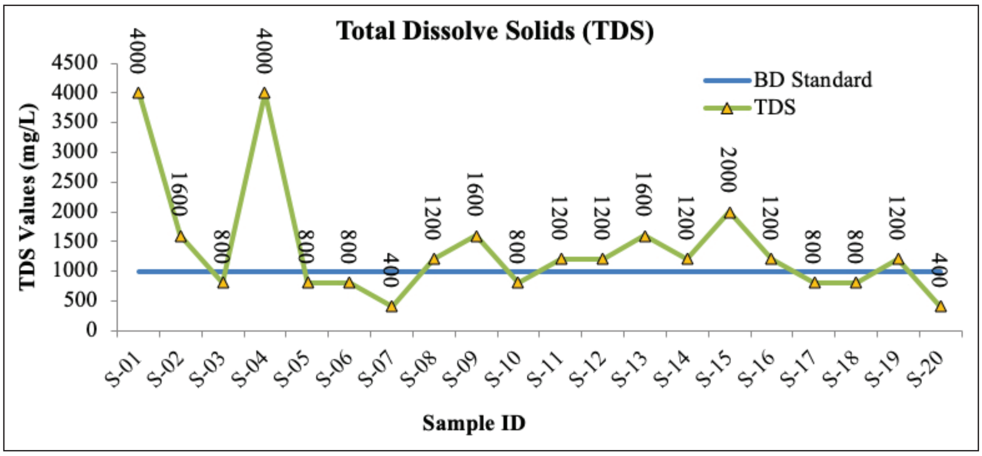

Figure 2. TDS values of the collected water samples.

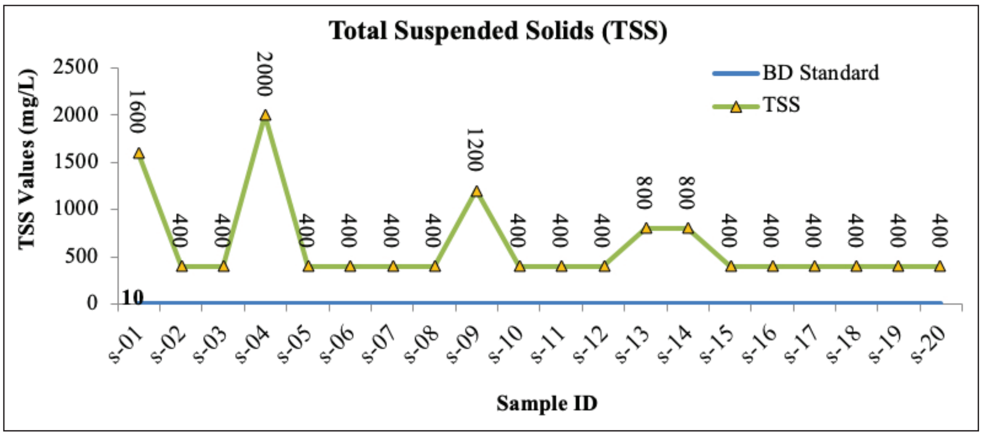

Figure 3. TSS values of the collected water samples.

ranging from 400 to 2000 mg/L. The TDS and TSS measurements of the groundwater in the investigated region are presented in Figures 2 and 3, respectively. These values are compared to the standard set by the ECR in 1997 (Environmental Conservation Rules 1997) known as the BD standard.

The BD regulations mandate TDS and TSS levels of roughly 1000 and 10 mg/L, respectively. According to these criteria, the analysis showed that most of the samples (12 samples) exceeded the recommended TDS values, while the remaining samples (8 samples) were within the acceptable range. Nonetheless, it's noteworthy that every sample was above the TSS limit. It's interesting to note that relatively optimum levels of TSS and TDS may aid in protection against cancer, heart disease, and other chronic illnesses.

Chemical Parameters

The evaluation of groundwater's solute load composition and potential chemical hazards relies heavily on the groundwat`er's chemical parameters. As, Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^-, SO_4^{2-}, and a variety of trace elements are among the common major components of natural water. Table 4 shows the values of the measured chemical parameters of the collected samples.

pH

The pH levels measured in the area were between 7.34 and 8.35. As can be seen in Figure 4, all of the samples had pH levels that fell within the boundaries recommended by both the WHO guidelines and the BD standard.

Arsenic (AS)

The majority of tube wells in the studied area were found to have arsenic levels below the acceptable limits set by both the BD standard (0.05 mg/L) and the WHO guideline (0.01 mg/L), as depicted in Figure 5.

However, two samples, S-01 (0.086 mg/L) and S-04 (0.091 mg/L), exceeded both limits. This indicates a potential arsenic problem in these wells, which could lead to various chronic health issues in humans, including symptoms such as nausea, vomiting, diarrhea, burning of the mouth and throat, and arsenicosis. It is advisable to refrain from the continuous consumption of water from these specific tube wells (S-01 and S-04) to mitigate the risk of these chronic diseases.

Electrical Conductivity (EC)

Figure 6 shows that the conductivity values of the samples from the studied area varied from 300 to 5000 µS/cm. With the exception of samples S-01 and S-04, all of the others were well below the BD standard's upper limit of 700 µS/cm.

Table 4. This table provides a summary of the measured chemical parameters of water samples

Sample ID	pH	As (mg/L)	EC (µS/cm)	DO (mg/L)	HCO^{3-} (mg/L)	Ca^{2+} (mg/L)	Cl^- (mg/L)	Fe (mg/L)	Mg^{2+} (mg/L)	SO_4^{2-} (mg/L)	PO_4^{3-} (mg/L)	K^+ (mg/L)	Na^+ (mg/L)
S-01	7.34	0.086	5000	6.91	683	36	3195	25	138	5	1.66	212	820
S-02	8.34	0.003	400	4.55	982	30	301	21.25	13	15	2.33	212	350
S-03	8.27	0.004	400	4.22	811	34	88	20	10.8	3	3.5	141	300
S-04	7.43	0.091	4800	6.80	725	118	2946	22.25	108	10	4.5	282	660
S-05	8.34	0.005	300	4.60	939	12	106	17.5	22.8	3.25	2.16	212	450
S-06	8.25	0.005	400	4.62	768	24	124	18.75	15.6	2.5	0.33	141	350
S-07	8.34	0.007	300	4.14	597	30	71	21.25	21.6	10	0.66	212	330
S-08	8.14	0.001	600	5.44	854	34	53	20	24	2.75	4.16	282	290
S-09	8.25	0.008	400	4.47	811	24	106	18.75	32.4	12.5	3.5	141	320
S-10	8.21	0.003	400	4.25	640	28	17.75	18.75	34.8	3.5	11.83	212	510
S-11	8.35	0.001	300	4.80	768	20	88	21.25	8.4	15	0.5	141	490
S-12	8.35	0.002	300	4.55	811	26	124	31.25	10.8	3	2.66	141	550
S-13	8.13	0.006	600	4.29	597	22	301	18.75	18	17.5	10	282	590
S-14	8.18	0.008	500	4.37	683	32	142	20	22.8	2.5	8.16	70.7	630
S-15	8.19	0.007	400	4.75	768	36	159	22.5	19	20	3.83	212	350
S-16	8.22	0.003	400	4.49	725	14	124	16.25	39.6	3	12.16	353	300
S-17	8.35	0.003	300	4.60	896	18	88	21.25	13	17.5	7.16	141	310
S-18	8.31	0.007	300	4.35	1110	12	159	16.25	19	2.75	4.83	212	360
S-19	8.29	0.004	400	4.25	982	22	142	15	12	15	5.83	70.7	400
S-20	7.93	0.004	600	4.29	512	28	124	17.5	18	3.25	5.5	212	420

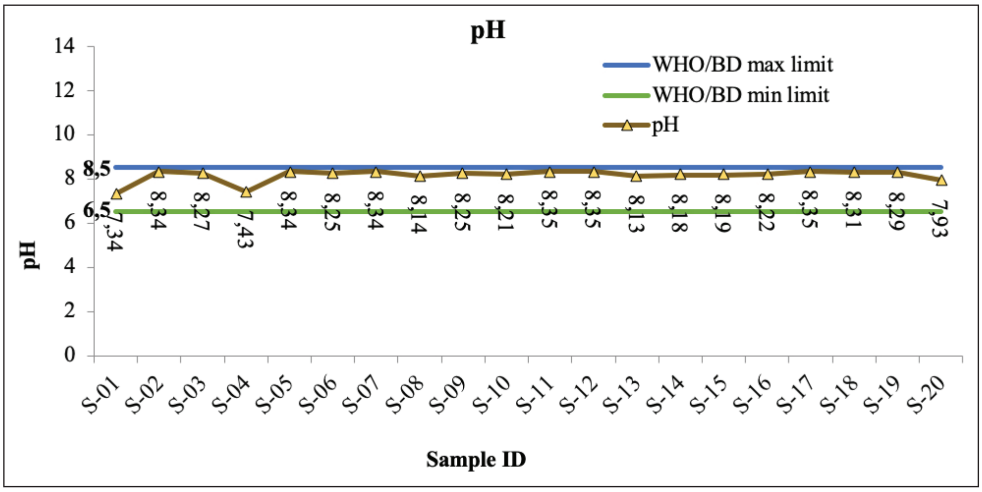

Figure 4. The pH values of the collected water samples.

