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Research Article

Analysis of Groundwater Quality in the Coastal Aquifer of the Effutu Municipality, Ghana

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The study sought to assess the suitability of groundwater for domestic and drinking purposes in the Effutu Municipality of Ghana. The paper employed laboratory protocols to analyse the water quality parameters' concentrations for groundwater samples collected from wells. Descriptive statistical analysis was used to analyse the data and the concentrations of parameters compared with the World Health Organisation's (WHO) permissible limits. Principal component analysis using the varimax rotation was employed to explore the main parameters which express groundwater quality in the municipality. Water quality index employing the weighted arithmetic method was also used to score groundwater suitability for domestic and drinking purposes. The study found that the main parameters determining groundwater quality in the Effutu Municipality are conductivity, total dissolved solids (TDS), salinity, hardness, chloride, calcium, magnesium, and sodium. Except for conductivity, manganese, TDS, total hardness, and calcium, the average concentrations for all studied water quality parameters were within limits proposed by WHO. The study further revealed that 48.15%, 44.44%, and 7.41% of the groundwater had excellent, good, and poor water quality indices, respectively. The investigation so advances that the groundwater resources of the Effutu Municipality are suitable for domestic purposes. Despite this, we recommend that abstracted groundwater should be treated by prioritizing the water quality parameters.

1. Introduction

Water quality is essential and indispensable for human survival, the ecological environment, and economic and regional sustainable development [1]. The significance of water quality cannot be undervalued because it affects public health everywhere [2]. It has been proven that the long-term consumption of water with poor quality increases the risk of health complications [3]. Rehman et al. [4] averred that contaminated water can result in diseases such as cancer, blue baby syndrome, skin diseases, renal damage, circulatory system issues, gastrointestinal stress, bone damage, and nervous system abnormalities. This is to express that the incidence of several water-borne, water-washed, water-based, and water sanitation-related diseases is linked to the quality of water. Projections from Pavlinac et al. [5] expressed that a number of children die each year from diseases caused by drinking contaminated water. Health Canada [6] has reported that calcium and magnesium in drinking water have a dose-dependent protective effect when it comes to cardiovascular disease. A large body of evidence suggests that excessive sodium intake contributes to age-related increase in blood pressure and may contribute essentially to hypertension [7–9]. Studies in humans in references [10–13] and [14] have found possible associations between aluminium ingestion and diseases of the nervous system; aluminium has been shown to have the potential to be toxicant to the central nervous, skeletal, and hematopoietic systems. According to the Minnesota Department of Health [15], children and adults who drink water with high levels of manganese for a long time may have problems with memory, attention, and motor skills; infants may develop learning and behaviour problems if they drink water containing too much manganese. It has also been established that neutral water ($pH \approx 7$) compared to acidic water ($pH \approx 3$) increases the chances of diabetes [16]. In their studies, Akhter and Mitchell [17], Fox and Lytle [18], Kent et al. [19], Levy et al. [20], MacKenzie et al. [21], Morris et al. [22], and Schuster et al. [23] have all linked the outbreaks of gastrointestinal illness to cases where turbidity of drinking water exceeded acceptable limits; Schwartz et al. [24] reported a relationship between drinking water turbidity and endemic gastrointestinal illness in children in Philadelphia. Subsequent studies in different settings including Morris et al. [22], Aramini et al. [25], and Schwartz et al. [26] have as well suggested the existence of an association between gastrointestinal illness and turbidity. Exposure to a high level of saline via drinking water in coastal populations increases cardiovascular and other diseases [27]. Talukder et al. [28] and Nahian et al. [29] acknowledged that several studies have identified association between excessive salinity in drinking water and an increased risk of hypertension. Drinking water salinity has also been linked to the risk of preeclampsia and gestational hypertension [30].

The quality of water determines its suitability for use, especially for drinking and domestic purposes. Rasool and Xiao [31] remarked that it is critical to address water quality to promote human health. This expresses the background on which the current study is hinged. There is increasing pollution of water bodies in the Effutu Municipality, making them unsafe for drinking and domestic purposes [32–36] [35, 36]. This underscores the expression that the conventional source of potable water in the Effutu Municipal is reported as deteriorating in terms of quality, which has been associated with anthropogenic interaction with the Ayensu River [37]. Adu-Boahen et al. [38] reported the incidence of microplastics pollution in the Akora River, a major tributary of the Ayensu River. Studies confirming the deterioration of the Ayensu River corroborate the findings of Ayivor and Gordon [39] who have found high turbidity, suspended solids, and colour in the Ayensu River. Consequently, the deteriorated quality of the Ayensu River can potentially harm the health of consumers of water sourced from the river when it is not well treated before use.

For its novelty, this study is the first of its kind in the Effutu Municipality, considering the fact that the literature is silent on groundwater quality in the municipality. A preliminary interaction with some residents identifies that groundwater in the Effutu Municipality is of poor quality and is generally considered "hard water." Citizen science has established that the local groundwater does not lather well with soap and hence the low usage of it. This position is supported by no scientific investigation, and as such, the quality of groundwater in the municipality is expressed on the grounds of conjecture. The aim of this study is to evaluate the suitability of the local groundwater for use for drinking and domestic purposes by establishing the quality of groundwater in the Effutu Municipality. The study investigates groundwater quality in the Effutu Municipality by establishing the concentrations of water quality parameters and analyzes the findings using statistics and the water quality index. By investigating the quality of groundwater samples, the study will provide an avenue to rethink the general position of locals on groundwater quality. The paper will contribute to sustainable management and use of groundwater in the Effutu Municipality. The study will also contribute to knowledge on underground water quality in Ghana, emphasising the Effutu Municipal.

