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Research article

Groundwater in the coastal areas of Ghana: Quality and associated health risks

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ABSTRACT

Self-supply water sources, particularly groundwater sources, play key roles in the water supply ecosystem of developing countries. Recent studies indicate that groundwater sources in coastal communities in Ghana are under threat from improper waste management practices, seawater intrusion and atmospheric aerosol deposition. In this study, Water Quality Index (WQI) and Nemerow's Pollution Index (NPI) were employed to assess groundwater quality in four coastal communities of Ghana. The health risks associated with metal pollution of groundwater were investigated using incremental life cancer risk and hazard quotient. pH of groundwater in all the studied communities were acidic during the rainy season. Electrical conductivity ranged from 0.44 to 2.61 mS/cm in the rainy season and from 0.43 to 2.45 mS/cm in the dry season for the four studied locations. Results also showed brackish conditions and mineralization of groundwater in Winneba, Accra, and Keta. Mean nitrate concentrations in Winneba and Accra were higher than the WHO standards for both the rainy and the dry season. Arsenic was higher than the acceptable level in Accra and Keta during the dry season, while iron was higher than the acceptable levels in Accra in both the rainy and dry seasons. Principal Component Analyses showed that Pb, As, and Fe had the highest loading in the first component in Essiama, while $PO_4^{3-}$and Pb had the highest loading in the second component in Accra. WQI showed that the quality of groundwater in all the studied communities ranged from marginal to poor indicating that groundwater in the coastal communities often or usually departs from desirable quality. NPI revealed that NO_3- , As, and Fe contribute to groundwater deterioration. Health risk assessment showed that As posed a high cancer risk in Accra and potential cancer risk in Essiama, Winneba, and Keta during the dry season. As also posed potential cancer risk in Accra during the rainy

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season. Non-cancer health risk was observed for As in Accra and Keta. The findings of this study suggest urgent regulations and monitoring strategies to improve groundwater quality in the coastal communities of Ghana.

1. Introduction

Water supply is key to the development of resilient cities and communities, but global water supplies are dwindling. Currently, almost 50 % of the global population lives in places where scarcity of water is experienced for at least one month annually [1]. The number of persons who experience water scarcity is expected to increase to 57 % by 2050 [1]. Water scarcity is driven by increase in water use due to population growth, increase in the pollution of water resources, and decrease in water resources [2]. Water scarcity is already a major problem in developing countries. Future stress on water resources is expected to be higher in these countries due to population growth [2].

Self-supply of water plays a vital role in the water supply ecosystem of developing countries and has the potential to pivot the pace toward the achievement of Sustainable Development Goals target 6.1 [3]. Self-supply comprises water sources (both groundwater and rainwater) within the premises of individual households that are owned and managed by these households [4]. Groundwater is the fastest growing means of meeting water demands in sub-Saharan African cities; over 1.5 billion urban residents depend on groundwater for their water supplies [5]. As is the case throughout the world, majority of sub-Saharan African cities are located along the continental coastal belts, where groundwater resources are vulnerable to the influence of seawater intrusion, atmospheric sea aerosol deposition, and pollution due to population pressure.

Since self-supply mechanisms play a key role in bridging the water supply gaps in urban, peri-urban, and rural areas, there is a need to include self-supply water resources in strategic planning. Concerted actions must be taken by water users and managers of water resources to protect and effectively manage the key source of self-supply for communities. Because most self-supply sources are owned by individuals and are within their premises, they present opportunities for their proper management and protection. Such management strategies require a clear understanding of the current state of groundwater resources and the possible risks posed to groundwater users. It also requires that water managers as well as groundwater users understand the water quality data of their wells and boreholes. However, water quality parameters are numerous and data obtained from water quality measurements can be bulky. Also, a given source of water can meet the criteria for some parameters while not meeting others, making the communication of water quality information difficult. For these reasons, water quality indices (WQIs) are used in evaluating and communicating water quality data. The WQIs serve as tools for summarizing numerous water quality data into a single figure that can be easily understood by a wide range of data users including professionals and non-professionals [6]. Similarly, the Nemerow Pollution Index (NPI) is an effective tool for evaluating and communicating the overall water quality status to water users and policymakers [7]. It emphasizes factors that contribute mostly to the contamination of groundwater while considering the contribution of other factors [8]. The WQIs have been employed across the globe to assess and communicate water quality information [9–17].

In Ghana, the institutions in charge of water supply and distribution are overburdened and are unable to meet the needs of water users, hence, self-supply water from wells and private boreholes is common [18–21]. Furthermore, Ghana is currently experiencing a high rate of urbanization, particularly in its coastal areas, as four out of its six largest cities are situated along the coast [22]. The implication of this is that more pressure is mounted on water infrastructure in these coastal areas. The negative impact of such pressures is often borne by the poor. While water managers may routinely monitor the quality of water in their distribution lines, individuals served through self-supply mechanisms do not carry out such checks. One implication of this is that in cases where these self-supply sources are contaminated, water users will consume such contaminated water, which may lead to negative health consequences. Despite these shortfalls, not much have been done to fully assess the quality of self-supply water sources in the coastal areas of Ghana. Most work on the subject is limited to small communities and, in rare cases, districts and regions [23–28]. There is currently no broad assessment of groundwater that encompasses the entire coastal areas of Ghana. Broad assessments of groundwater hold the advantage of providing a broader perspective on the resource, unveiling trends and patterns, streamlining decision-making processes and fostering cooperation amongst different stakeholders by provding them a common basis for understanding the resource. In addition, indices such as the WQI and NPI that provide an overall clear picture and easy-to-understand information on self-supply water source have found limited use in the these areas. Furthermore, some studies have reported the contamination of groundwater sources in coastal areas with heavy metals [24,29–32]. However, the assessment of the health risks posed by heavy metals in the coastal region regarding drinking water from groundwater sources is limited. Due to the toxicity of heavy metals, mere comparison of their values with set standards is largely insufficient in unraveling their health effects on these coastal communities [33]. To this end, this study, therefore, sought to assess groundwater quality in coastal areas of Ghana using a WQI and the Nemerow Pollution Index. The study also sought to assess the health risks associated with the use of groundwater in the four coastal areas.

2. Materials and methods

2.1. Description of study sites

Four coastal communities (Essiama, Winneba, Korle Lagoon catchment of Accra, and Keta town) were selected for the study (Fig. 1). Essiama is located in the Ellembelle District, in southwestern Ghana. The district lies within the wet semi-equatorial climate zone and experiences a bimodal rainfall regime from February to July as its peak and August to November as its trough [34,35]. Mean temperatures range from 22 to 32 °C [35]. The town is mainly covered by moist semideciduous rain forest which has turned into a secondary forest due to activities such as tree felling [34]. The geology of Essiama is mainly of the Birimian Supergroup and the Apollonian group [34,36]. The Apollonian group consist of Cretaceous-Eocene marine sedimentary rocks such as siltstone, sandstone, shale, mudstone, conglomerate, and limestone which overlie the Birimian rocks [37]. Some of the shale rocks have iron sulfide content and are carbonaceous [38]. The Birimian rocks consist of evenly spaced N-E belts made up of both metasedimentary and metavolcanic rocks [34]. They are made up of alternating shales, phyllites , greywacke, and argillaceous beds with tuffs and lavas. The metavoltic rocks are of volcanic and pyroclastic origin [34]. The Birimian rocks are known to store considerable amounts of water that flows through foliations, joints, and fractures [37]. The major economic activities in the town are fishing, farming, trading, and services in the petrochemical and mining industries. The presence of petrochemical and mining industries in the communities has turned Essiama into a cosmopolitan town.