Considerable evidence suggests that electrical conductivity (EC) is a useful indicator of the concentration of dissolved nutrients in water.

Dissolved Oxygen (DO)

Figure 7 shows that the DO values for the samples collected in the study area varied from 4.22 to 6.91 mg/L. With the exception of samples S-01 and S-04, all other samples (18 samples) were found to be below the BD limit of 6 mg/L.

Having enough DO in the water is essential for keeping it in good condition. Besides being crucial to aerobic organisms' metabolic processes, DO also contributes a role in influencing inorganic chemical reactions.

Bicarbonates (HCO_3^-)

The carbonate form was not detected in any of the samples. The HCO_3^- content in the samples within the studied area varied between 512 and 1110 mg/L, as illustrated in Figure 8. 85% of the samples (17 samples), apart from other 15% (S-07, S-13, and S-20), exhibited higher bicarbonate levels than the BD standard (600 mg/L).

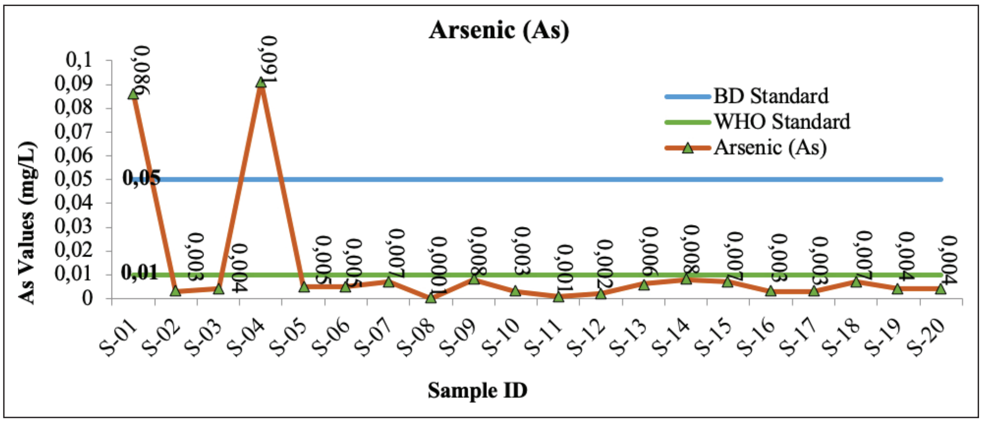

Figure 5. The As values of the collected water samples.

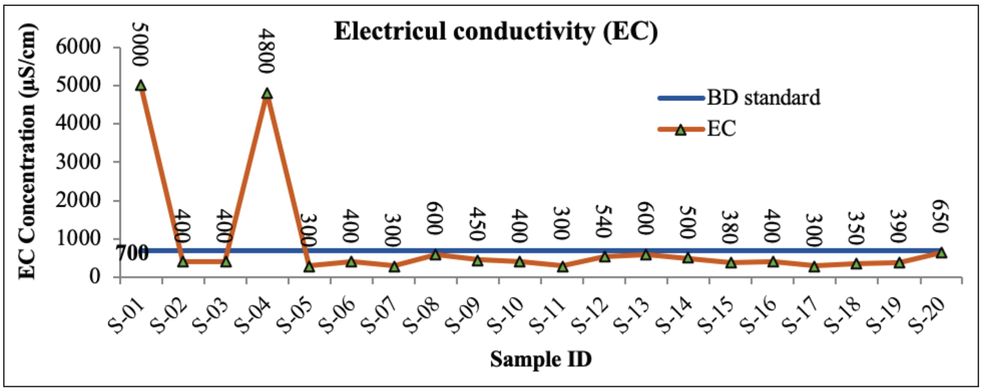

Figure 6. EC values of the collected samples.

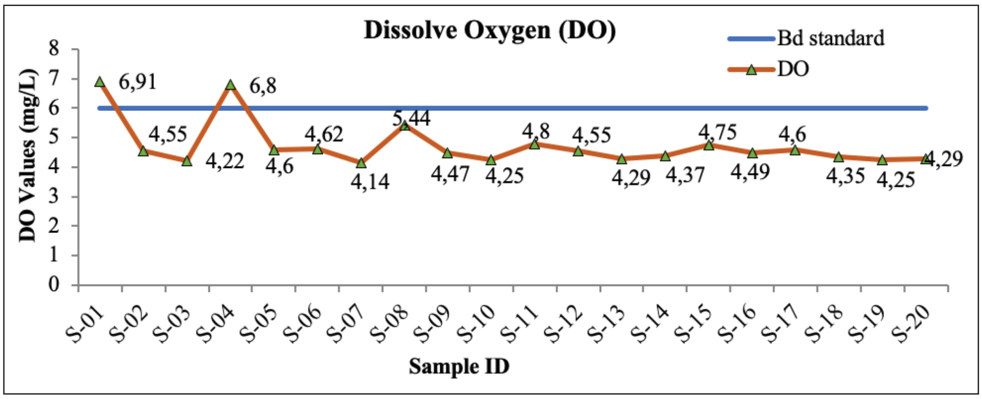

Figure 7. DO values of the collected water samples.

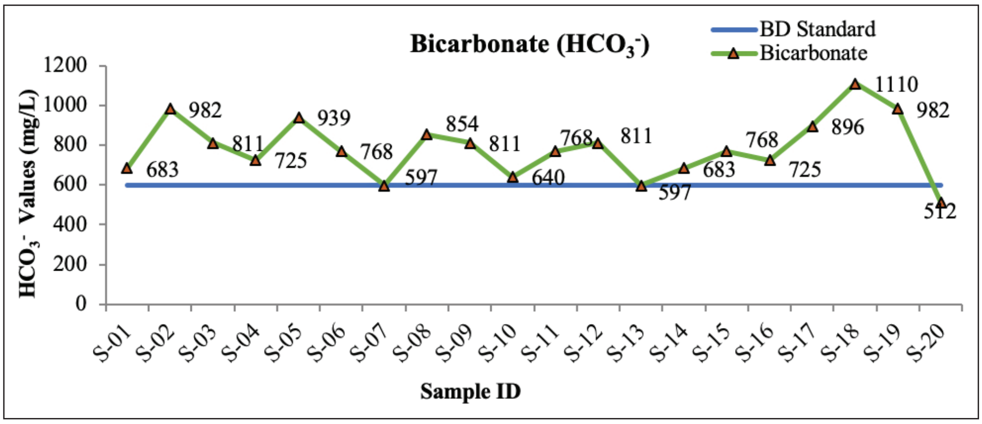

Figure 8. Bicarbonate values of the collected samples.

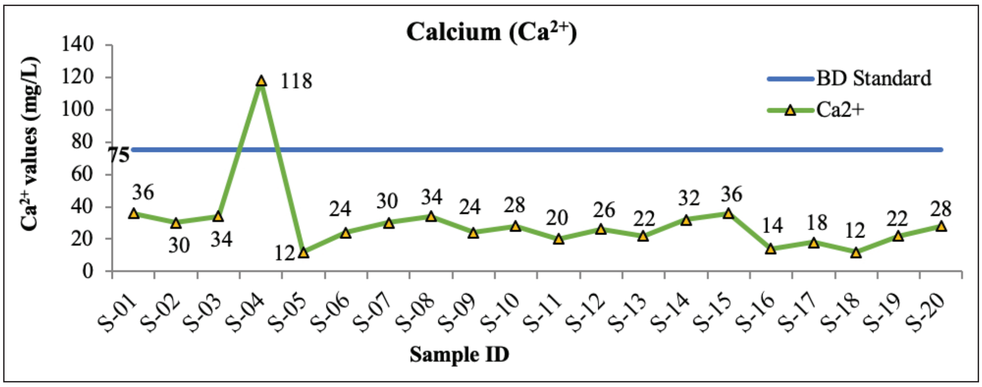

Figure 9. Calcium concentration of the collected water samples.

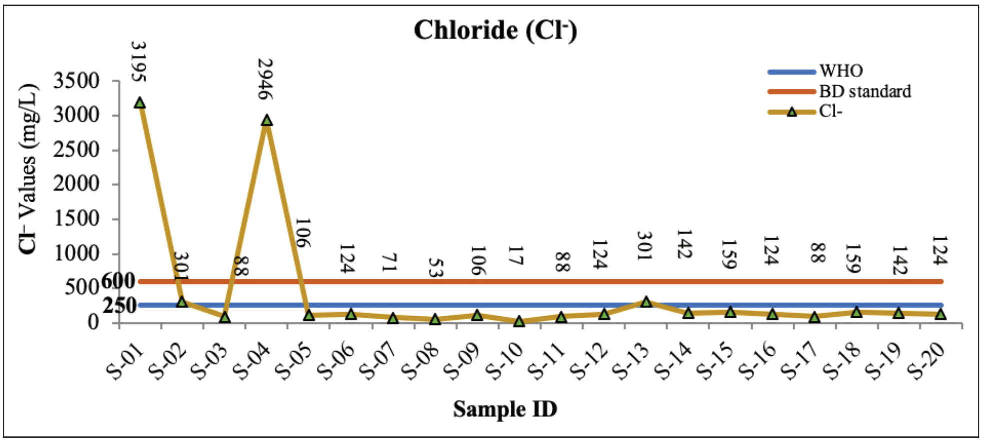

Figure 10. Chloride concentrations of the collected samples.