2. Materials and Methods

2.1. Profile of the Study Area. The Effutu Municipality is a coastal area in the Central Region of Ghana. The municipality shares administrative boundaries with the Awutu Senya East District in the east, the Gomoa West District in the west, the Gomoa East District in the north, and the Gulf of Guinea (the Atlantic Ocean) in the south. In absolute terms, the Effutu Municipality is perched between longitudes 0°33′11.87″W and 0°40′21.78″W and latitudes 5°19′38.17″N and 5°26′30.45″N (Google Earth readings). The areal extent of the Effutu Municipality is approximately 85 km^2 [40]. The Ayensu and Gyahadze rivers drain the municipality and empty into the sea at Woarabeba and Opram, respectively. The Effutu Municipality is located in a dry-equatorial climatic area with yearly precipitation averages of 400–500 mm, and typical temperatures range from 22°C to 28°C. The area's flora is driven by coastal savannah grassland supported by saline clayey soil [40]. Figure 1 presents a map of the Effutu Municipal in national and regional contexts.

According to the 2021 population and housing census, the population of the Effutu Municipality stands at 107,798 persons, of which 54,723 (50.76%) are males and 53,075 (49.24%) are females [42]. A significant component of the livelihoods of the indigenous residents of the Effutu Municipality is fishing and related engagements. However, due to several formal sector entities, there are persons with other professions in the area.

2.2. Hydrocensus. Wells and boreholes in the municipality were identified, and their locations were recorded. During this exercise, active groundwater (water bearing) and inactive (dry) wells and boreholes were mapped with a handheld Garmin GPS. All the identified active wells were sampled for groundwater sampling. The locations of sampled wells have been presented in Figure 2.

2.3. Groundwater Sample Collection. Groundwater samples were collected from wells following strict scientific protocols. Water samples were collected in the dry season when water resources are expected to run low. According to Akurugu, Chegbeleh, and Yidana [43], the dry season is an ideal time to collect water samples for water quality assessments. Sampling bottles were capped after groundwater sampling. The bottles were labelled and stored in a refrigerator pending transportation to the laboratory. This protocol was observed from Nyantakyi et al. [47] and Chegbeleh et al. [48] who averred that before laboratory investigations, water samples collected for water quality assessment should be stored at or below 4°C. The samples were transported to the laboratory for water quality investigation.

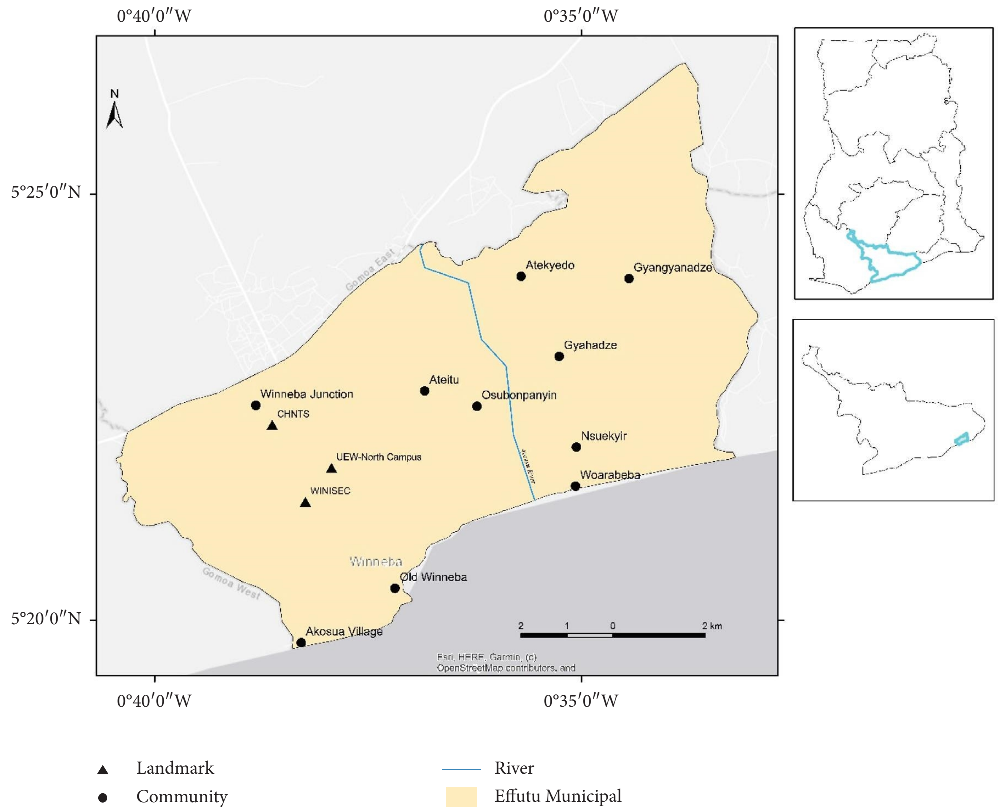

Figure 1: Effutu Municipal in national and regional context. Source: Kyeremeh et al. [41].