Winneba is located in the Central Region of Ghana and is the capital of Effutu Municipal Assembly. The town is 140 km east of Cape Coast. Winneba lies in the dry-equatorial climate zone and has a tropical climate [39]. The town has a long dry season of about 5 months. The rainfall regime is bimodal, where April to July are the peak months [40]. Average temperatures range from 22 °C to 28 °C [40]. The geology of the area is mainly of the Birimian Supergroup which comprises the metasediments that form a sedimentary basin, and metavolcanic rocks which form a volcanic belt [41]. Granites and pegmatites intrude the metasediments [41]. Fishing, trading and services are the major economic activities in the town [42,43].

The Korle lagoon catchment area is situated in the southwestern part of Accra, the capital city of Ghana. The Korle lagoon has a total surface area of approximately 0.6 km^2 while the catchment area drained by it is approximately 400 km^2 [44]. Sixty percent of floodwater in Accra is drained by the lagoon and its catchment area [45]. The Korle Lagoon lies in the tropical savannah climate zone which has a bimodal rainfall regime with the highest rainfall occurring between April and July [46]. Annual temperatures range from 27.6 to 25.9 °C [46]. The geology of the area is that of the Accraian series which consists mainly of sandstone, shale, and mudstone with some ironstone and grit [46–48]. The Accraian series is part of the coastal sedimentary rocks. The area is home to popular slums such as Agbogbloshie, Old Fadama, Sabon Zongo and Jamestown. In this study, samples were collected from Agbogbloshie, Old Fadama, and Jamestown.

Keta is a municipality located in the southeastern part of Ghana (Fig. 1). The municipality lies in the dry equatorial climate zone and has an average temperature of 28 °C [49]. The area experiences two rainfall regimes with the major rainy season occurring between April and July [50]. The Keta area falls within the Keta basin which is a Mesozoic/tertiary sedimentary basin along the coast of the Gulf of Guinea and characterized by block-faulting [37,50]. The basin mainly comprises of sedimentary rocks formed in the Mesozoic/tertiary and comprising of Cretaceous – Eocene marine sediments: limestone, shale, and glauconitic sandstone exposed towards the east near the boundary between Ghana and Togo; and the Paelozoic era within the Lower to Middle Devonian period and comprises of marine shale, sandstone, and siltstone, overlain by Jurassic dolerites and sills [50,51]. The Keta area is underlain by limestone which forms the lower layer of two limestone horizons in the subsurface of the Keta basin [52]. Fishing is the major economic activity in Keta while communities surrounding the town are involved in farming [43]. The town is also home to the largest lagoon in Ghana: the Keta Lagoon [53].

Fig. 1. A map showing the coastal areas sampled.

2.2. Sample collection

Water samples were collected from wells and boreholes in each location for spatial and temporal comparison of physicochemical parameters, nutrients, and heavy metals. A total of thirty [30] water samples were collected in each community except in the Korle Lagoon catchment area where twenty-seven [27] samples were collected. For heavy metals, three [3] composite samples were collected from each community due to the high cost of analysis. This was done by dividing the number of the sampled wells and boreholes in each location into 3 equal parts and compositing equal volumes of water in each part. Salinity, Electrical Conductivity (EC), pH, and Total Dissolved Solids (TDS) were measured *in situ* with the use of a EUTECH Multi-Parameter probe while turbidity was measured with an Oakton T-100 turbidimeter. Water samples for heavy metals and nutrients analysis were collected in pre-washed polyethylene bottles. All sample bottles were rinsed several times with the sampled water before about 500 ml of water was collected. To prevent sampling stagnant water, hand-dug wells were sampled after the wells had been actively used by the communities [54] while boreholes were purged for about 5 min before samples were collected. Samples for heavy metal analyses were preserved by the addition of 1 ml of concentrated nitric acid. This was to prevent the heavy metals from adsorbing onto the surface of the polyethylene bottles. Samples were stored at 4 °C and transported to the laboratory of the Department of Fisheries and Aquatic Sciences, University of Cape Coast.

2.3. Laboratory analyses

Nitrate (NO_3^-) and phosphate (PO_4^{3-}) were analyzed by the cadmium reduction and ascorbic acid methods, respectively, using HACH DR 900 Spectrophotometer [55,56]. To do this, 100 ml of groundwater samples were filtered through 0.45 μm pore size lead acetate paper into sterile sampling bottles. For each parameter, 10 ml of the filtered sample was transferred into a HACH sample cell followed by addition of a reagent (NitraVer® 5 Nitrate reagent powder pillow and PhosVer 3 Phosphate powder pillow reagent for the analysis of NO_3^- and PO_4^{3-}, respectively). Samples for nitrates were then shaken for a minute and allowed to stand for 5 min to react while samples for phosphate were shaken for 30 s, and thereafter, left to react for 2 min. In all cases, a blank filtered water sample was used to calibrate the HACH-DR 900. The prepared samples were then placed in the cell holder of the HACH-DR and reading taken at an absorbance of 520 nm and 880 nm, respectively for NO_3–N and PO_4^{3-}. NO_3–N content in the samples were converted to NO_3^- in mg/l by multiplying the reading by 4.43 [55].

Heavy metals (As and Pb) were determined using Inductively Coupled Plasma - Mass Spectrometry (US EPA200.8) [57] while Fe was determined by Inductively Coupled Plasma- Optical Emission Spectrometry (APHA 3120B). Quality assurance and control (QA/QC) were performed for all the laboratory analyses using replicates, spikes, and blanks (Table A1).

2.4. Data analyses

Groundwater data from the four (4) study locations were analyzed statistically for the mean ± standard deviation (SD) and range (min-max). Pearson correlation was used to assess the possible association/relation between the parameters (physico-chemical and metal) measured in groundwater samples. Principal component analysis (PCA) was used to ascertain the contribution of physico-chemical parameters and metals to variations in the dataset. Microsoft Excel and Past software (Version 4.13) were used for the analyses.

2.5. Water Quality Index

The Canadian Council of Ministers of the Environment (CCME) WQI was employed in this study. The choice of the CCME-WQI was due to its flexibility as the parameters, time, and guidelines (standards to be used) are not strictly defined. This makes it applicable in assessing the water quality in different regions, at different times, and in water use scenarios. Parameters, standards and sampling time can be chosen based on prevailing local conditions, the purpose for which the water is used, and the existing water quality issues [6]. The CCME water quality categories are shown in Table 1 [16].