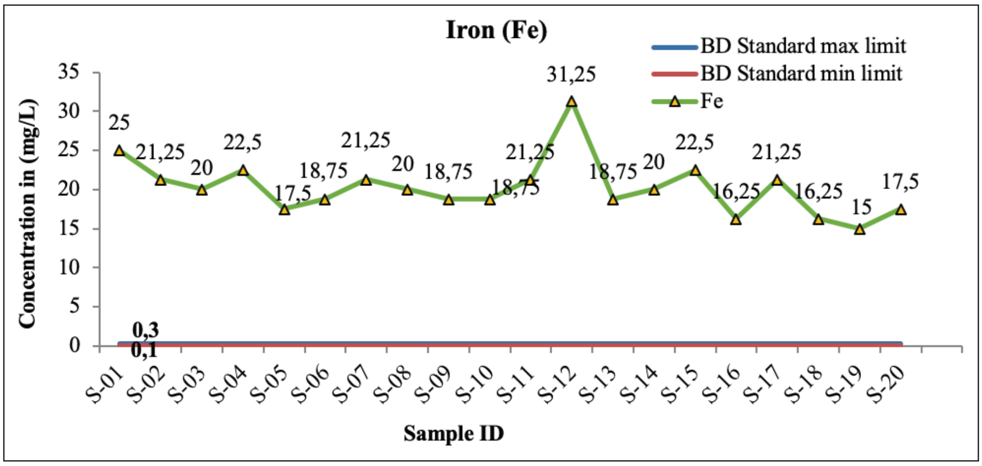

Figure 11. Iron concentrations of the collected water samples.

The acidity of food can be mitigated by consuming an adequate amount of HCO_3^-, which also acts as a buffer for lactic acid produced during exercise. Additionally, it helps keep cavities under control.

Calcium (Ca^{2+})

The calcium content of the samples within the studied area displayed a range of 12–118 mg/L, as depicted in Figure 9. 19 samples out of 20 exhibited calcium concentrations close to the recommended standard of 75 mg/L (BD standard), with the exception of one sample (S-04) which had a calcium concentration of 118 mg/L. The activity of cell membranes and the body's pH both depend on adequate calcium levels.

Chloride (Cl^-)

Figure 10 shows that the chloride concentrations in the samples collected in the study area ranged widely from 17.75 to 3195 mg/L.

Most samples had chloride concentrations below the min-

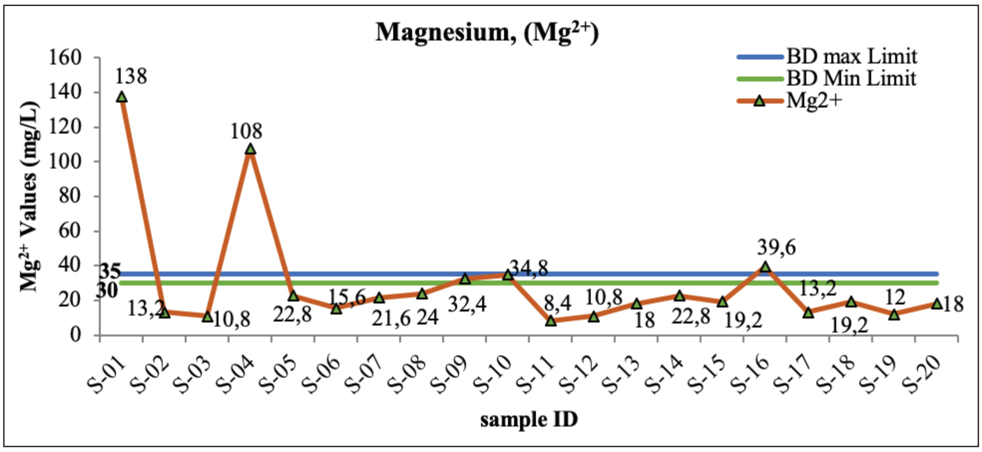

Figure 12. Magnesium concentrations of the collected water samples.

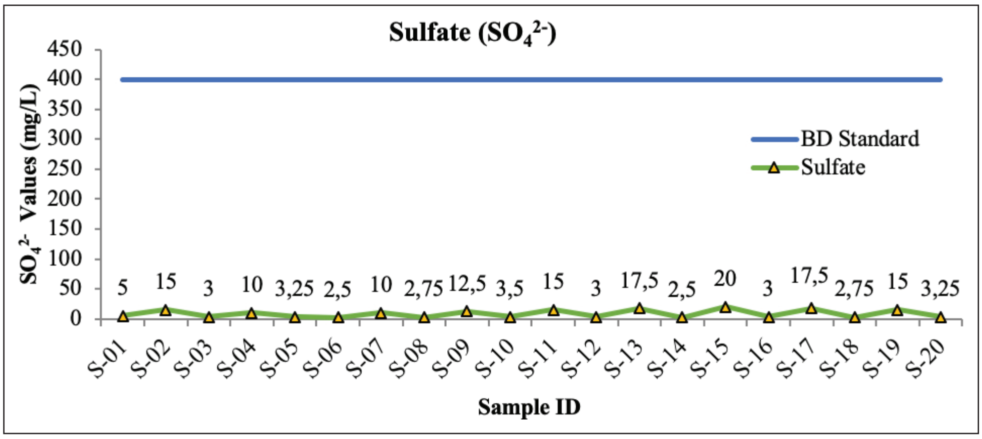

Figure 13. Sulfate concentrations of the collected water samples.

imum and maximum levels allowed (250 mg/L for WHO and 150–600 mg/L for BD, respectively). Two samples, S-01 and S-04, in particular, showed significantly high chloride concentrations. Chloride is essential for the body to keep its fluid levels stable.

Iron (Fe)

The iron concentrations within the samples collected from the study area displayed a range of 15–31.25 mg/L, as illustrated in Figure 11. Notably, all of the samples well exceeded the iron content standard from 0.1 to 0.3 mg/L (BD standard). The iron contents are pretty much concentrated in water samples. Among them S-12 has the highest (31.25 mg/L) and S-19 has the lowest (15 mg/L) concentration.

Symptoms like nausea and vomiting may manifest due to an iron overload, which can lead to serious conditions like diabetes and hemochromatosis, as well as digestive tract problems.

Magnesium (Mg^{2+})

As shown in Figure 12, magnesium concentrations in the samples collected from the study area varied from 8.4 to 138 mg/L. Except for two samples (S-01 and S-04), all of the others were within the tolerance range of 30–35 mg/L (BD standard), which is notable. Magnesium plays a vital role as an activator of enzymes and is essential for the regulation of neuromuscular excitability and cellular permeability.

Sulfate (SO_4^{2-})

As shown in Figure 13, the sulfate concentrations in the samples taken from the study area varied from 2.5 to 17.5 mg/L. Notably, the SO_4^{2-} levels in all of the samples were significantly lower than the Bangladesh standard of 400 mg/L. Severe chronic diarrhea caused by high sulfate levels is possible, and in extreme cases, it can be fatal.

Phosphate (PO_4^{3-})

Figure 14 depicts the observed range of phosphate concentrations within the samples, which was between 0.33 and 12.16 mg/L.

15 samples out of 20 had concentrations that were below the BD-recommended threshold of 6 mg/L. Elevated levels of PO_4^{3-} were found in four samples (S-10, S-13, S-14, S-16, and S-17), though. DNA materials contain phosphates, and phosphates play an important role in the distribution of energy throughout the body.

Potassium (K^+)

The potassium content observed in the samples from the

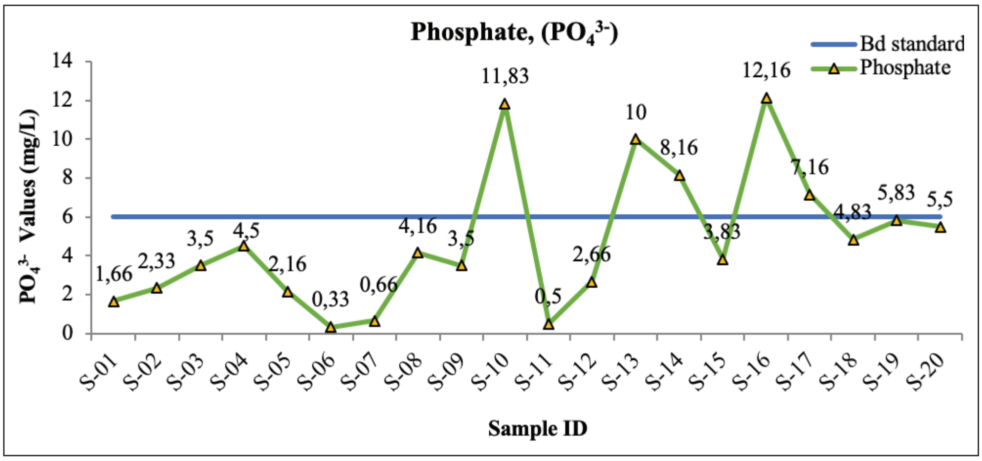

Figure 14. Phosphate concentration of the collected water samples.