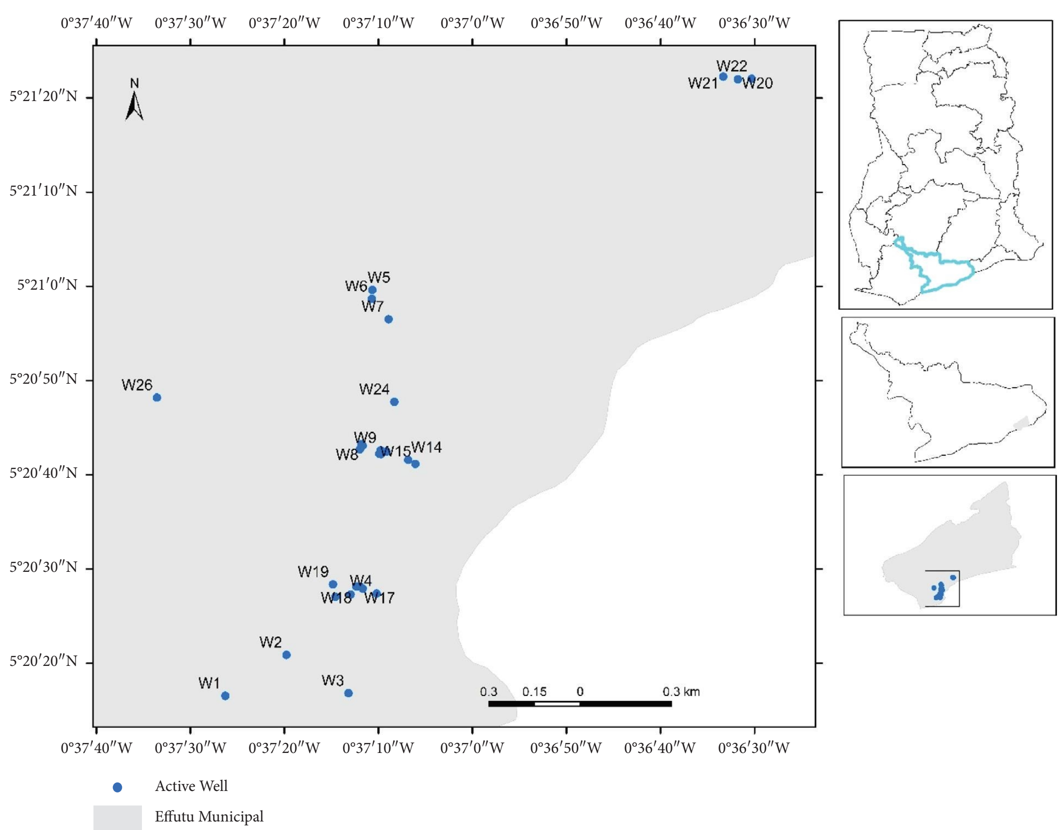

Figure 2: The location of wells in the Effutu Municipality. Source: Fieldwork (2022).

2.4. Groundwater Physicochemical Properties' Assessment Protocols. The pH, conductivity, total dissolved solids, and salinity of groundwater samples were analysed using Horiba Digital Water Quality Checker (model U-50). Turbidity was measured using a standardised Hanan turbidity meter (115V-H198703-01). A clean 250 ml conical flask was filled with 50 ml of the groundwater sample for the investigation of total alkalinity and bicarbonates. Two drops of the methyl red indicator were added to 50 ml of groundwater in the conical flask. Following a guideline established by the American Society for Testing and Materials, the solution was titrated against a standard 0.01 M HCl solution to a pink endpoint [46]. The formula (V x M x 50,000/Vs) (where V is the volume of acid used, M is the molarity of the acid used, and Vs is the volume of the groundwater sample used) is used to calculate total alkalinity. Bicarbonate concentrations were computed by multiplying total alkalinity by a factor of 1.22.

The measurements of the concentrations of calcium (Ca), magnesium (Mg), sodium (Na), manganese (Mn), and iron (Fe) were performed on a PerkinElmer PinAAcle 900T atomic absorption spectrometer. The determination of Ca, Mg, Na, Mn, and Fe was carried out using the flame atomic absorption spectrophotometer (FAAS). Air-acetylene gas was used as the source of fuel for the metals. Total hardness is expressed as calcium carbonate in milligrams per litre (mg/l), which was calculated from the following equation:

$$\text{hardness} = 2.497\,(\text{Ca}) + 4.118\,(\text{Mg}). \tag{1}$$

Five drops of a phenolphthalein indicator solution were added to 50 ml of the groundwater sample and neutralised with 0.1 N sulphuric acid to the colourless side of phenolphthalein. 1 ml of potassium chromate indicator solution was added before titration with standard silver nitrate solution to a pinkish-yellow endpoint. A blank reagent titration was carried out in parallel to the sample titration. Chloride quality was calculated using the following formula:

$$\text{Chloride}\left(\frac{\text{mg}}{l}\right) = \left[(A - B)x\,N\,x\,\frac{(35.45\,x\,1000)/10m}{L}\right], \tag{2}$$

where A = silver nitrate solution (in ml) for sample titration; B = silver nitrate solution used for blank titration (in ml); N = normality of the silver nitrate solution; and V = groundwater sample volume (in ml).

The fluoride levels were estimated by using the SPADNS method [47] and Program 190 of the fluoride HACH DR1900 spectrophotometer.

2.5. Quality Control and Quality Assurance Procedures. As stated in the WHO guidelines, quality control and quality assurance procedures were followed throughout sampling and laboratory analysis of groundwater in order to minimize or limit errors [48]. All monitoring equipment for groundwater were calibrated following quality assurance and control protocols. During sample collection, quality assurance and control were ensured by following the methods outlined in the water quality sampling manual [49]. Each groundwater sample was accurately labelled according to the well's identity and location. Field blanks and standard solutions were used in the study to ensure the accuracy and repeatability of the findings as reported by Taiwo et al. [50]. Using techniques based on standard methods for the analysis of water [49] and the use of calibration standards and laboratory blanks, quality assurance and control were achieved during the analysis of groundwater samples.