In this study, seven (7) parameters (pH, TDS, turbidity, nitrate, As, Pb, and Fe) were used in estimating water quality and sampling was done for both the wet and the dry seasons. Although the CCME recommends that at least four parameters monitored at least four times be used in the estimation of water quality, it states that in some cases, monitoring can be done once per season. Additionally,

Table 1
CCME water quality categories.

WQI Category	Index Value	Description
Excellent	95–100	All measurements are within the objectives all the time
Good	80–94	Conditions rarely depart from desirable levels
Fair	65–79	Conditions sometimes depart from desirable levels
Marginal	45–64	Conditions often depart from desirable levels
Poor	0–44	Conditions usually depart from desirable levels

CCME- Canadian Council of Ministers of the Environment.
WQI - Water Quality Index.

several samples (at least 27 in each community except for the heavy metals samples) were collected to compensate for any effects that the reduction in sample times might have.

CCME-WQI was calculated using equation (1):

$$\mathrm{CCME} - \mathrm{WQI} = 100 - \frac{\sqrt{FI^2 + F2^2 + F3^2}}{1.732} \tag{1}$$

Where

$$F1 = Scope = \frac{Number\ of\ failed\ parameters}{Total\ number\ of\ parameters} \times 100$$

$$F2 = Frequency = \frac{Number\ of\ failed\ test}{Total\ number\ of\ test} \times 100$$

$$F3 = Amplitude = \frac{NSE}{0.01\ NSE + 0.01}$$

The scope represents the percentage of parameters that fail to meet the guideline at least once during the period under consideration; the frequency is the percentage of individual tests that fail to meet the guideline; and the amplitude is the amount by which the failed test values do not meet their guidelines. NSE is the normalized sum of excursion. The excursion (Eqn. (2)) represents the number of times by which an individual concentration is greater than the guideline. NSE (Eqn. (3)) was calculated as follows

$$\mathrm{Excursion_i} = \left(\frac{Failed\ test\ value}{Objective\ _j}\right) - 1 \tag{2}$$

$$\mathrm{NSE} = \sum_{\mathrm{i}=1}^{n} \left(\frac{Excursioni}{Number\ of\ tests}\right) \tag{3}$$

2.6. Nemerow's pollution index

Nemerow's Pollution Index (NPI) is a simple pollution index that was introduced by Neme [58] also referred to as Raw's Pollution Index. It unveils the extent of contamination for a given water quality parameter with reference to its standard/recommended value. The calculation and analysis of NPI values of different water quality parameters for an area help in the identification of principal contaminants in that area which is very useful for the enhancement of water quality in the area [59]. It is also very useful in conveying raw environmental information to managers, decision-makers, technicians, and the general public [60].

NPI was calculated using the equation applied by Refs. [7,58,59] as in equation (4).

$$NPI = \frac{Ci}{Li} \tag{4}$$

Where.

Ci represents the measured concentration of the ith parameter while
Li represents the permissible limit of the ith parameter.

Each value of NPI represents the relative pollution contributed by a given parameter and should be less than or equal to one [58]. If the NPI values exceed one for a given parameter, it is an indication of impurity [58].

2.7. Health risk assessment

Incremental Lifetime Cancer Risk (ILCR, Eqn. (5)) and Hazard Quotient (HQ) were respectively used to determine the carcinogenic and non-carcinogenic health risks of the heavy metals. As and Pb have been classified as group 1 and group 2A carcinogens, respectively, by the International Agency for Research on Cancer [61]. The carcinogenic risk of As and Pb were calculated using equations (5) and (6) as employed by Ref. [62].

$$\mathrm{ILCR} = \mathrm{ADI} \times \mathrm{SF} \tag{5}$$

$$ADI = \frac{C \times IR \times ED \times EF}{BW \times AT} \tag{6}$$

Where ADI (Eqn. (6)) is the average daily intake (in mg/kg.day over a lifetime), SF is the cancer slope factor for the given heavy metal:1.5×10^{-3} for As and 8.5×10^{-3} for Pb [33,63], C is the heavy metal concentration (mg/kg), IR is the ingestion rate (2.2 L/day), ED is the exposure duration (70 years), EF is exposure frequency (365 days/year), BW is body weight (70 kg), and AT is the average

Table 2

Statistical summary of physicochemical parameters and concentration of metals of groundwater sources in the coastal areas of Ghana.

Parameters	Rainy				Dry				WHO 2017
	Essiama	Winneba	Accra	Keta	Essiama	Winneba	Accra	Keta	
pH	3.22 ± 1.89	4.08 ± 1.72	3.11 ± 2.41	4.57 ± 2.16	7.00 ± 0.78	8.25 ± 0.26	7.67 ± 0.78	8.54 ± 0.31	6.5–8.5
	0.26–6.54	2.02–7.12	0.00–7.20	2.43–8.43	5.18–9.18	7.70–8.77	5.55–9.05	8.05–9.22	
EC (mS/cm)	0.44 ± 0.25	2.54 ± 1.14	2.61 ± 1.18	1.57 ± 0.91	0.43 ± 0.24	2.41 ± 1.04	2.45 ± 1.25	1.77 ± 1.53	2.5[a]
	0.16–1.05	0.77–5.24	0.22–4.91	0.30–3.56	0.14–0.99	0.75–5.02	0.27–5.67	0.28–7.74	
TDS (g/l)	0.29 ± 0.16	1.63 ± 0.72	1.61 ± 0.70	1.29 ± 1.18	0.29 ± 0.16	1.50 ± 0.71	1.57 ± 0.79	1.13 ± 0.97	0.6
	0.10–0.97	0.49–3.30	0.14–3.14	0.19–5.86	0.091–0.64	0.11–3.16	0.18–3.57	0.18–4.87	
Salinity (ppt)	0.28 ± 0.44	1.31 ± 0.61	1.30 ± 0.60	1.05 ± 1.05	0.22 ± 0.13	1.24 ± 0.57	1.27 ± 0.68	0.91 ± 0.84	
	0.07–2.50	0.37–2.81	0.10–2.62	0.14–5.20	0.06–0.55	0.36–2.69	0.13–3.05	0.13–4.26	
Turbidity (NTU)	5.09 ± 8.09	4.37 ± 4.93	11.63 ± 18.65	8.83 ± 7.36	4.63 ± 7.80	2.37 ± 4.37	15.20 ± 25.49	0.43 ± 0.57	5.0
	0.00–27.00	0.00–18.00	0.00–60.00	0.00–24.00	0.00–39.00	0.00–18.00	0.00–114.00	0.00–2.70	
PO_4^{3-} (mg/l)	0.14 ± 0.19	1.35 ± 1.13	0.31 ± 0.44	1.63 ± 1.86	0.28 ± 0.83	1.41 ± 1.14	0.65 ± 1.27	1.50 ± 1.88	30
	0.00–0.74	0.10–3.54	0.04–2.31	0.00–5.58	0.00–4.55	0.11–4.18	0.00–5.23	0.07–6.23	
NO_3^- (mg/l)	37.10 ± 31.19	135.41 ± 66.87	92.24 ± 80.72	40.76 ± 52.51	46.74 ± 43.65	150.50 ± 67.17	74.56 ± 88.40	41.95 ± 50.13	50
	1.33–112.21	3.99–233.02	0.00–210.87	0.00–171.00	3.10–173.88	10.19–287.51	0.00–249.85	1.77–178.53	
Pb (µg/l)	BDL	BDL	BDL	BDL	0.80 ± 0.30	1.20 ± 0.00	0.60 ± 0.00	0.60 ± 0.00	10
	BDL	BDL	BDL	BDL	0.60–1.10	BDL-1.20	BDL-0.60	BDL-0.60	
As (µg/l)	BDL	BDL	10.00 ± 0.00	BDL	5.00 ± 2.00	3.30 ± 2.00	62.00 ± 0.00	11.00 ± 0.00	10
	BDL	BDL	BDL-10.00	BDL	BDL-6.70	1.1–5.00	BDL-62.00	11.00–11.00	
Fe (mg/l)	0.27 ± 0.21	0.1 ± 0.00	3.65 ± 1.06	0.15 ± 0.07	0.10 ± 0.00	BDL	1.27 ± 2.02	0.30 ± 0.17	0.3
	0.10–0.50	BDL-0.10	BDL-4.40	BDL-0.20	BDL-0.10	BDL	0.10–3.60	0.20–0.50	