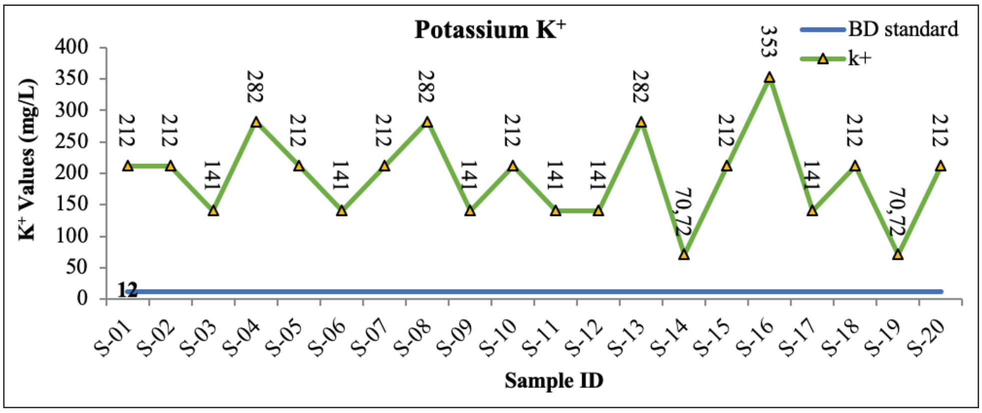

Figure 15. Potassium concentration of the collected water samples.

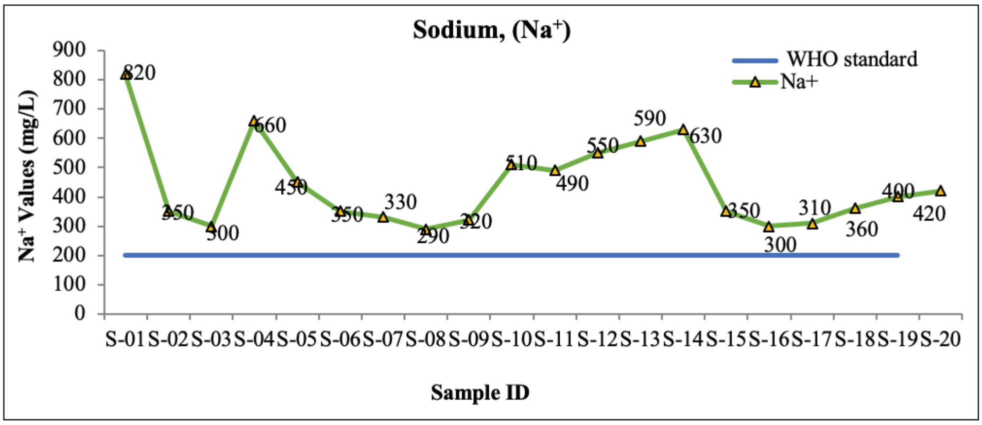

Figure 16. Sodium concentrations of the collected water samples.

study area displayed a range of 70.72 to 353 mg/L, as depicted in Figure 15. Significantly higher levels of K^+ were found in all samples compared to the Bangladesh standard of 12 mg/L. Elevated concentrations of potassium in the body have the potential to induce detrimental health consequences, such as renal dysfunction, cardiac arrhythmias, and hyperkalemia.

Sodium (Na^+)

Sodium concentrations in the studied area's samples ranged from 290 to 820 mg/L, as depicted in Figure 16. All samples were found to have Na^+ concentrations well above the recommended upper limit of 200 mg/L (WHO and BD standard). A high sodium intake has been linked to an increased risk of developing osteoporosis, stomach cancer, kidney disease, kidney stones, cardiomyopathy, and migraines.

Bacteriological Analysis (TC and FC)

Most samples do not have any detectable levels of coliform bacteria. Figure 17 shows that *E. coli* bacteria are present in only 6 of 20 samples.

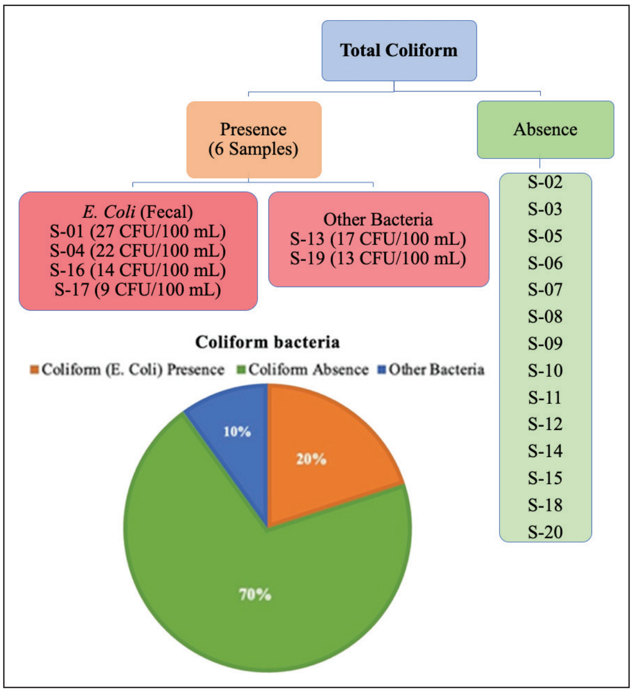

Figure 17. Total coliform and E. coli bacterial counts in tested samples.

There is a disproportionately high concentration (visual observation) of *E. coli* in two of the samples (S-01 and S-04). Acute diarrhea, abdominal cramps, nausea, headache, vomiting, and fever are just some of the symptoms of a disease brought on by *E. coli* in the water supply. It's possible that at sufficiently high concentrations, human life might become dead. Possible causes include insufficient tube well depth, a lack of proper sanitation (for example, a short distance between toilets and tube wells), or a lack of quality soil (which would otherwise filter out bacteria in groundwater being pumped from great depths).

DISCUSSIONS

In our study, the average TDS concentration was measured at 1380 mg/L. A comparative study conducted across nine Upazilas in the Khulna region reported a similar TDS concentration of 1089 mg/L, which is slightly lower than the value obtained in this study [96]. It is important to note, though, that the TDS level was much higher in the Khulna district (averaging 1,556.05 mg/L) and in Shyamnagar, Satkhira (averaging 3,691 mg/L), which is higher than the TDS level found in this study [97, 98]. It is important to note that the pH levels in the groundwater samples were between 7.34 and 8.35. This is similar to what another study found, which was a pH of 7.85±0.40, showing that the pH values are similar [96, 99]. Another study was also found an average pH value of 7.89±0.2, which backs up the idea that our results are similar to theirs [99]. The average As content in our study was determined to be 0.013 mg/L, which falls below the established standards in BD and closely aligns with the findings of a study that reported an average As concentration of 0.017 mg/L [96, 100]. As levels were also

Table 5. Correlation coefficient between the physical parameters

Parameters	TS	TDS	TSS
TS	1		
TDS	0.988	1	
TSS	0.942	0.878	1

the same in a different study done in the coastal Shyamnagar sub-district of the Satkhira district. It was found to be 0.0166 mg/L, which shows that As levels are consistent in coastal areas [97]. The EC values exhibited a range from 300 to 5000 µS/cm in this study, with a mean value of 855 µS/cm. Another study that was done in the Khulna district found that EC values varied similarly, ranging from 498 to 5,910 µS/cm, which backs up what we found [98]. In addition, it is worth mentioning that EC values were much higher in the nearby district of Shyamnagar, Satkhira. They were about 7,135.67±3,433.58 µS/cm, which is a lot more than the values we found [97].

Apart from samples S-01 and S-04, all samples exhibited DO levels below the established limits in Bangladesh, and this trend is consistent with the findings presented by Mahmud et al. [99] in 2020, where they reported an average DO concentration of 1.61 mg/L in their study of Khulna city. Additionally, another independent study observed a lower average DO value of 3.07 mg/L during the pre-monsoon season in Khulna [101]. These collective findings across different studies underscore the suboptimal status of dissolved oxygen levels in this region, falling significantly below the standard requirements. The chloride (Cl^-) values displayed a wide range, spanning from 17.75 to 3195 mg/L, indicating significant variability. This variation aligns with findings from a 2022 study conducted in the northern part of Khulna city, where the Cl^- content was observed to fluctuate from 21 to 2063 mg/L [102]. Similarly, another study in the Khulna city region reported a comparable range of Cl^- content, ranging from 10 to 3550 mg/L [96]. Notably, a recent investigation in a coastal area of the Satkhira district documented a substantially higher Cl^- content, with an average of 2,940.78±1,563.5 mg/L, which is approximately 6.5 times greater than the average value observed in this study [97]. Also, the average chloride level was recorded at 2,005.74±2,685.5 mg/L in coastal areas like Khulna, Bagerhat, Satkhira, and Patuakhali [103]. This is a lot higher than the levels seen in this study. This substantial chloride concentration is regarded as an indicative measure of the overall salinity levels, as chloride levels are closely associated with salinity. Hence, the salinity issue in the Khulna district is a matter of concern, as there is ample documentation highlighting the detrimental impact of salinity on human health [104]. The increased salinity levels in the area could be attributed to the dissolution of salts such as NaCl, Na_2CO_3, KCl, and $CaCl_2$ from processes such as weathering and rock leaching, the influx of seawater through tidal channels [105], brine shrimp aquaculture activities [106], and the discharge of industrial waste and sewage [107]. Studying high school students in Massachusetts and Chi-

Table 6. Correlation coefficient between the physical parameters

Parameters	pH	As	EC	DO	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	Fe	SO_4^{3-}	PO_4^{3-}	HCO^{3-}
pH	1												
As	-0.929	1											
EC	-0.953	0.993	1										
DO	-0.869	0.912	0.933	1									
Ca^{2+}	-0.687	0.747	0.723	0.680	1								
Mg^{2+}	-0.924	0.954	0.961	0.892	0.599	1							
Na^{+}	-0.697	0.698	0.713	0.596	0.403	0.680	1						
K^{+}	-0.329	0.241	0.267	0.311	0.229	0.341	-0.016	1					
Cl^{-}	-0.932	0.992	0.996	0.924	0.699	0.955	0.719	0.254	1				
Fe	-0.217	0.308	0.317	0.386	0.279	0.249	0.413	-0.100	0.335	1			
SO_4^{3-}	0.119	-0.034	-0.055	-0.040	0.063	-0.139	-0.094	-0.086	-0.020	0.038	1		
PO_4^{3-}	0.019	-0.158	-0.139	-0.247	-0.088	-0.037	0.039	0.309	-0.165	-0.375	-0.042	1	
HCO^{3-}	0.387	-0.187	-0.215	-0.080	-0.225	-0.246	-0.366	-0.226	-0.173	-0.153	0.083	-0.228	1

cago, USA, researchers hypothesized that those living in areas with high salinity (272 mg/L) in their public drinking water would have higher systolic and diastolic blood pressure, with values elevated by 3–5 mmHg compared to those living in areas with low salinity (20 mg/L) [104].