2.6. Analysis and Procedures for Investigating Groundwater Quality. The study analysed the groundwater quality parameters by statistical approaches. The minimum and maximum concentrations for water quality parameters were established along with their mean concentrations, which are compared with the recommended standards of WHO [48]. Principal component analysis (PCA) was performed to identify the main parameters controlling groundwater quality. The PCA was used as a factor extraction method which required preceding estimates of the amounts of variations within groundwater quality parameters studied. The number of factors to keep was determined using Kaiser's criterion (the Eigenvalue rule) [51]. Eigenvalues are the percentage of variation explained by each component; each parameter had a variance of 1, and the total variance for the complete dataset was 16. Fluoride was not entered into the PCA because concentrations were uniform with no variations for all sources studied. Factors with Eigenvalues greater than 1 explained more variations in the data than individual groundwater quality parameters, and factors with Eigenvalues less than 1 explained less total variations than particular variables. Therefore, only factors with Eigenvalues greater than one were retained for interpretation. The varimax rotation extraction was used to interpret the groundwater quality data [51, 52]. Strong parameters are those whose coefficients are greater than 0.75, indicating that the factor explains a large portion of the parameter's variance. Similarly, moderate parameters are those whose coefficients are between 0.50 and 0.75, and weak parameters are those whose coefficients are between 0.30 and 0.50, indicating that the factor explains only a small portion of the parameter's variance, and hence, its contribution is, therefore, less significant.

The water quality index for groundwater samples was also computed. The weighted arithmetic method proposed and developed by Horton [53] and Brown et al. [54] served as the foundation for calculating the indices. The calculation of the indices was performed according to the following formula:

$$\text{WQI} = \frac{\sum_{i=1}^{N} WiQi}{\sum_{i=1}^{N} Wi}, \tag{3}$$

where N is the number of water quality parameters; W_i is the unit weight for the ith water quality parameter; and Q_i is the quality rating of the ith water quality parameter.

The water quality parameters considered for the water quality index are pH, conductivity, total dissolved solids, turbidity, total alkalinity, total hardness, chloride, calcium, magnesium, sodium, iron, manganese, aluminium, and fluoride.

3. Results and Discussion

3.1. Groundwater Quality for Drinking and Domestic Usage. This section presents data and discusses the quality of sampled groundwater in terms of the concentrations of parameters. The concentrations of water quality parameters established by laboratory protocols are shown here. Graphs and tables are used to present the levels of concentrations of parameters studied. Total alkalinity, aluminium, bicarbonates, calcium, chloride, colour, conductivity, fluoride, iron, magnesium, manganese, pH, salinity, sodium, total dissolved solids, total hardness, and turbidity were studied. Where necessary, the concentrations are compared with the permissible limits according to WHO [48]. Almost all the wells identified in the study area are hand-dug wells with hand-drawn withdrawal systems (plastic buckets fitted with ropes). In identifying groundwater abstraction systems, our observations found a few mechanised boreholes which were fitted with electric-powered pumps and boreholes with hand pumps in the study area. All of the boreholes identified were inactive and abandoned. Figure 2 shows the active wells where water samples were collected for groundwater quality investigation.

Groundwater quality is assessed based on the physical, chemical, and biological qualities of the water [55]. Hydrogeologists increasingly rely on groundwater quality attributes to determine geochemistry-hydrology interaction and contamination of groundwater. This study presents the findings on the descriptive statistics for concentrations of water quality parameters for groundwater samples from the Effutu Municipality. As shown, the presentations are graphical and tabular, which depict the minimum, the maximum, the mean, and in the case of the table, the standard deviation (SD) of concentrations for parameters.

The pH of groundwater in the Effutu Municipal reveals a minimum pH of 6.78 and a maximum pH of 7.65. A mean pH of 7.33 has been found, expressing that the groundwater samples generally have neutral pH. WHO recommends a permissible pH range of 6.5–8.5 for drinking water. Based on this, the study concludes that the pH of groundwater in the Effutu Municipality is within the permissible range defined for drinking water. Compared with similar research, a coastal Ghanaian survey conducted in the Ga East Municipality found a mean pH of 5.66, expressing more acidic groundwater for the Ga East Municipal [56]. This presents a deviation from the findings for the Effutu Municipal as the acidic nature of the groundwater in the Ga East Municipal makes it less commendable for drinking purposes. Sofi et al. [57] found that changing the drinking water from acidic ($pH \approx 3$) to neutral ($pH \approx 7$) decreased diabetes incidence and the rate of progression. As such, finding a mean pH of 7.33 projects that the groundwater resource of the Effutu Municipal could serve as a potential remedy to diabetic conditions should be considered for drinking.

The study found that the average groundwater conductivity is almost twice the recommended drinking water level. The study found a mean conductivity of 1966.148 μS/cm, with minimum and maximum levels of 620.00 μS/cm and 3630.00 μS/cm, respectively, as presented in Table 1. The recorded high values are attributed to the somewhat proximity of wells to the sea as the Effutu Municipality borders the Gulf of Guinea in the south. It is known that the more the ions present in a sample of water, the higher the conductance of the water. The possibility of sea sprays depositing ions in local wells has also been deduced. Fernández-Martínez et al. [58] reiterated that sea spray aerosol is responsible for large-scale transfer of particles from the sea, leading to significant deposition of a range of ions, mainly Na^+, K^+, Mg^{2+}, Ca^{2+}, and Cl^-. In their study, the authors established that distance to sea has an effect on the chemical composition of groundwater. Groundwater sources which are sited closer to the sea have higher Cl^-, SO_4^{2-}, Na^+, Mg^{2+}, K^+, and Ca^{2+} concentrations than those for sources which are sited further away from the sea [58]. The current study relates the higher electrical conductivity values to the relative proximity of the municipality to the Atlantic Ocean.