± denotes standard deviation (SD).

[a] European Union Guideline; BDL: Below Detection Level; DL for Fe- 0.1 mg/l; DL for Pb and As- 0.5 µg/l.

time (25,550 days) [64].

When ILCR is between 10^{-6} and 10^{-4}, it indicates that the cancer risk is acceptable while ILCR higher than 10^{-4} indicates high cancer risk [65].

The HQ for As, Pb, and Fe was calculated using equation (7) as employed by Ref. [62].

$$HQ = \frac{ADI}{RfD} \tag{7}$$

Where RfD is the oral reference dose of the heavy metal in mg/kg.day. Established oral reference doses from USEPA were used: 3.0×10^{-4} for As, 3.6×10^{-3} for Pb, and 7×10^{-1} for Fe [63].

Hazard quotients less than 1 indicate that there is no risk of a non-cancer hazard, while hazard quotients greater than 1 indicate that there is a risk of non-cancer adverse health effects.

3. Results

3.1. Water quality parameters

The mean and range of values for all the parameters for both wet and dry season are presented in Table 2. Results of water quality analyses show acidic groundwater for all communities during the rainy season. Mean pH values of groundwater samples in all the studied communities were outside of the pH range recommended by the World Health Organization and below the lower limit of 6.5. A mean pH value of 3.22 was recorded for Essiama with a range between 0.26 and 6.54; in Winneba, a mean of 4.08 and a range between 2.02 and 7.12 was recorded; in Accra, a mean of 3.11 and range between 0.00 and 7.20 was recorded while in Keta a mean of 4.57 and range between 2.43 and 8.43 was recorded. Dry season results shows a comparatively less acidic conditions in all communities with mean values reflecting neutral conditions and most values falling within acceptable standards for drinking water with the exception of Keta where values were slightly higher than the upper limit of 8.5. Values of pH ranged between 5.18 and 9.18 with a mean of 7.0 for Essiama. For Winneba, pH ranged between 7.70 and 8.77 with a mean of 8.25. For Accra, pH ranged from 5.55 to 9.05 with a mean 7.67. Whereas for Keta, pH values ranged between 8.05 and 9.22 with a mean of 8.54.

Similarly, mean values higher than the standard were recorded for electrical conductivity (EC) in Winneba (0.77–5.24 mS/cm, mean 2.54 mS/cm) and Accra (0.22–4.91 mS/cm, mean 2.61 mS/cm) during the rainy season. During the dry season, EC values for all the studied communities were at acceptable levels. Total dissolved solids in Essiama was at an acceptable level for the two seasons. For the other study locations, the values for TDS were above acceptable levels for both seasons, although the rainy season values were generally higher than the dry season values. Mean turbidity was also above the acceptable level in most of the studied communities during the rainy season (except Winneba), while during the dry season, mean turbidity was at acceptable levels in most of the studied communities (except Accra).

Mean nitrate concentrations were found to be higher than the WHO standards in Winneba and Accra for both the rainy and the dry season while in Essiama and Keta the concentrations were at acceptable levels for both seasons. In all the studied communities, Pb was at an acceptable level during the rainy and dry seasons. Arsenic was however found to be higher than the acceptable level for Accra and Keta during the dry season, while iron was higher than the acceptable levels in Accra in both the rainy and dry seasons.

3.2. Relationship between water quality parameters

Pearson correlation of physicochemical parameters and metals are presented in Fig. 2(a–d). In almost all the studied communities,

Table 3
CCME-WQI of groundwater sources in the coastal areas of Ghana.

WQI	Locations			
	Essiama	Winneba	Accra	Keta
F1	71.40	57.10	85.70	85.70
F2	31.10	58.50	53.30	46.50
F3	33.00	49.70	60.00	35.90
CCME-WQI	51.10	44.70	32.20	40.00
WQI Category	Marginal	Poor	Poor	Poor
Sum of Failed Tests	126.50	254.60	321.40	137.00
Normalized Sum of Excursion	0.50	1.00	1.50	0.60
Total Samples	60.00	60.00	50.00	60.00
Total Variables	7.00	7.00	7.00	7.00
Actual Variables Tested	7.00	7.00	7.00	7.00
Total Tests	257.00	258.00	214.00	245
Number of Failed Tests	80.00	151.00	114.00	114.00
Number of Passed Tests	177.00	107.00	100.00	131.00
Number of Less than Detected	8.00	13.00	10.00	8.00

CCME- Canadian Council of Ministers of the Environment; WQI- Water Quality Index; F1- Scope; F2- Frequency and F3- Amplitude.

EC, TDS, and salinity had strong positive correlations as expected. In Essiama, there were strong positive correlations of pH with Pb, pH with As, $NO_3^-$with Pb, NO_3^- with As, PO_4^{3-} with As, and Pb with As. Strong positive correlations were also recorded in Winneba for pH with As, and As with Pb. Also, in Accra, turbidity and Pb, PO_4^{3-} and Pb, and As and Pb had strong positive correlations while pH with As and pH with Fe had strong negative correlations. There were strong positive correlations of pH with As in Keta's groundwater sources.