The average iron (Fe) content was determined to be 20.18 mg/L, which is notably higher, approximately three to four times, than a study conducted in the coastal region of Khulna. In the Khulna study, the average Fe content was reported as 6.24±8.41 mg/L during the wet season and 5.13±7.02 mg/L during the dry season [103]. Additionally, a different study done in Shyamnagar and Assasuni in the Satkhira district found groundwater with Fe levels that were about four times lower, at 4.9±4.76 mg/L and 3.59±2.50 mg/L, respectively [54, 97]. In a recently conducted study within the northern part of Khulna city, which is not in proximity to the sea, notably lower Fe concentrations were observed in their sampled water, ranging from approximately seven to twenty times lower than the Fe levels found in our study [102].

Statistical Analysis

Correlation Between Physical Parameters

Table 5 presents the correlation analysis results between TS, TDS, and TSS. The findings reveal strong correlations among these variables, with TS exhibiting a notably robust positive correlation with TDS (r=0.988) and TSS (r=0.942). Similarly, TDS and TSS also demonstrate a strong positive correlation (r=0.878). These strong correlation coefficients suggest a significant and interrelated association between the variables, indicating their close connection within the dataset.

Correlation Between Chemical Parameters

Table 6 presents the correlation analysis results between pH, As, EC, DO, calcium, magnesium, sodium, potassium, chloride, iron, sulfate, phosphate, and bicarbonate.

pH exhibits a negative correlation with most parameters, except for SO_4^{3-} (r=0.119), PO_4^{3-} (r=0.019), and HCO_3^- (r=0.387). Notably, the correlation between pH and HCO_3^- is comparatively stronger, signifying a more pronounced association between these two variables within the dataset. Whereas As is positively correlated with all the parameters except the above three parameters. As is very strongly correlated with EC (0.993), DO (0.912), Mg^{2+} (0.0.954) and Cl^- (0.992). Conversely, As demonstrates positive correlations with all parameters, except for SO_4^{3-}, PO_4^{3-}, and HCO_3^-. Particularly noteworthy is the remarkably strong positive correlation observed between As and EC (r=0.993), DO (r=0.912), Mg^{2+} (r=0.954), and Cl^- (r=0.992). EC exhibits a pattern akin to that of As, as it showcases notably strong correlations with DO, Mg^{2+}, and Cl^-. DO is showing negative correlation with SO_4^{3-} (r=-0.04), PO_4^{3-} (r=-0.247), and HCO_3^- (r=0.0.080) among all the parameters. Conversely, the positive correlation observed with other variables suggests that they exhibit synchronized changes, increasing or decreasing in a similar manner in response to variations in the dataset. Ca^{2+} exhibits strong correlations with four parameters, namely As, EC, DO, and Cl^-. The correlation coefficient values for these associations range from 0.680 to 0.747, indicating a substantial and positive relationship between Ca^{2+} and these parameters. Mg^{2+} also demonstrates positive correlations with 10 chemical parameters out of 13. Notably, it exhibits the most negative correlation with HCO_3^-, with a coefficient value of -0.246. Conversely, Na^+ reveals predominantly positive correlations with the parameters. There are only three instances of negative correlation, specifically with K^+ (r=0.016), SO_4^{3-} (r=-0.094) and HCO_3^- (r=-0.366). It is intriguing to note that K^+ consistently lacks a very strong positive correlation with any parameters. The positive correlation coefficients vary in the range of 0.229 to 0.341. Fe is also demonstrating a pattern like that of K^+. Among all the positive correlations of Cl^- with other parameters, the correlation with Fe (r=0.335) is relatively weak. SO_4^{3-}, PO_4^{3-}, and HCO_3^- consistently exhibit negative correlations with all parameters except pH, as well as between SO_4^{3-} and HCO_3^- themselves.

Water Quality Status

The comprehensive analysis of the experiment reveals that the examined physical parameters, namely color, odor, and taste, fall within acceptable ranges. However, a significant proportion of the samples exhibited relatively elevated concentrations of TDS and TSS compared to the established standards for drinking water. In terms of chemical parameters, the pH levels were generally within acceptable limits for drinking purposes.

Most of the samples met the prescribed standards for DO (90%), Cl^- (80%), Mg^{2+} (85%), EC (90%), and Ca^{2+} (95%), making them suitable for drinking purposes. SO_4^{2-} levels were notably lower than the acceptable limit. On the contrary, concentrations of Fe, K^+, Na^+ for all the samples, and, in the case of HCO_3^-, the majority (85%) exceeded the standard ranges for drinking water.

Furthermore, Total Coliform (TC) bacteria were detected in 30% of the samples, with 20% of these instances being *Escherichia coli* (*E. coli* or FC), and the remaining 10% consisting of other types of bacteria. It's important to note that samples meeting acceptable limits for specific parameters may be considered safe for drinking in terms of those particular criteria, while others may not meet the required standards for various parameters, thus impacting their overall suitability for consumption.

Specific parameters related to color, taste, odor, pH, EC, DO, As, Ca^+, Cl^-, SO_4^{3-}, and Mg^{2+} were generally suitable for drinking, except for a couple of samples. However, TDS, TSS, Na^+, K^+, Fe, HCO_3^-, and PO_4^{3-} levels in all samples were not conducive for drinking.

It is crucial to highlight that coliform bacteria were more prevalent in samples from shallow-depth tube wells, emphasizing the importance of using water from relatively deeper tube wells for drinking to mitigate health risks. The high salinity levels observed in the studied regions render the water unsuitable for drinking, suggesting the potential benefit of utilizing deeper tube wells. Furthermore, the elevated arsenic concentrations in tube wells at Islam Nagar and Khorshed Nagar pose significant health risks, warranting the discontinuation of their use.

While these findings shed light on the water quality in the investigated areas, ongoing monitoring and remediation efforts are essential to ensure safe and accessible drinking water for the local population.

However, it's important to note several limitations in the study:

1. Not all parameters, including trace and toxic elements like Cu, Zn, Pd, Cd, nitrogen species, etc., were analyzed in this study.
2. Limited laboratory facilities may have affected the ability to conduct experiments comprehensively and accurately for certain elements.

CONCLUSION

In summary, the findings of this study provide valuable insights into the quality of tube well water in the investigated regions. While the recorded water temperatures, color, taste, and odor generally met the standard criteria, there were exceptions with some samples exhibiting a slightly yellowish hue. Notably, most samples exhibited elevated TSS values, which significantly exceeded established standards while the TDS values are moderately higher.

The pH levels and parameters such as DO, EC, and Cl^- adhered to recommended conditions for safe drinking, with a few exceptions. Most samples did not contain harmful levels of As, although samples from specific areas showed elevated levels beyond acceptable limits.

Calcium and magnesium ion concentrations were within acceptable ranges for most samples, while iron concentrations exceeded recommended standards across the board. A substantial percentage of samples exhibited acceptable phosphate levels. Bicarbonate concentrations were marginally below standards in only a few samples, with higher levels in the rest. Sodium and potassium ions were present at elevated concentrations in all samples.

While approximately 70% of the samples were free from coliform bacteria, the presence of *E. coli* and other coliform bacteria in 20% and 10% of the samples, respectively, suggests the need for vigilance.

ACKNOWLEDGEMENTS

I want to express my sincere and profound gratitude to my respected supervisor, Dr. Khandoker Qudrata Kibria, Professor, Soil, Water and Environment discipline, Khulna University, for his scholastic guidance, valuable suggestions, instructions, and time throughout the progress of this research work and at the preparation of this research. I sincerely thank Professor Dr. Shaikh Motasim Billah, Chair, Soil, Water and Environment Discipline, Khulna University, for providing all possible facilities during this project. Authors also want to thank Civil Engineering Department, Khulna University of Engineering & Technology for their suppor. There was no funding to support this study.

DATA AVAILABILITY STATEMENT

The author confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

REFERENCES

[1] K. Roy, Q. Bari, S. Mostakim, and D. B. P. Argha, "Water supply history of Khulna City," 2019.