Groundwater turbidity was found to be lower than the WHO's permissible limit. The study found that turbidity ranged from 0.00 NTU to 0.9 NTU for all groundwater samples except for well 22, where turbidity was 57.8 NTU. Prakash and Somashekar [59] indicated that high turbidity points to the presence of suspended and colloidal matter such as clays, silt, and fibrous particles like asbestos minerals. For borehole studies, bacterial growth in the casing pipes due to improper maintenance and filthy surroundings may account for higher turbidity [59]. Leaching of organic matter, industrial, and domestic wastes, etc. also contribute to turbidity in groundwater samples. Causes of high turbidity, according to Sawyer et al. [60], identify that inorganic nutrients such as nitrogen and phosphorus present in agricultural runoff stimulate the growth of algae, which also contributes to turbidity. Turbidity in water samples indicates water pollution, mainly due to the source close to a drain, cesspool, ditch, or manured ground. The case of high turbidity for well 22 can be explained by the fact that the well is shallow and not covered and open to the environment. Yidana et al. [61] concurred that the superficial nature of this well and the fact that the well is not covered and remains unprotected render groundwater in this well susceptible to many anthropogenic contamination sources in the area, hence the higher turbidity. The establishment of higher turbidity for well 22 expresses the likelihood of the consumers of the well contracting gastrointestinal illness. This has been stated following Kent et al. [19], Akhter and Mitchell [17], MacKenzie et al. [21], Fox and Lytle [18], Morris et al. [22], Levy et al. [20], Aramini et al. [25], Schwartz et al. [26], and Schuster et al. [23] who have all linked the outbreaks of gastrointestinal illness to cases of high turbidity in drinking water.

Table 1: Descriptive statistics of concentrations of water quality parameters.

Parameters	Min.	Max.	Mean	SD	CV (%)	Skewness		Kurtosis	
						Stat.	SE	Stat.	SE
pH	6.78	7.65	7.33	0.22	3	−1.05	0.45	0.63	0.88
Salinity (%)	0.30	1.94	1.00	0.43	43	0.87	0.45	0.25	0.88
Colour (Pt-Co)	5.00	210	70.7	60.3	85.3	0.82	0.45	−0.08	0.88
Cond. (μS/cm)	620	3630	1966	788	40.1	0.77	0.45	0.12	0.88
Turbidity (NTU)	0.00	57.8	2.33	11.1	476	5.19	0.45	26.9	0.88
Aluminium (mg/l)	0.00	0.08	0.01	0.02	200	4.8	0.45	24.1	0.88
Iron (mg/l)	0.00	0.13	0.01	0.02	200	5.1	0.45	26.3	0.88
Manganese (mg/l)	0.00	0.59	0.03	0.11	366	5.15	0.45	26.7	0.88

Cond = conductivity; Min = minimum concentration; Max = maximum concentration; SD = standard deviation; CV = coefficient of variation; Stat. = statistic; and SE = standard error. Source: Fieldwork (2022).

The aluminium concentration in groundwater in the Effutu Municipality ranges from 0.000 mg/l to 0.81 mg/l. A mean aluminium concentration of 0.006 mg/l with a standard deviation of 0.015 mg/l has been found for the groundwater samples investigated. The highest concentration of aluminium was observed as well for well 22. A percentage recovery of 99.5 was established for groundwater aluminium. All concentration levels are below the WHO's permissible limit for aluminium in drinking water. Concluding on this finding for the concentration of aluminium, we are of the view that the groundwater resource in the Effutu Municipality would not induce oral aluminium consumption-induced complications of the central nervous, skeletal, and hematopoietic systems as revealed by the literature.

The study found a minimum iron concentration of 0.000 mg/l, a maximum of 0.127 mg/l, and a mean concentration of 0.0054 mg/l. For all the groundwater water samples considered, except for wells 20 (0.003 mg/l), 21 (0.001 mg/l), 22 (0.127 mg/l), and 24 (0.014 mg/l), the iron concentrations found were 0.00 mg/l. An iron recovery percentage of 99.7 was established for the case. The mean iron concentration found for groundwater in the Effutu Municipality is below the WHO's permissible limit of 0.3 mg/l. According to Ram et al. [62], the most common source of iron in groundwater is weathering of iron-bearing minerals and rocks. Iron occurs naturally in the reduced Fe^{2+} state in aquifers, but its dissolution increases the iron concentration in groundwater. Iron in this state, however, is soluble and generally does not create any health hazard. The Minnesota Department of Health [63] avers that iron in water does not usually present a health risk; the human body needs iron to transport oxygen in the blood. In a like coastal environment, Ram et al. [62] found a minimum groundwater iron concentration of 0.099 mg/l, a maximum of 0.402 mg/l, and a mean concentration of 0.275 mg/l. Ackah et al. [56] found a mean iron concentration of 0.87 mg/l. As expressed, the concentrations of iron found by Ram et al. [62] and Ackah et al. [56] were above those recorded for this study.

Going forward, the study has established that the average concentration of groundwater manganese in the Effutu Municipality is 0.0272 mg/l. This was found with minimum and maximum groundwater manganese of 0.000 mg/l and 0.592 mg/l, respectively, as have been presented in Table 1. A recovery percentage of 98.9 was established for groundwater manganese. The average manganese concentration found is below the permissible limit for manganese in drinking water, as proposed by WHO [48]. Despite this, the case found for well 7 reveals an extreme concentration level (0.592 mg/l) above the WHO's permissible limit. According to WHO [48], a health-based value of 0.4 mg/l is appropriate for drinking water manganese. The study, therefore, positions that the groundwater of the Effutu Municipal is safe for drinking purposes on finding a mean manganese concentration below the permissible limit for drinking water. In spite of this, as the study has found that the concentration for well 7 exceeds the WHO threshold for drinking water manganese, the well should be checked for manganese before consumption.