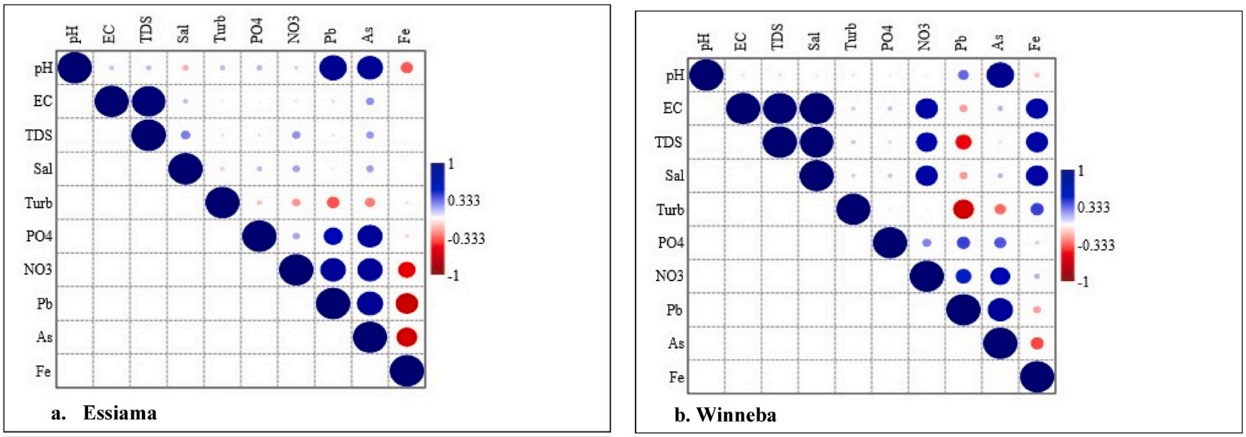
Principal component biplots of groundwater quality variables are shown in Fig. 3(a–d). In Essiama, PCA revealed that Component 1 explained 24.89 % and Component 2 explained 20.94 % of the 45.83 % cumulative variance in the groundwater sources. Pb, As, and Fe had the highest loading in the first component while EC and TDS were highly loaded in the second component. Cumulative percentage variance of 57.17 % was recorded for the first two components in Winneba, where Component 1 explained 36.65 % and Component 2 explained 20.52 % of the entire variance in the groundwater sources. The loadings of EC, TDS, and salinity were highly loaded in the first component whereas Pb and As were highly loaded in Component 2.

In Accra, Component 1 explained 31.07 % while Component 2 explained 21.89 % of the total variance in the dataset. Cumulatively, the first two (2) components in the principal component analysis of groundwater quality properties were responsible for about 52.96 % of the variation in the system. Simliar to Winneba, EC, TDS, and salinity were highly loaded in the first component. On the other hand, phosphate and lead were highly loaded in the second component. Of the 50.13 % cumulative variance explained by the first 2 components in Keta, Component 1 was responsible for 29.94 % and Component 2 was responsible for 20.19 %. Like in the case of Winneba and Accra, EC, salinity, and TDS were highly loaded in the first component. As and Fe were highly loaded in the second component for Keta.

3.3. *Water quality and pollution indicators*

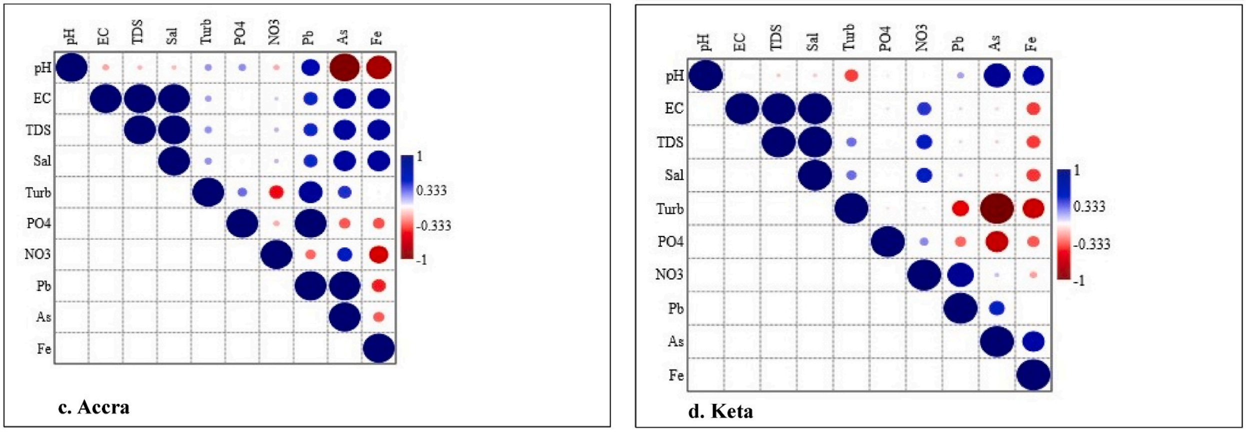
Details of the CCME-WQI of groundwater sources in the four locations along the coast of Ghana are shown in Table 3. The index showed that marginal water quality category was recorded for Essiama while the groundwater sources in Accra, Winneba, and Keta were categorised in the poor water quality category. Essiama recorded the highest CCME-WQI (51.10), followed by Winneba (44.70) and Keta (40.00) while the least was recorded in Accra (32.20).

Results of the NPI are shown in Table 4. Results showed that nitrate contributed to the pollution of groundwater sources in Winneba (2.71 and 3.01 for rainy and dry seasons respectively) and Accra (1.84 and 1.49 for rainy and dry seasons respectively), while arsenic



a. Essiama

b. Winneba



c. Accra

d. Keta

Fig. 2. (a–d): Pearson Correlation of physicochemical parameters and metals of groundwater sources
Figure 2(a–d): Pearson Correlation of physicochemical parameters, metals and bacteria of groundwater sources.