[2] P. Roy, M. A. Ahmed, and A. Kumer, "An overview of hygiene practices and health risks related to street foods and drinking water from roadside restaurants of Khulna city of Bangladesh," EJERE, Vol. 3(2), pp. 47–55, 2019.

[3] S.-H. Chong, and S. Ham, "Interaction with the surrounding water plays a key role in determining the aggregation propensity of proteins," Angewandte Chemie International Edition, Vol. 53(15), pp. 3961–3964, 2014. [CrossRef]

[4] R. V. Southwell, S. L. Hilton, J. M. Pearson, L. H. Hand, and G. D. Bending, "Water flow plays a key role in determining chemical biodegradation in water-sediment systems," Science of The Total Environment, Vol. 880, Article 163282, 2023. [CrossRef]

[5] W. J. Cosgrove, and D. P. Loucks, "Water management: Current and future challenges and research directions," Water Resources Research, Vol. 51(6), pp. 4823–4839, 2015. [CrossRef]

[6] M. F. Chaplin, "Water: its importance to life," Biochemistry and Molecular Biology Education, Vol. 29(2), pp. 54–59, 2001. [CrossRef]

[7] Kasim, D. Gursoy, F. Okumus, and A. Wong, "The importance of water management in hotels: a framework for sustainability through innovation," Journal of Sustainable Tourism, Vol. 22(7), pp. 1090–1107, 2014. [CrossRef]

[8] F. Hamzaoui-Azaza, M. Ketata, R. Bouhlila, M. Gueddari, and L. Riberio, "Hydrogeochemical characteristics and assessment of drinking water quality in Zeuss–Koutine aquifer, southeastern Tunisia," Environmental Monitoring and Assessment, Vol. 174(1), pp. 283–298, 2011. [CrossRef]

[9] P. Roy, M. A. Ahmed, Md. S. Islam, Md. A. K. Azad, Md. S. Islam, and Md. R. Islam, "Water supply, sanitation system and water-borne diseases of slum dwellers of Bastuhara Colony, Khulna," presented at the 5th International Conference on Civil Engineering for Sustainable Development (ICCESD 2020), Khulna, Bangladesh: Department of Civil Engg., KUET, 2020.

[10] S. Varol and A. Davraz, "Evaluation of the groundwater quality with WQI (Water Quality Index) and multivariate analysis: a case study of the Tefenni plain (Burdur/Turkey)," Environmental Earth Sciences, Vol. 73(4), pp. 1725–1744, 2015. [CrossRef]

[11] K. Biswas, "Integrated water resources management: A reassessment," Water International, Vol. 29(2), pp. 248–256, 2004. [CrossRef]

[12] K. Biswas, and C. Tortajada, "Future water governance: Problems and perspectives," International Journal of Water Resources Development, Vol. 26(2), pp. 129–139, Jun. 2010. [CrossRef]

[13] P. H. Gleick, "Water in crisis: Paths to sustainable water use," Ecological Applications, Vol. 8(3), pp. 571–579, 1998. [CrossRef]

[14] H. Tropp, "Water governance: trends and needs for new capacity development," Water Policy, Vol. 9(Suppl 2), pp. 19–30, 2007. [CrossRef]

[15] M. R. Ahmed, M. A. Ahmed, M. Islam, and S. Saha, Study on rainwater harvesting in dacope upazila, Khulna, Bangladesh. 4th International Conference on Advance in Civil Engineering (ICACE 2018), Chittagong, 2018.

[16] G. Katz, T. B. Coplen, T. D. Bullen, and J. H. Davis, "Use of chemical and isotopic tracers to characterize the interactions between ground water and surface Water in Mantled Karst," Groundwater, Vol. 35(6), pp. 1014–1028, 1997. [CrossRef]

[17] Li, M. L. Wrzesien, M. Durand, J. Adam, and D. P. Lettenmaier, "How much runoff originates as snow in the western United States, and how will that change in the future?," Geophysical Research Letters, Vol. 44(12), pp. 6163–6172, 2017. [CrossRef]

[18] Y. Tsur, "The stabilization role of groundwater when surface water supplies are uncertain: The implications for groundwater development," Water Resources Research, Vol. 26(5), pp. 811–818, 1990. [CrossRef]

[19] R. T. Nickson, J. M. McArthur, B. Shrestha, T. O. Kyaw-Myint, and D. Lowry, "Arsenic and other drinking water quality issues, Muzaffargarh District, Pakistan," Applied Geochemistry, Vol. 20(1), pp. 55–68, 2005. [CrossRef]

[20] N. Carrard, T. Foster, and J. Willetts, "Groundwater as a source of drinking water in Southeast Asia and the Pacific: A multi-country review of current reliance and resource concerns," Water, Vol. 11(8), Article 1605, 2019. [CrossRef]

[21] K. Katsanou, and H. K. Karapanagioti, "Surface water and groundwater sources for drinking water," in Applications of Advanced Oxidation Processes (AOPs) in Drinking Water Treatment, A. Gil, L. A. Galeano, and M. Á. Vicente, Eds., in The Handbook of Environmental Chemistry. Cham: Springer International Publishing, pp. 1–19, 2019. [CrossRef]

[22] M. A. Ahmed, M. Hossain, and M. Islam, Prediction of solid waste generation rate and determination of future waste characteristics at South-Western region of Bangladesh using artificial neural network. KUET, Khulna, 2017.

[23] M. A. Ahmed, and S. D. Chakrabarti, "Scenario of existing solid waste management practices and integrated solid waste management model for developing country with reference to Jhenaidah municipality, Bangladesh," presented at the 4th International Conference on Civil Engineering for Sustainable Development (ICCESD 2018), Khulna, Bangladesh: Department of Civil Engineering, KUET, 2018.

[24] Md. M. Rahman, D. B. P. Argha, and M. Haque, "Present scenario of municipal solid waste management in Satkhira municipality," International Con-

ference on Civil Engineering for Sustainable Development, Khulna, Bangladesh, 2018.

[25] T. Khan, D. B. P. Argha, and M. S. Anita, "An Analysis of Existing Medical Waste Management and Possible Health Hazards in Jhenaidah Municipality," 6th International Conference on Engineering Research, Innovation and Education (ICERIE 2021), 26-28 February 2021, pp. 677–683, 2021.

[26] M. R. Rashid, and M. Ashik, "Evaluation of physico-chemical treatment technologies for landfill leachate induced dissolved organic nitrogen (DON)," AEESP Research and Education Conference, Northeastern University, June 20-23, 2023.

[27] M. A. Ahmed, and M. Redowan, "Fate and Transport of the Biologically Treated Landfill Leachate Induced Dissolved Organic Nitrogen (DON)," AEESP Research and Education Conference, Northeastern University, June 20-23, 2023, 2023.

[28] Z. Chengli, M. Ronghua, W. Qi, Y. Mingrui, C. Rui, and Z. Xiaonan, "Photocatalytic degradation of organic pollutants in wastewater by heteropolyacids: a review," Journal of Coordination Chemistry, Vol. 74(11), pp. 1751–1764, 2021. [CrossRef]

[29] M. N. Subramaniam, P. S. Goh, D. Kanakaraju, J. W. Lim, W. J. Lau, and A. F. Ismail, "Photocatalytic membranes: a new perspective for persistent organic pollutants removal," Environmental Science and Pollution Research, Vol. 29(9), pp. 12506–12530, 2022. [CrossRef]

[30] M. Meena, P. Sonigra, G. Yadav, and T. Barupal, "Wastewater treatment techniques: An introduction," in Removal of Emerging Contaminants Through Microbial Processes, M. P. Shah, Ed., Singapore: Springer, pp. 161–182, 2021. [CrossRef]

[31] H. Ghazal, E. Koumaki, J. Hoslett, S. Malamis, E. Katsou, D. Barcelo, and H. Jouhara, "Insights into current physical, chemical and hybrid technologies used for the treatment of wastewater contaminated with pharmaceuticals," Journal of Cleaner Production, Vol. 361, Article 132079, 2022. [CrossRef]

[32] C. K. Chandrawanshi, and K. S. Patel, "Fluoride deposition in central India," Environmental Monitoring and Assessment, Vol. 55(2), pp. 251–265, 1999. [CrossRef]

[33] M. S. Rahaman, "Evaluation of groundwater quality and environmental health in the coastal belt of Khulna, Bangladesh," 2014. https://www.academia.edu/68769922/Evaluation_of_groundwater_quality_and_environmental_health_in_the_coastal_belt_of_Khulna_Bangladesh

[34] P. K. Chakraborty, "Need of applied research on water quality management," Indian Journal of Environmental Protection, Vol. 19(8), pp. 595–597, 1999.