The concentrations of dissolved solids found for groundwater samples revealed a mean total dissolved solids concentration of 1317.1852 mg/l. As shown in Figure 3, the study found a minimum total dissolved solids concentration of 415 mg/l and a maximum total dissolved solids concentration of 2420 mg/l. This classifies the groundwater samples as brackish. The mean total dissolved solids found for the groundwater samples studied exceed the permissible limit of 1000 mg/l defined by WHO [48]. The study has established that except for wells 1, 2, 20, 21, 22, 26, and 27, the total dissolved solids concentration for all the other samples exceeded the WHO's permissible limit. In considering the case for salinity, the finding for groundwater samples' salinity ranged from 0.3% to 1.94%, with an average salinity of 1.006%. This expresses that most of the groundwater samples have salinity below 1%, indicating a commendable groundwater salinity situation, at least for a coastal aquifer.

The groundwater resource of the Effutu Municipality is not worthy for drinking purposes according to the measure of its total hardness. The study found an average total hardness above the WHO permissible limit of 200 mg/l. That is, the study found a minimum total hardness of 378.16 mg/l, a maximum of 2104.71 mg/l, and a mean of 878.1252 mg/l, as has been depicted in Figure 3. As coastal as the Effutu Municipality, the total hardness level found for groundwater in the Ga East Municipal does not resonate with the situation in the case of the Effutu Municipality, as Ackah et al. [56] established a mean groundwater total hardness of 18.79 mg/l

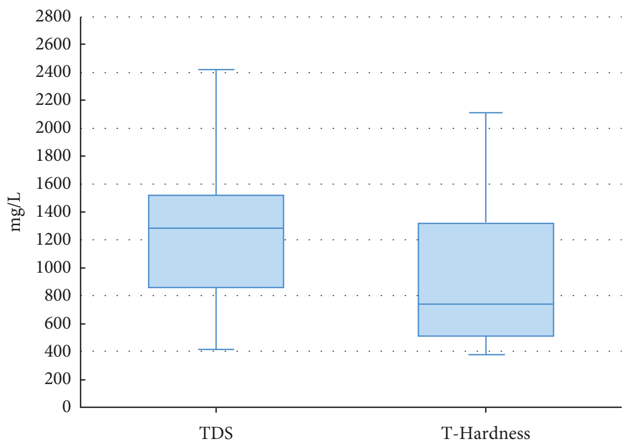

Figure 3: Box plot for groundwater total dissolved solids and total hardness. Source: Fieldwork (2022).

which is significantly below even the WHO's permissible limit. This brings to bear that the preliminary revelation according to citizen science is valid and thus holds. That is, the municipality's groundwater has high total hardness, which indicates that it is less suitable for drinking and domestic usage. The study so calls for groundwater softening to enhance usability.

A minimum total alkalinity of 89 mg/l and a maximum of 240.00 mg/l were found. A mean concentration of 140.59 mg/l with a standard deviation of 50.19 mg/l has also been found for groundwater in the Effutu Municipality. The mean concentration found in the current study is less than the permissible limit of 200 mg/l for drinking water quality according to WHO. According to Ram et al. [62], total alkalinity levels above the permissible limit of 200 mg/l cause drinking water to be unpleasant. On individual levels, the study however identified that there are four wells with concentrations being higher than the WHO's permissible limit. The groundwater in the Effutu Municipality, therefore, is generally safe for drinking regarding the total alkalinity level.

The study found a minimum bicarbonate level of 108.5 mg/l and a maximum of 292.8 mg/l. For these concentrations, a mean bicarbonate of 171.523 mg/l with a standard deviation of 61.229 mg/l is established for bicarbonates. Ackah et al. [56] found a low mean bicarbonate concentration of 68.35 mg/l for groundwater in the Ga East Municipality. However, in the case of the groundwater in the Keta Basin of Ghana, Yidana et al. [61] established a mean bicarbonate concentration of 242.62 mg/l. This situation is higher than that found for the Effutu Municipality. On the background of its coastal nature, the high concentration of bicarbonate in the Keta basin was attributed to seawater intrusion and the weathering of carbonate minerals in the local sediments [61].

Regarding the minimum chloride concentration, the study found a minimum level of 66.47 mg/l and a maximum level of 498.52 mg/l, along with a mean chloride level of 223.614 mg/l and a standard deviation of 115.17 mg/l. The average groundwater chloride is below the WHO's permissible limit, expressing a generally good groundwater chloride level. Despite this, wells 4, 6, 7, 9, 16, 17, 18, 19, and 22 have been found to have groundwater chloride above the permissible limits according to the WHO's [48] drinking water standards. The chloride concentration recorded for these wells, possibly, is due to several uncertain factors, such as geological processes or human activities. In this light, the study calls for advanced investigation into the cause of higher chloride concentrations for the individual wells, after Abidin et al. [64] concurred that the cases found require further study. On this background, we bear the view that the cases found for wells 4, 6, 7, 9, 16, 17, 18, 19, and 22 should be investigated and the higher concentrations should be ameliorated to avert potential complications from chloride toxicity.

The study also found that groundwater samples' average calcium level was below the established permissible limit. Despite this, wells 4, 7, 16, 17, 18, and 19 are cases with concentrations which exceed the permissible limit of 200 mg/L, according to WHO [48]. A recovery percentage of 98.1 was established for calcium after establishing minimum and maximum calcium concentrations of 37.80 mg/l and 330.00 mg/l, with a mean of 140.711 mg/l and a standard deviation of 83.57 mg/l. The findings for calcium express a better groundwater quality when compared with findings for groundwater from the Keta basin of Ghana, where a mean calcium concentration of 291.32 mg/l has been established [61].