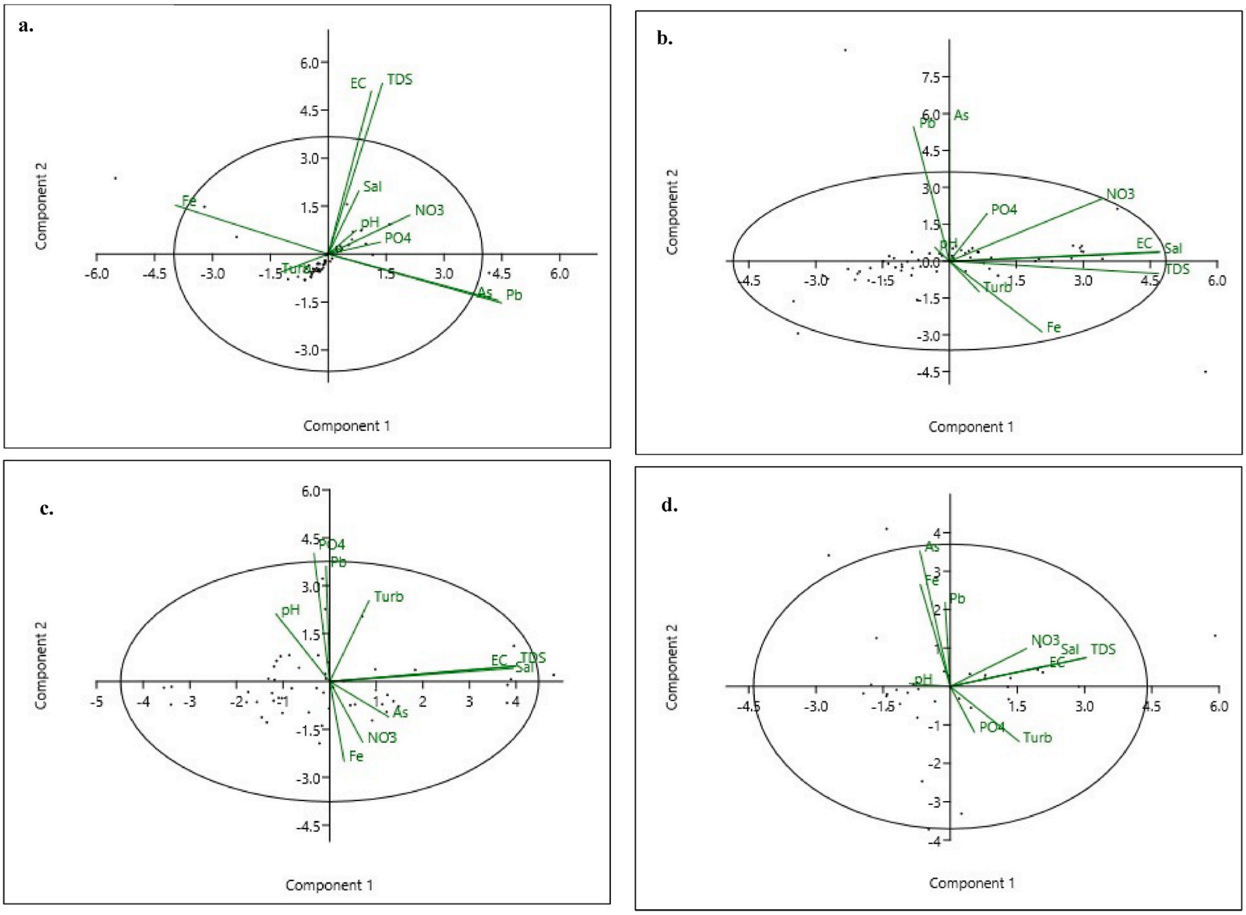


Fig. 3. (a–d): Principal component analysis biplots of physicochemical parameters and metals of groundwater sources (a) Essiama (b) Winneba (c) Accra (d) Keta.

only contributed to the contamination of groundwater in Accra (6.20) and Keta (1.10) in the dry season. Also, iron contributed to the contamination of groundwater sources in Accra in the rainy (12.17) and dry (4.23) seasons, and in Keta during the dry season (1.00).

3.4. Human health risk indicators

The health risk associated with the use of groundwater sources in the studied communities is presented in Table 5. The Incremental Life Time Cancer Risk (ILCR) recorded across the studied communities is 0 for both Pb and As in the rainy season except in Accra where an ILCR of 4.71×10^{-7} was recorded for As. On the other hand, during the dry season, an ILCR of 1.60×10^{-7} was recorded for Pb in Accra and Keta while Essiama and Winneba had ILCR of 2.14×10^{-7} and 3.21×10^{-7} respectively. For As, ILCR of 2.36×10^{-7}, 1.56×10^{-7}, 2.92×10^{-6}, and 5.19×10^{-7}, respectively, were recorded in Essiama, Winneba, Accra and Keta. A hazard quotient (HQ) of 0 was recorded for Pb and As across all the communities in the rainy season except in Accra where HQ for As was 1.05. For Fe, HQ were 1.21×10^{-2}, 4.49×10^{-3}, 1.64×10^{-1} and 6.74×10^{-3} in Essiama, Winneba, Accra, and Keta, respectively in the rainy season implying the absence of non-cancer risks. HQ for Pb were 6.98×10^{-3}, 1.05×10^{-2}, 5.24×10^{-3}, and 5.24×10^{-3} in Essiama,

Table 4
Nemerow Pollution Index of groundwater in coastal areas of Ghana.

Parameters	Rainy Season				Dry Season			
	Essiama	**Winneba**	**Accra**	**Keta**	**Essiama**	**Winneba**	**Accra**	**Keta**
PO_4^{3-}	0.01	0.05	0.01	0.05	0.01	0.05	0.02	0.05
NO_3^-	0.74	**2.71**	**1.84**	0.82	0.93	**3.01**	**1.49**	0.84
Pb	0.12	0.00	0.00	0.00	0.08	0.12	0.06	0.06
As	0.00	0.00	0.00	0.22	0.50	0.33	**6.20**	**1.10**
Fe	0.90	0.33	**12.17**	0.50	0.33	0.00	**4.23**	**1.00**

Table 5
Human health risk indicators of metals in the groundwater sources.

Incremental Life Time Cancer Risk								
Parameters	Rainy Season				Dry Season			
	Essiama	Winneba	Accra	Keta	Essiama	Winneba	Accra	Keta
Pb	0.00	0.00	0.00	0.00	2.14×10^{-7}	3.21×10^{-7}	1.60×10^{-7}	1.60×10^{-7}
As	0.00	0.00	4.71×10^{-7}	0.00	2.36×10^{-7}	1.56×10^{-7}	2.92×10^{-6}	5.19×10^{-7}
Hazard Quotient								
Pb	0.00	0.00	0.00	0.00	6.98×10^{-3}	1.05×10^{-2}	5.24×10^{-3}	5.24×10^{-3}
As	0.00	0.00	**1.05**	0.00	5.24×10^{-1}	3.46×10^{-1}	**6.50**	**1.15**
Fe	1.21×10^{-2}	4.49×10^{-3}	1.64×10^{-1}	6.74×10^{-3}	4.49×10^{-3}	0.00	5.70×10^{-2}	1.35×10^{-2}

Winneba, Accra, and Keta, respectively during the dry season. HQ for As were 5.24×10^{-1}, 3.46×10^{-1}, 6.50, and 1.15 in Essiama, Winneba, Accra, and Keta, respectively while HQ for Fe were 4.49×10^{-3}, 0.00, 5.70×10^{-2}, and 1.35×10^{-2}.

Results on health risk assessment for the heavy metals shows that no potential cancer risk for lead in all the study locations and seasons. For arsenic, potential cancer risk were observed for the arsenic concentrations found in Essiama, Winneba and Keta during the dry season; and the concentrations in Accra during the rainy season. However, high cancer risk were observed in Accra during the dry season. Hazard quotient showed that lead and iron do not pose any significant non-cancer health risk in all the studied communities for the two seasons considered. However, arsenic was observed to pose potential non-cancer risk at the concentrations observed in Accra during the rainy season, and in Keta during the dry season.