[35] H. Zhang, G. Xu, H. Zhan, X. Chen, M. Liu, and M. Wang, "Identification of hydrogeochemical processes and transport paths of a multi-aquifer system in closed mining regions," Journal of Hydrology, Vol. 589, Article 125344, 2020. [CrossRef]

[36] Y. Gao, H. Qian, C. Huo, J. Chen, and H. Wang, "Assessing natural background levels in shallow groundwater in a large semiarid drainage Basin," Journal of Hydrology, Vol. 584, Article 124638, 2020. [CrossRef]

[37] Z. Zhang, C. Xiao, O. Adeyeye, W. Yang, and X. Liang, "Source and Mobilization Mechanism of Iron, Manganese and Arsenic in Groundwater of Shuangliao City, Northeast China," Water, Vol. 12(2), Article 534, 2020. [CrossRef]

[38] T. J. Troy, L. C. Bowling, S. A. Jame, C. I. Lee, J. Liu, C. Perry, and B. Richter, "Envisioning a sustainable agricultural water future across spatial scales," Environmental Research Letters, Vol. 18(8), Article 085003, 2023. [CrossRef]

[39] P. Roy, Md. A. Ahmed, and Md. H. Shah, "Biogas generation from kitchen and vegetable waste in replacement of traditional method and its future forecasting by using ARIMA model," Waste Disposal & Sustainable Energy, Vol. 3(2), pp. 165–175, 2021. [CrossRef]

[40] Md. A. Ahmed, P. Roy, A. Bari, and M. Azad, Conversion of Cow Dung to Biogas as Renewable Energy Through Mesophilic Anaerobic Digestion by Using Silica Gel as Catalyst, 5th ed. Chittagong: ICMERE 2019, Chittagong University of Engineering & Technology (CUET), 2019.

[41] A. Kumar, A. Ranjan, K. Gulati, S. Thakur, and T. Jindal, "Assessment of chemical and microbial contamination in groundwater through leaching of sewage waste in Delhi, India," Environmental Earth Sciences, Vol. 75(3), Article 275, 2016. [CrossRef]

[42] R. R. Dash, I. Mehrotra, P. Kumar, and T. Grischek, "Lake bank filtration at Nainital, India: water-quality evaluation," Hydrogeology Journal, Vol. 16(6), pp. 1089–1099, 2008. [CrossRef]

[43] M. Mahmud, S. Mukharjee, M. Khalil, M. Rahman, and F. Hossen, "Physicochemical and Microbiological analysis of tube-well water from Noakhali district, Bangladesh," World Journal of Microbiology, Vol. 3, pp. 43–49, 2016.

[44] R. Datta, M. Hossain, M. Aktaruzzaman, and A. N. M. Fakhruddin, "Antimicrobial resistance of pathogenic bacteria isolated from tube well water of costal area of Sitakunda, Chittagong, Bangladesh," Effluent and Water Treatment Journal, Vol. 1, pp. 1–6, 2013. [CrossRef]

[45] M. Shaibur, M. Hossain, and S. Sony, "Drinking water quality of hand tube well water at sub-urban areas of Jashore Municipality, Bangladesh," Vol. 4, pp. 11–22, 2019.

[46] M. S. Islam, A. Siddika, M. N. H. Khan, M. M. Goldar, M. A. Sadique, A. N. M. H. Kabir, A. Huq, and R. R. Colwell, "Microbiological analysis of tube-well water in a rural area of Bangladesh," Applied and Environmental Microbiology, Vol. 67(7), pp. 3328–3330, 2001. [CrossRef]

[47] D. van Halem, S. Olivero, W. W. J. M. de Vet, J. Q. J.

C. Verberk, G. L. Amy, and J. C. van Dijk, "Subsurface iron and arsenic removal for shallow tube well drinking water supply in rural Bangladesh," Water Research, Vol. 44(19), pp. 5761–5769, 2010. [CrossRef]

[48] M. G. M. Alam, G. Allinson, F. Stagnitti, A. Tanaka, and M. Westbrooke, "Arsenic contamination in Bangladesh groundwater: A major environmental and social disaster," International Journal of Environmental Health Research, Vol. 12(3), pp. 235–253, 2002. [CrossRef]

[49] S. Luby, M. S. Islam, and R. Johnston, "Chlorine spot treatment of flooded tube wells, an efficacy trial," Journal of Applied Microbiology, Vol. 100(5), pp. 1154–1158, 2006. [CrossRef]

[50] T. Prosun, M. Rahaman, S. Rikta, and M. Rahman, "Drinking water quality assessment from ground water sources in Noakhali, Bangladesh.," International Journal of Development and Sustainability, Vol 7(5), pp. 1676–1687, 2018.

[51] M. R. Shaibur, M. S. Hossain, S. Khatun, and F. K. S. Tanzia, "Assessment of drinking water contamination in food stalls of Jashore Municipality, Bangladesh," Applied Water Science, Vol. 11(8), Article 142, 2021. [CrossRef]

[52] A. J. Pickering, A. Ercumen, B. F. Arnold, L. H. Kwong, S. M. Parvez, M. Alam, D. Sen, S. Islam, C. Kullmann, C. Chase, R. Ahmed, L. Unicomb, J. M. Colford Jr, and S. P. Luby, "Fecal Indicator Bacteria along Multiple Environmental Transmission Pathways (Water, Hands, Food, Soil, Flies) and Subsequent Child Diarrhea in Rural Bangladesh," Environmental Science & Technology, Vol. 52(14), pp. 7928–7936, Jul. 2018. [CrossRef]

[53] S. Sarker et al., "Quality Assessment of Surface and Drinking Water of Nakla Paurosova, Sherpur, Bangladesh," Advances in Microbiology, Vol. 09(08), Article 08, 2019. [CrossRef]

[54] Md. A. Rahman, S. Kumar, A. A. Mohana, R. Islam, Md. A. Hashem, and L. Chuanxiu, "Coliform bacteria and trace metals in drinking water, Southwest Bangladesh: Multivariate and human health risk assessment," International Journal of Environmental Research, Vol. 13(2), pp. 395–408, 2019. [CrossRef]

[55] T. Islam, M. Acharjee, N. Tabassum, and M. R. Acharjee, "Bacterial propagation in municipal water and deep tube-well water in Kashipur Locality of Narayanganj City, Bangladesh," Journal of Water and Environment Technology, Vol. 18(5), pp. 327–337, 2020. [CrossRef]

[56] D. D. Mara, and R. G. A. Feachem, "Water- and excreta-related diseases: Unitary environmental classification," Journal of Environmental Engineering, Vol. 125(4), pp. 334–339, 1999. [CrossRef]

[57] K. Yang, J. LeJeune, D. Alsdorf, B. Lu, C. K. Shum, and S. Liang, "Global distribution of outbreaks of water-associated infectious diseases," PLOS Neglected Tropical Diseases, Vol. 6(2), Article e1483, 2012. [CrossRef]

[58] P. K. Pandey, P. H. Kass, M. L. Soupir, S. Biswas, and V. P. Singh, "Contamination of water resources by pathogenic bacteria," AMB Express, Vol. 4(1), Article 51, 2014. [CrossRef]

[59] G. Cissé, "Food-borne and water-borne diseases under climate change in low- and middle-income countries: Further efforts needed for reducing environmental health exposure risks," Acta Tropica, Vol. 194, pp. 181–188, 2019. [CrossRef]

[60] J. A. Adetunji, "Response of parents to five killer diseases among children in a Yoruba community, Nigeria," Social Science & Medicine, Vol. 32(12), pp. 1379–1387, 1991. [CrossRef]

[61] H. Irena, M. Mwambazi, and V. Mulenga, "Diarrhea is a major killer of children with severe acute malnutrition admitted to inpatient set-up in Lusaka, Zambia," Nutrition Journal, Vol. 10(1), Article 110, 2011. [CrossRef]

[62] N. Simakachorn, V. Pichaipat, P. Rithipornpaisarn, C. Kongkaew, P. Tongpradit, and W. Varavithya, "Clinical evaluation of the addition of lyophilized, heat-killed lactobacillus acidophilus LB to oral rehydration therapy in the treatment of acute diarrhea in children," Journal of Pediatric Gastroenterology and Nutrition, Vol. 30(1), Article 68, 2000. [CrossRef]

[63] W. P. Cunningham, M. A. Cunningham, and B. W. Saigo, "Environmental science: A global concern, Vol. 412," McGraw-Hill; 2001.

[64] E. Lopez-Gunn and W. T. Jarvis, "Groundwater governance and the Law of the Hidden Sea," Water Policy, vol. 11(6), pp. 742–762, 2009. [CrossRef]

[65] W. T. Jarvis, "Transboundary groundwater: geopolitical consequences, commons sense, and the law of the hidden sea." [Doctorial Thesis], Oregon State University.

[66] W. T. Jarvis, "Integrating Groundwater Boundary Matters into Catchment Management," in The Dilemma of Boundaries: Toward a New Concept of Catchment, M. Taniguchi and T. Shiraiwa, Eds., Global Environmental Studies., Tokyo: Springer Japan, 2012, pp. 161–176. [CrossRef]

[67] Massoud MA, Al-Abady A, Jurdi M, and Nuwayhid I, "The challenges of sustainable access to safe drinking water in rural areas of developing countries: case of Zawtar El-Charkieh, Southern Lebanon," Journal of Environmental Health, Vol. 72(10), pp. 24–30, 2010.

[68] B. J. Lloyd, and J. K. Bartram, "Surveillance solutions to microbiological problems in water quality control in developing countries," Water Science and Technology, Vol. 24(2), pp. 61–75, 1991. [CrossRef]

[69] M. D. Sobsey, "Drinking water and health research: a look to the future in the United States and globally," Journal of Water and Health, Vol. 4(Suppl 1), pp. 17–21, 2006. [CrossRef]

[70] World Health Organization, "Guidelines for Drinking-water Quality," World Health Organization, 2004.