The graphical presentation of magnesium in Figure 4 reveals concentration levels of 45.12 mg/l, 320.40 mg/l, and 127.92 mg/l as the minimum, maximum, and average magnesium concentrations. A percentage recovery of 99.6 was established for magnesium. The findings express that the average magnesium concentration does not exceed the WHO's recommended level of 150 mg/l. Despite the average concentration being lower than the WHO's permissible limit, the concentrations found for wells 3, 4, 6, 18, 19, 23, and 25 exceed 150 mg/l. The findings of a similar coastal study in North Dhi-Qar province, south of Iraq, observe significantly higher concentrations as follows: 59 mg/l, 1849 mg/l, and 507 mg/l were established, respectively, for the minimum, maximum, and mean concentrations [65]. This connotes that groundwater magnesium in the Effutu Municipality is better. However, in similar Ghanaian contexts, Ackah et al. [56] and Yidana et al. [61] found lower concentrations than those in the Effutu Municipal. Mean magnesium concentrations of 2.4 mg/l [56] and 21.33 mg/l [61] support the case.

Figure 4 lastly presents that groundwater sodium concentration in the Effutu Municipality ranges from 69.4 mg/l to 109.0 mg/l, with a mean concentration of 96.91 mg/l. WHO [48] recommends a permissible limit of 200 mg/l for sodium concentration in drinking water. A recovery percentage of 97.8 was established for groundwater sodium. Finding a mean sodium concentration of 96.91 mg/l suggests good water quality. According to WHO [48], no health-based guideline value is proposed for sodium. However, concentrations above 200 mg/l may yield an unacceptable taste of drinking water. In agreement with this finding, other

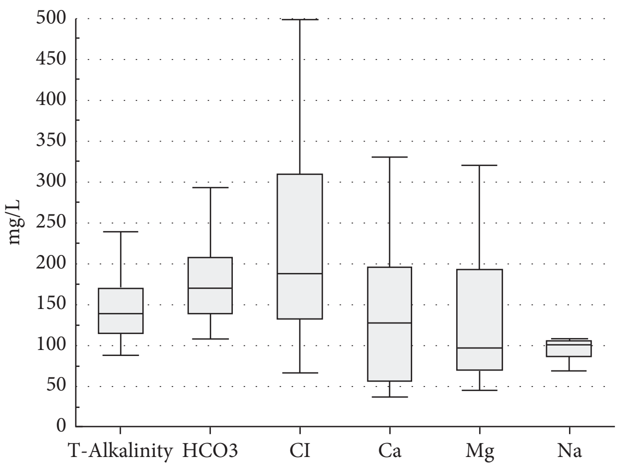

Figure 4: Box plot showing the maximum, mean, and minimum concentrations of total alkalinity, bicarbonates, chlorine, calcium, magnesium, and sodium. Source: Fieldwork (2022).

Ghanaian studies in coastal areas found concentrations less than 200 mg/l. Ackah et al. [56] found a mean groundwater sodium level of 116.61 mg/l in the Ga East Municipal, while Yidana et al. [61] established a mean concentration of 177.09 mg/l in the Keta basin, Ghana.

The study found no fluoride concentration for all the 27 groundwater samples. There is a position that fluoride compounds are abundant in the earth's crust, about 0.06%–0.09% [66], and are found in rocks, soils, salt, seawater, and they are also present in rivers, lakes, and almost all fresh groundwater at varying concentrations. In groundwater, concentrations vary with the type of rock through which the water flows but do not usually exceed 10 mg/l. WHO [48] however reiterated that the highest natural level reported is 2800 mg/l. Despite the position of fluoride abundance in the earth's crust, the levels of concentrations found in the study would not be expected. This is because Saxena and Ahmed [67] and Ozsvath [68] have expressed that the area they studied, which is composed of granite and gneiss, is commonly found to contain fluorite (CaF_2) as an accessory mineral. The geological profile of the Effutu Municipality reveals the presence of granite and like geological makeup, which could spike the groundwater fluoride concentration in the municipality rather than the case found. Establishing the controllers of the hydrogeochemistry of the municipality will present a justification for this finding. Thus, the study advises that an advanced investigation into the rock-groundwater interaction is essential to establish the factors controlling groundwater geochemistry in the Effutu Municipality.

3.2. Principal Component Analysis. Factors with Eigenvalues of 1.0 or greater were considered, with factors of higher Eigenvalues considered the most significant and retained. Five principal components were returned to be retained according to Kaiser's criterion. The principal components extracted explain 89.205% of the variance in the groundwater quality dataset, as shown in Table 2. The first principal component (PC1), expressing the main determiner of groundwater quality in the Effutu Municipality, explained 43.338% of the total variance in the data. PC1 showed strong positive loadings on conductivity, total dissolved solids, salinity, total hardness, calcium, and sodium. Moderate positive loadings onto PC1 were observed for chloride and magnesium. Usman et al. [69] explained that the high conductivity loading is due to the active participation of dissolved ions in the groundwater quality. The high loadings of calcium and magnesium corroborate the high loading of total hardness, underscoring the less suitability of groundwater for domestic and drinking purposes in the municipality. The study suggests that groundwater treatment should prioritise parameters that were loaded unto PC1, especially conductivity, total dissolved solids, and total hardness, which were all identified to exceed the WHO's permissible limit.

Table 2: Factor loading and Eigenvalues of principal components.