4. Discussion

4.1. Groundwater quality

The results of this study show that seasonal variations exists in the water quality parameters and amongst the study sites. Groundwater in the study areas are mineralized with high EC/TDS/Salinity in addition to the presence of fecal matter in groundwater inferred by nitrates in water samples.

Groundwater was found to be acidic and near neutral pH conditions, respectively, during the rainy and dry seasons for the four coastal communities. These conditions have previously been reported in shallow (wells) and deep groundwater (boreholes) sources within communities along the coast of Ghana [54,66–69] and have variously been attributed to wastewater infiltration [54] and the geology [67]. In our case, we attribute the acidic conditions observed in the sources to both wastewater infiltration and dissolution of granitoid minerals. All four communities under study are densely populated municipalities and in many cases without proper wastewater management practices as it is the case in many parts of Ghana [70]. This assertion is reflected in the high nitrate content in groundwater sources within the Winneba and Accra areas. The sources of the nitrates may be attributed to poor sanitary conditions around the wells especially, the presence of pit latrines, septic tanks and waste dumps that are located at short distances from the groundwater sources; these are common conditions that affect groundwater quality in many high population communities (slums and peri-urban) in parts of the Sub-Saharan Africa region [71–73]. Septic tanks, for example, have been implicated as the main source of nitrate pollution in communities that lack central wastewater systems [74] as it is the case in all the four communities. Additionally, mineral dissolution might have contributed to the acidic conditions especially within two of the communities (Winneba and Essiama) underlain by sediments intruded by granitoid which are known to produce acidic groundwater [67].

Our results indicate that average EC values ranged between 0.44 and 2.61 mS/cm during the rainy season and from 0.43 to 2.45 mS/cm in the dry season for the four studied locations. It was noted that as high as 7.74 mS/cm was measured in a well in Keta. These values can be considered to be fresh to brackish waters according to the classification scheme by Park et al. [75]. From the results, only Essiama with an average EC < 1000 μS/cm indicated fresh water according to the classification by Park et al. [75]. EC values for the rest of the communities showed brackish conditions i.e., 1.5 mS/cm $<$ EC $<$ 3 mS/cm [75] indicating that groundwater in the three communities is mineralized. Our results are comparable to previous findings in coastal aquifers within the country e.g. Zume et al. [69]: 0.4 to 6.7 mS/cm, mean 1.85 mS/cm; Lutterodt et al. [54]: 0.2 to 2.7 mS/cm; and Asare et al. [27]: 0.71 to 9.76 mS/cm, mean 1.1 mS/cm). We attribute the brackish nature of water to the influence of the sea through seawater intrusion and/or deposition of atmospheric sea aerosol, dissolution of minerals and infiltrating wastewater in the neighborhood of the wells. Similar to our findings for Accra and Winneba, another study [23] reported higher values of EC/TDS in the wet season compared to the dry season in their work in the Keta area. It is difficult to explain the observed higher EC/salinity values in the rainy season compared to the dry season for Accra and Winneba; it is common for the vice versa to be observed and usually attributed to dilution in concentrations of chemicals and other physical water quality parameters during the wet season and evaporation in the dry season increasing concentrations of chemical parameters and physical quality values. We speculate the possibility of plug flow conditions within the neighborhood of the wells: low chemical content recharging water pushing stagnant and chemically modified water into wells.

The high turbidity recorded for most of study locations in the rainy season could be attributed to the effects of runoff, seepage and re-suspension of particles which may be due to the effect of groundwater flow rate changes in the neighborhood of the wells. Some of the wells in the study locations lack wellheads, this can lead to direct inflow of runoffs into those wells; this was common incidence in

Keta, in addition to the shallow nature of the water table in the study area in Accra. Apart from the Accra area which recorded high average turbidity in the dry season compared to the rainy season values, the oppositw was observed for the rest of the other communities. Turbidity is known to affect the acceptability/potability of water, and can pose a health concern, as the suspended particles in turbid water can serve as food, shelter, and surfaces for the attachment of microbes, thus aiding their survival [76]. Furthermore, suspended particles can provide attachment for heavy metals. High turbidity values for the other three communities during the rainy season may be as a result of two possibilities: (1) direct inflow of run-off water into especially large diameter hand dug wells that lacks protective apron walls which was a common observation in the Keta area (note that the Keta area is known to experience seasonal flooding [23] and therefore compliments the assertion that run-off may flow directly into some of the wells); and/or (2) rapid changes in hydrodynamic conditions within the aquifer in the neighborhood of the wells and boreholes during the rainy season. Increased groundwater flow rates can result in dislodging of sediments from the surfaces of aquifer media and re-suspension of these sediments together with quartz colloids in water within groundwater flow lines. Note that, the two communities (Accra and Keta) that observed high turbidity in groundwater samples are underlain by sedimentary rocks. For example, the Keta area is made up of unconsolidated sediments with a high possibility of entrainment of these loosely held sediments into flowing water during the wet season. A study in the Keta area made similar findings [23]. The high turbidity recorded in wells in Accra during the dry season cannot be explained, we speculate the possible seepage of wastewater into the shallow groundwater system of the area. Note that in the Agbogbloshie area the depth to the water surface is short and close to the surface (<0.3 m by visual inspection). In addition, groundwater seem to be more vulnerable in the area as wastewater flows freely in the area in addition to the e-waste recycling activities in the area, ranking in the top ten of most polluted sites in the World in 2013 [77].

The high As content in groundwater samples in the Agbogbloshie area of Accra can be attributed to e-waste cycling site. Previous studies in the area indicate significant enrichment of the soils in the area with As [78]. The high concentrations of iron in Accra may be due to the natural sources, as high iron levels in groundwater is a common situation in Ghana [79].

Generally, groundwater quality was better during the dry season than the rainy season as most water quality parameters were within the WHO acceptable standards during the dry season. The pollution of groundwater during the rainy season can be attributed to wastewater infiltration and seepage of effluents from waste dumps, direct run-off into wells with shallow depth to water surface as it is the case in the communities under study.

4.2. Relationship between water quality parameters

The strong correlations between the various physicochemical parameters and metals concentrations showed that there are associations between this parameters. Strong correlations between TDS, EC and salinity are expected due to their theoretical links [54]. Strong associations were also observed between the parameters in almost all locations, as well as between pH and heavy metals. pH influence the movement of heavy metals into groundwater. Acidic conditions favour the leaching of heavy metals into groundwater [80].

The high loading of EC, TDS and salinity in Component 1 of Winneba, Accra, and Keta is expected as the areas under study are coastal communities which often have high halite contents when compared to inland areas. However, the high loading of Pb, As, and Fe in Component 1 of Essiama may be due to the mining activities in neighbouring town around the community. Nkroful and the Ankobra River Basin are major mining locations situated around Essiama.