[71] F. X. R. van Leeuwen, "Safe drinking water: the toxicologist's approach," Food and Chemical Toxicology, Vol. 38, pp. S51–S58, 2000. [CrossRef]
[72] M. H. Minar, M. B. Hossain, and M.Samsuddin, "Climate change and coastal zone of Bangladesh: Vulnerability, resilience and adaptability," Middle-East Journal of Scientific Research, Vol. 13, pp. 114–120, 2013.
[73] M. A. Baten, L. Seal, and K. S. Lisa, "Salinity intrusion in interior coast of Bangladesh: Challenges to agriculture in South-Central Coastal Zone," American Journal of Climate Change, Vol. 4(3), 2015. [CrossRef]
[74] R. Chakraborty, K. M. Khan, D. T. Dibaba, M. A. Khan, A. Ahmed, and M. Z. Islam, "Health implications of drinking water salinity in coastal areas of Bangladesh," International Journal of Environmental Research and Public Health, Vol. 16(19), Article 3746, 2019. [CrossRef]
[75] U. Habiba, Md. A. Abedin, R. Shaw, and A. W. R. Hassan, "Salinity-induced livelihood stress in coastal region of Bangladesh," in Water Insecurity: A Social Dilemma, Emerald Group Publishing Limited, pp. 139–165, 2014. [CrossRef]
[76] S. Rasheed, S. Jahan, T. Sharmin, S. Hoque, M. A. Khanam, M. A. Land, M. Iqbal, S. M. A. Hanifi, F. Khatun, A. K. Siddique, and A. Bhuiya, "How much salt do adults consume in climate vulnerable coastal Bangladesh?," BMC Public Health, Vol. 14(1), Article 584, 2014. [CrossRef]
[77] C. Li, X. Gao, S. Li, and J. Bundschuh, "A review of the distribution, sources, genesis, and environmental concerns of salinity in groundwater," Environmental Science and Pollution Research, Vol. 27(33), pp. 41157–41174, 2020. [CrossRef]
[78] Md. M. Rahman and M. M. Rahaman, "Impacts of Farakka barrage on hydrological flow of Ganges river and environment in Bangladesh," Sustainable Water Resources Management, Vol. 4(4), pp. 767–780, 2018. [CrossRef]
[79] N. Saito, "Bangladesh: Strengthening the Resilience of the Water Sector in Khulna to Climate Change," 2008. https://policycommons.net/artifacts/401066/bangladesh/1370051/
[80] M. A. Kawser, and M. A. Samad, "Political history of Farakka Barrage and its effects on environment in Bangladesh," Bandung, Vol. 3(1), pp. 1–14, 2016. [CrossRef]
[81] Md. S. Hossain, J. A. Dearing, M. M. Rahman, and M. Salehin, "Recent changes in ecosystem services and human well-being in the Bangladesh coastal zone," Regional Environmental Change, Vol. 16(2), pp. 429–443, 2016. [CrossRef]
[82] M. H. Rahman, T. Lund, and I. Bryceson, "Salinity impacts on agro-biodiversity in three coastal, rural villages of Bangladesh," Ocean & Coastal Management, Vol. 54(6), pp. 455–468, 2011. [CrossRef]
[83] K. Roy, A. K. Gain, B. Mallick, and J. Vogt, "Social, hydro-ecological and climatic change in the southwest coastal region of Bangladesh," Regional Environmental Change, Vol. 17(7), pp. 1895–1906, 2017. [CrossRef]
[84] M. B. Alam, C. R. Kabir Rocky, N. S. Tarakki, A. Al Aftab, and C. Quamruzzaman, "Groundwater and surface water quality as-sessment for irrigation and drinking purposes of Khulna District, South-Western, Bangladesh," International Journal of Scientific and Engineering Research, Vol. 6(2), Article 470, 2015.
[85] M. A. Abedin, and R. Shaw, "Safe water adaptability for salinity, arsenic and drought risks in Southwest of Bangladesh," Risk, Hazards & Crisis in Public Policy, Vol. 4(2), pp. 62–82, 2013. [CrossRef]
[86] M. A. Abedin, U. Habiba, and R. Shaw, "Community perception and adaptation to safe drinking water scarcity: salinity, arsenic, and drought risks in coastal Bangladesh," International Journal of Disaster Risk Science, Vol. 5(2), pp. 110–124, 2014. [CrossRef]
[87] T. Roy, D. Chandra, M. M. A. A. M. Sony, and M. S. Rahman, "Impact of salinity intrusion on health of coastal people: reflections from dacope upazila of Khulna District, Bangladesh," Khulna University Studies, pp. 57–66, 2020. [CrossRef]
[88] M. Akib Jabed, A. Paul, and T. K. Nath, "Peoples' perception of the water salinity impacts on human health: a case study in South-Eastern Coastal Region of Bangladesh," Expo Health, Vol. 12(1), pp. 41–50, 2020. [CrossRef]
[89] J. Aryal, B. Gautam, and N. Sapkota, "Drinking water quality assessment," Journal of Nepal Health Research Council, 2012.
[90] M. L. Jackson, Soil Chemical Analysis. Prentice Hall Inc., 1958. http://archive.org/details/soilchemicalanal030843mbp
[91] G. Schwarzenbach, W. Biedermann, and F. Bangerter, "Complexones VI. New simple titration methods for determining water hardness," Helvetica Chimica Acta, Vol. 29(4), pp. 811–818, 1946. [CrossRef]
[92] M. L. Jackson, "Soil chemical analysis," Prentice Hall of India Pvt. Ltd., 1973.
[93] M. Jackson, "Soil chemical analysis prentice," Hall of India Private Limited, Vol. 498(1), 1967.
[94] J. Hunt, "Determination of total sulphur in small amounts of plant material," Analyst, Vol. 105(1246), pp. 83–85, 1980. [CrossRef]
[95] L. S. Clesceri, "Standard methods for examination of water and wastewater," American Public Health Association, Vol. 9, 1998.
[96] Md. A. Rahman, Md. R. Islam, S. Kumar, and S. M. Al-Reza, "Drinking water quality, exposure and health risk assessment for the school-going children at school time in the southwest coastal of Bangladesh," Journal of Water, Sanitation and Hygiene for Development, Vol. 11(4), pp. 612–628, 2021. [CrossRef]
[97] M. A. Rakib, J. Sasaki, H. Matsuda, S. B. Quraishi, M. J. Mahmud, M. Bodrud-Doza, A. K. M. Atique Ullah,

K. J. F, M. A. Newaz, and M. A.H. Bhuiyan, "Groundwater salinization and associated co-contamination risk increase severe drinking water vulnerabilities in the southwestern coast of Bangladesh," Chemosphere, Vol. 246, Article 125646, 2020. [CrossRef]
[98] S. D.-U. Islam, M. A. H. Bhuiyan, T. Rume, and G. Azam, "Hydrogeochemical investigation of groundwater in shallow coastal aquifer of Khulna District, Bangladesh," Applied Water Science, Vol. 7, pp. 4219–4236, 2017. [CrossRef]
[99] Mahmud, S. Sikder, and J. C. Joardar, "Assessment of groundwater quality in Khulna city of Bangladesh in terms of water quality index for drinking purpose," Applied Water Science, Vol. 10(11), Article 226, 2020. [CrossRef]
[100] M. A. Rahman, and M. A. Hashem, "Arsenic, iron and chloride in drinking water at primary school, Satkhira, Bangladesh," Physics and Chemistry of the Earth, Parts A/B/C, Vol. 109, pp. 49–58, 2019. [CrossRef]
[101] M. Sikder, N. Mistri, M. Rahaman, and N. Saiara, "Evaluation of groundwater quality and environmental health in the coastal belt of Khulna, Bangladesh," Journal of Biological Pharmaceutical and Chemical Research, Vol. 1, pp. 113–122, 2014.
[102] Q. H. Bari, M. Shafiquzzaman, and Q. S. Bari, "Success rate in sinking deep tube-wells to search new water source in the northern periphery of Khulna city," in 6th International conference on civil engineering for sustainable development (ICCESD), pp. 10–12, 2022.
[103] R. M. T. Islam, M. T. Siddiqua, A. Zahid, S. S. Tasnim, and M. M. Rahman, "Drinking appraisal of coastal groundwater in Bangladesh: An approach of multi-hazards towards water security and health safety," Chemosphere, Vol. 255, Article 126933, 2020. [CrossRef]
[104] P. Vineis, Q. Chan, and A. Khan, "Climate change impacts on water salinity and health," Journal of Epidemiology and Global Health, Vol. 1(1), pp. 5–10, 2011. [CrossRef]
[105] M. Rahman, M. Sohel, and F. Ahmed, "Physico-chemical and bacteriological analysis of drinking tube-well water from some primary school, Magura, Bangladesh to evaluate suitability for students," International Journal of Applied Sciences and Engineering Research, Vol. 4(10), pp. 355–360, 2015.
[106] J. C. Ayers, G. George, D. Fry, L. Benneyworth, C. Wilson, L. Auerbach, K. Roy, R. Karim, F. Akter, and S. Goodbred, "Salinization and arsenic contamination of surface water in southwest Bangladesh," Geochemical Transactions, Vol. 18, pp. 1–23, 2017. [CrossRef]
[107] Y. Meride, and B. Ayenew, "Drinking water quality assessment and its effects on residents health in Wondo genet campus, Ethiopia," Environmental Systems Research, Vol. 5(1), pp. 1–7, 2016. [CrossRef]