Parameters	Components				
	PC1	PC2	PC3	PC4	PC5
pH	0.51	0.01	0.35	−0.31	0.62
Conductivity	**0.96**	0.07	−0.09	−0.02	0.14
Total dissolved solids	**0.96**	0.07	−0.08	−0.01	0.14
Salinity	**0.95**	0.06	−0.1	−0.03	0.14
Turbidity	−0.27	**0.93**	−0.2	0.04	0.02
Colour	0.2	**0.68**	0.16	−0.34	0.13
Total alkalinity	0.57	0.29	**0.69**	−0.06	−0.27
Bicarbonates	0.57	0.29	**0.69**	−0.06	−0.27
Total hardness	**0.84**	−0.04	−0.35	−0.12	−0.33
Chloride	**0.72**	0.37	−0.20	0.33	−0.00
Calcium	**0.81**	−0.06	−0.33	0.25	0.12
Magnesium	**0.66**	−0.02	−0.28	−0.33	−0.53
Sodium	**0.81**	−0.14	−0.11	0.06	0.16
Iron	−0.3	**0.93**	−0.18	0.02	0.04
Manganese	0.25	0.12	0.33	**0.80**	−0.06
Aluminium	−0.24	**0.94**	−0.19	0.00	−0.00
Total	6.93	3.43	1.71	1.17	1.03
% of variance	43.34	21.45	10.68	7.3	6.44
Cumulative (%)	43.34	64.79	75.47	82.8	89.21

Source: Fieldwork (2022). The bold values represent the coefficients of the strong and moderate parameters.

The second principal component (PC2) explained 21.451% of the variance in the groundwater quality data. PC2 showed strong positive loadings on turbidity, iron, and aluminium and a moderately favourable loading on colour. The mutual loadings on colour, turbidity, and iron justify the position that most causes of groundwater colour are the presence of minerals and organic matter. According to Usman et al. [69], red and brown colours of groundwater are due to the presence of iron.

The third principal component (PC3) revealed moderate positive loadings on total alkalinity and bicarbonates and explained 10.676% of the variance in the data analysed. The fourth and fifth principal components (PC4 and PC5) explained 7.299% and 6.441% of the total variance in the groundwater quality data, where the former showed a strong loading on manganese, with the latter showing moderate loading on pH.

Table 3: Water quality index of groundwater samples.

WQI	Rating class	Number of samples	% of samples
0 to 26	Excellent	13	48.15
26 to 50	Good	12	44.44
51 to 75	Poor	2	7.41
Total	—	27	100

Source: Fieldwork (2022).

3.3. Water Quality Index of Groundwater in the Effutu Municipality. Despite the findings from the descriptive statistics and the principal component analysis, the study identified that 13 of the 27 groundwater samples, making up 48.15%, were indexed as excellent water quality according to the National Sanitation Foundation Water Quality Index (NSFWQI). As shown in Table 3, the study revealed that 12 of the 27 (44.44%) groundwater samples were classified as having a good water quality index, with only 2 (7.41%) samples being found to be of a poor water quality index. A study on groundwater quality assessment in Monaragala, a pericoastal region in Sri Lanka, found that the WQI values ranged from 1.27 to 334. The study established that about 48% of water samples were rated as a "good" category [70], which is similar to the case in the Effutu Municipality. Appearing higher than what was found in this study, Udeshani et al. [70] found that about 28% of the samples they studied exceeded WQI of 100, indicating that the water is not suitable for drinking purposes. Observing a lower number and percentage of poor-classed groundwater samples presupposes that the Effutu Municipality is better off in terms of the water quality index of groundwater. In essence, the results indicate that the groundwater resource perched in the geological units of the Effutu Municipal is generally good for drinking purposes.

4. Conclusion

In spite of the study achieving the objective of establishing the suitability of groundwater for drinking and domestic purposes, there was a limitation of identifying only a few active wells which are as well not well spaced or evenly distributed across the municipality but are clustered to a limited area in the Municipality. This situation had the potential to mar the validity of predicting the concentrations of groundwater quality parameters for areas with unknown concentrations based on the concentrations of parameters established for active wells.

The water quality index for the samples revealed that the groundwater in the municipality is generally reasonable. The study found that average groundwater conductivity, total dissolved solids, and total alkalinity are high above the permissible limits according to WHO, which require treatment before use. The principal component analysis confirms that conductivity, total dissolved solids, salinity, total hardness, chloride, calcium, magnesium, and sodium are the significant parameters controlling the quality of groundwater. Observing the highest factor loadings, we conclude that groundwater treatment should focus on total hardness, total dissolved solids, and conductivity. The groundwater in the Effutu Municipality is suitable for use based on its quality. The study recommends the groundwater resource of the municipality for consumption, especially with the growing reports that the quality of the Ayensu River, which is the conventional source of potable water, is deteriorating in quality, and diminishing in volume, rendering higher cost of treating water, and rationing of supply. This is, however, not a call for a stop to using water from the Ayensu River but a call to consider an integration of groundwater into public water services.

4.1. Recommendation. There should be efforts to treat groundwater, especially with water softening after abstraction, in order to enhance its quality and induce more benefits from using the groundwater resource in the Effutu Municipality. We recommend installing abstraction systems after drillings to factor the integration of groundwater treatment systems. We call for a geohydrochemical characterisation of the Effutu Municipality to give more insight into the nature of controls of groundwater quality in the area. Considering the season-biased nature of this study as only the dry season was studied, we further call for a season-specific groundwater quality assessment and hydrogeochemical characterisation in the Effutu Municipality to make cases for seasonal regimes for groundwater quality in the municipality.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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