The high loading of heavy metals in the second component in Winneba, Accra and Keta may be attributed to both geogenic and anthropogenic sourrces. Arsenic is an important geogenic groundwater contaminants; it affect millions of people in every continent in the world [81]. Anthropogenic pollution of groundwater results from agricultural activities, urbanization, increase in population, industrialization, and climate change.

The high loading of phosphate is Component 2 in Accra may be the resultant effect of indiscriminate discharge of human, industrial, and household wastes in the area. Urbanization has a strong link with phosphate contamination of groundwater [82]. The Korle lagoon catchment area of Accra is densely populated and lacks adequate toilet facilities; urine, kitchen waste and other household wastes are often emptied into faulty water drains found within the area. Furthermore, the Odaw River, which drains the area, is also linked to other drains in some major industrial areas upstream. This may also serve as a conduit for contaminants to groundwater within the river basin.

4.3. Water quality and pollution indicators

The water quality category in this study ranged from poor to marginal category with implications for groundwater use for domestic purposes. The marginal groundwater quality recorded in Essiama indicates that groundwater in the community often depart from desirable levels. Whereas the poor groundwater quality recorded in Accra, Winneba, and Keta indicates that groundwater in these communities usually departs from desirable levels.

The poor water quality category recorded in the Accra Korle-Lagoon Catchment may be caused by the poor sanitary conditions in the area which result from improper waste management, high population density, and urbanization. Agbogbloshie, Old Fadama and James Town in Accra where water samples were collected are characterized by informal settlements and inadequate sanitation infrastructure [83]. Likewise, the poor water quality in Winneba may also have resulted from poor sanitation and siting of groundwater sources near septic tanks while the poor water quality recorded in Keta may be due to the absence of well covers and construction of wells without aprons. Marginal water quality category in Essiama could be as a result of mining activities in the area. The results of PCA where Essiama was the only study location that had heavy metals loaded in the first component supports this. Mining as a major anthropogenic activity resulting to ground and surface water pollution have been reported in the area [84,85]. Mining wastes have been reported to be associated with the contamination of groundwater in the Western Region of Ghana [86–89]. Similar to the finding of this study, another study [90] reported marginal and poor groundwater quality for some groundwater sources in South Tongu and Ada East of Ghana. Poor and marginal groundwater quality category have also been reported in other jurisdictions [91,92].

The contribution of nitrate to the contamination of Winneba and Accra groundwater sources in both rainy and dry season is an indication of pollution from sewage waste disposals and improper siting of groundwater sources especially wells and boreholes. The contributions of Fe and As to the contamination of Keta may be attributed to natural enrichment of the underlying rock materials with these metals as there are no known human activities in the community that can result to such enrichment. Whereas, in Accra, the contribution of As to groundwater contamination maybe due to both natural and anthropogenic sources as Agbogbloshie is a notable e-waste hub in Ghana. The contribution of Fe to the contamination of groundwater in Accra may be due to the naturally high Fe concentrations in most aquifers in Ghana [79].

4.4. Human health risk assessment

Results on health risk assessment show that there was no potential cancer and non-cancer risk for Pb in all the study locations and both seasons. A study [93] that obtained HQ values of $7.17x10^{-5}$ observed similar results for non-cancer risk of lead in Iran, but contrary to our findings, they obserevd potential cancer risk with mean ILCR of $8.54x10^{-4}$. Lead have been implicated in abnormal brain development, intellectual disability, anaemia, kidney diseases, hypertension, immunotoxicity and toxicity to the reproductive system [94].

In this study, HQ for Fe was below 1 in all the studied communities, showing that it had no significant non-cancer risk. This is similar to the findings of a study [95] which reported an HQ value of $7.68x10^{-4}$. The findings, however, contradict the findings in groundwater in Dadinkowa dam and Kwadon, Nigeria, where an HQ value of 1.27 was reported [96]. These differences in HQ may be the result of differences in geological formations. Iron is an essentail nutrient for humans, but excess iron in drinking water can affect its aesthetic quality and lead to health disorders such as cardiovascular diseases, parkinson disease, diabetes, huntington disease, hyperkeratosis, body pigmentation, alzheimer disease, kidney, liver, respiratory and neurological disorders [97].

Arsenic, on the other hand, show cancer risk in Accra during the dry season. HQ estimation also show that arsenic pose non-cancer adverse health risk in Accra and Keta. Similar to our findings, Shah et al. observed cancer and non-cancer health risk in their study on groundwater in Pakistan with mean HQ of 3.9 and ILCR of $1.8x10^{-3}$ [98]. Zhang et al. also reported similar trend in groundwater in China [99]. In the same vein, Rahman et al. also reported cancer and non-cancer health risk in their study in Southwest Bangladesh [100]. Arsenic is the most significant chemical contaminant in drinking water globally [101]. The cancer risk associated arsenic in Accra may be due to the presence of the e-waste hub in the Agbogbloshie and its environs. Arsenic has been classified as a Group I carcinogen. Prolonged exposures to arsenic can lead to cancer of the bladder, skin, lungs, liver, digestive tract, and lymphatic system [102]. Non-cancer related effects of arsenic include adverse pregnancy outcomes, developmental impairment, lung diseases, diabetes, and arsenic-induced myocardial infarction [101].

5. Conclusion

The current study assessed groundwater quality and associated health risks in four (4) coastal communities in Ghana. Turbidity, EC, TDS, nitrate, and As in the study locations were generally above the WHO standard limits during the rainy season in some of the studied communities. Results of EC show that groundwater in Essiama was fresh ($EC < 1000$ μS/cm) while that of Winneba, Accra and Keta is brackish and mineralized (1500 μS/cm $< EC < 3000$ μS/cm). CCME-WQI also show that groundwater quality in the studied communities ranged from poor to marginalwater quality categories (32.20–51.10). Nemerow's Pollution Index show that nitrate, arsenic and iron are important groundwater contaminants in some of the studied communities. Health risk assessment show that As posed cancer risk in Accra (2.92×10^{-6}) during the dry season. Similarly, As posed non-cancer health risk in Keta (1.05) during the rainy season and in Accra (6.50 in the dry season and 1.05 in the rainy season). It is suggested that urgent regulations through policy and monitoring strategies must be put in place to improve groundwater quality in the coastal areas of Ghana.

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Data availability

Data will be made available on request.

CRediT authorship contribution statement

Emuobonuvie G. Ayeta: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **Levi Yafetto:** Writing – review & editing, Supervision, Project administration, Conceptualization. **George Lutterodt:** Writing – review & editing, Supervision, Conceptualization. **Joel F. Ogbonna:** Writing – review & editing, Supervision, Conceptualization. **Michael K.**

Miyittah: Writing – review & editing, Supervision, Project administration, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interestsMichael K. Miyittah reports financial support, administrative support, and equipment, drugs, or supplies were provided by University of Cape Coast, Ghana. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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