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Hydrogeochemical and anthropogenic influence on the quality of water sources in the Rio del Rey Basin, South Western, Cameroon, Gulf of Guinea

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This study which focuses on the hydrogeochemical and anthropogenic influence on water sources in the Rio del Rey Basin has provided an insight into the sources of major ions, water mineralisation processes, and the suitability of the water sources for drinking and agricultural purposes. Fifty-one (51) samples (38 groundwater, 9 surface water, 1 tap, 1 reservoir and 2 rainfall events) were analysed for physico-chemical and microbial quality. The pH of groundwater samples ranged from 5.5 to 8. Sixty percent (60%) of the groundwater samples were slightly acidic (5.5-6.4) and were different from the WHO (2004) standard for drinking water. Electrical conductivity values (3-274 µS/cm) and total dissolved solids (7.66 to 248.30 mg/l) for groundwater sources were low and signified low mineralisation and freshwater conditions. The relative abundance of major ions (meq/l) was $Na^+>K^+>Mg^{2+}>Ca^{2+}$ for cations and $HCO_3^->NO_3^->SO_4^{2-}>Cl^-$ for anions. The main water types were: $Na-HCO_3$ (45%), $Ca-HCO_3$ (35%), $Na-Ca-HCO_3$ (15%), Ca-Mg-Cl (2%) and NaCl (2%). The processes that influenced the water chemistry were incongruent silicate dissolution and cation exchange. The chemical constituents were low and within the WHO (2004) guidelines for drinking water except for high concentrations of NO_3^- (77.28 mg/l) and Br^- (0.08 mg/l) in one open well. Water quality index calculated using the adjusted form of CCME (2001) based on the major and chemical parameters (TDS, pH, F^- and Br^-) for groundwater and surface water data indicated that 90, 6, 2 and 2% provided excellent, good, marginal and poor water quality, respectively for drinking purposes. The evaluation of results showed that 90% of groundwater sources were suitable for agricultural purposes. Total coliform counts indicated that 97% of the groundwater sources were polluted.

Key words: Groundwater chemistry, microbial quality, anthropogenic influence, Rio del Rey Basin.

INTRODUCTION

In sub-Saharan Africa, almost all communities in coastal areas depend on groundwater for drinking and domestic purposes (Edet, 2008). This is because it is available and is relatively cleaner than surface water sources which are exposed to pollution from domestic wastes and runoff especially during the rainy season. Lastly, groundwater does not need extensive treatment before use (Yidana, 2010). The concept of water quality has been evaluated

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in recent years owing to greater understanding of water mineralization processes and greater concern about its origin (Chenini and Khemiri, 2009; Nwankwoala and Udom, 2011). Some of the factors that control groundwater quality and it's chemistry along the African coast are enhanced Na^+, Ca^{2+}, Mg^{2+} and HCO^-_3, due to silicate and carbonate weathering and enhanced NO^-_3 from indiscriminate waste disposal from human activities (Edet, 2008; Olufemi et al., 2010; Nduka and Orisakwe, 2011). Following the works of several authors (Chebotarev, 1955; Gibbs, 1970; Palmer and Cherry, 1984; Lawrence et al., 2000; Ellis and Rivett, 2007; Eneke et al., 2011), it is generally accepted that the chemical quality of groundwater is controlled by natural processes such as precipitation, mineral weathering and evaporation-crystallisation and also significantly influenced by anthropogenic processes (Lerner and Barrett, 1996). Variation in levels of water constituents (major ions) may be attributed to the differential derivation from source rocks, discharge of untreated effluents from industries, agricultural and domestic waste (Edet, 2009; Nduka and Orisakwe, 2011). The demand for potable water is rising due to population increase in developing countries. Such areas are expected to experience imbalances of potable water demand and supply due to climate change (Vairavamoorthy et al., 2008). The chemical constituents of groundwater is known to cause some health risks, so supply cannot be said to be safe if specific information on water quality which is needed for sustainable resource development and management is lacking (Nwankwoala and Udom, 2011).

The majority of health problems faced by African countries are water related: typhoid, diarrhoea, cholera, dysentery (Hamer et al., 1998; Kuitcha et al., 2008; WHO Regional Office for Africa, 2012). Managing the microbial aspects of water quality control is a major issue in the humid tropics as it has a direct effect on human health (Roche, 1993). For human consumption, the most important water quality parameter is total coliform (Younger, 1994). Studies carried out in different parts of Cameroon indicate that most domestic water sources have an alarming level of microbiological pollution (Katte et al., 2003; Mpakam, 2009; Wirmvem et al., 2013). Cases of water-borne diseases such as typhoid, cholera and amoebic dysentery are recurrent in most localities in Cameroon (Kuitcha et al., 2010) and these have been traced to the use of water from shallow, unprotected hand-dug wells (Nola, 1996).

Regrettably, the identification and evaluation of the quality of potential fresh water resources in rural and remote areas, as a precondition for sustainable management of water resources, has not been systematically carried out in Cameroon (Katte et al., 2003). Less than 40% of the population of Cameroon has access to pipe borne potable water (Tanawa et al., 2002). The vast majority is thus compelled to turn to alternative sources like springs, wells and streams whose chemical and microbial qualities are greatly compromised by their proximity to both point and diffuse sources of pollution.

Unlike the Douala Basin and other Basins along the coast of the Gulf of Guinea (e.g. the Niger Delta in the west of the Rio del Rey Basin), where hydrogeological and hydrogeochemical studies have been carried out (Edet, 2009; Williams and Benson, 2010; Eneke et al., 2011; Nduka and Orisakwe, 2011), little or no comprehensive data on the hydrogeochemistry and anthropogenic influence on the quality of water sources has been generated within the Rio del Rey Basin. Information on the quality of water sources used for household and agricultural purposes within the Bakassi Peninsular and its environs is non-existent; hence, the need to assess the suitability of these water source for users.

The present study accordingly aimed to evaluate the physico-chemical characteristics, sources of ions and mineralisation processes, the microbial quality and the suitability of the water sources for drinking and agricultural uses. The results from this study is useful towards the generation of a baseline hydrogeochemical and microbial data in the area in general and within the remote Bakassi Peninsular in particular for the first time; and will provide suitable information for harnessing potable water for the inhabitants.

The study area

The Rio del Rey Basin is located in the South Western Coast of Cameroon at the western end of the Gulf of Guinea (Figure 1). The basin is an extension of the western margin of the Niger Delta of Nigeria (Regnoult, 1986), and one of the Equatorial Atlantic marginal basins in the Gulf of Guinea. Together with the Douala and Kribi-Campo Basins, it was formed during the Aptian-Albian times (Agyingi et al., 2006). It is bordered in the west and northwest by the Niger Delta Basin, in the south it is limited by the Gulf of Guinea (Atlantic Ocean), in the north by the Rumpi Hills and to the east by the Cameroon Volcanic Line which separates the basin from the Douala Basin. The drainage pattern is dendritic (Figure 1) dominated by Rivers Ndian, Moko, Meme, Mungo and Akwayafe which have watersheds from high altitudes (800-1050 m) from the Rumpi Hills, the Manengouba mountains and the highlands of the Korup National Park.

It has a varied geological setting comprising of Cretaceous limestones, Tertiary and Quaternary sediments which are essentially clastics consisting of sands, sandstones, conglomerates, limestones, shales, clays and alluvium which are terminated landward by basaltic lava flows from the Rumpi Hills and by Precambrian basement rocks composed of gneisses, micaschists and quartzites (Dumort, 1968; Obenesaw et al., 1997; Njoh and Petters, 2008). The lithologic description made by Njoh and Petters (2008) describes

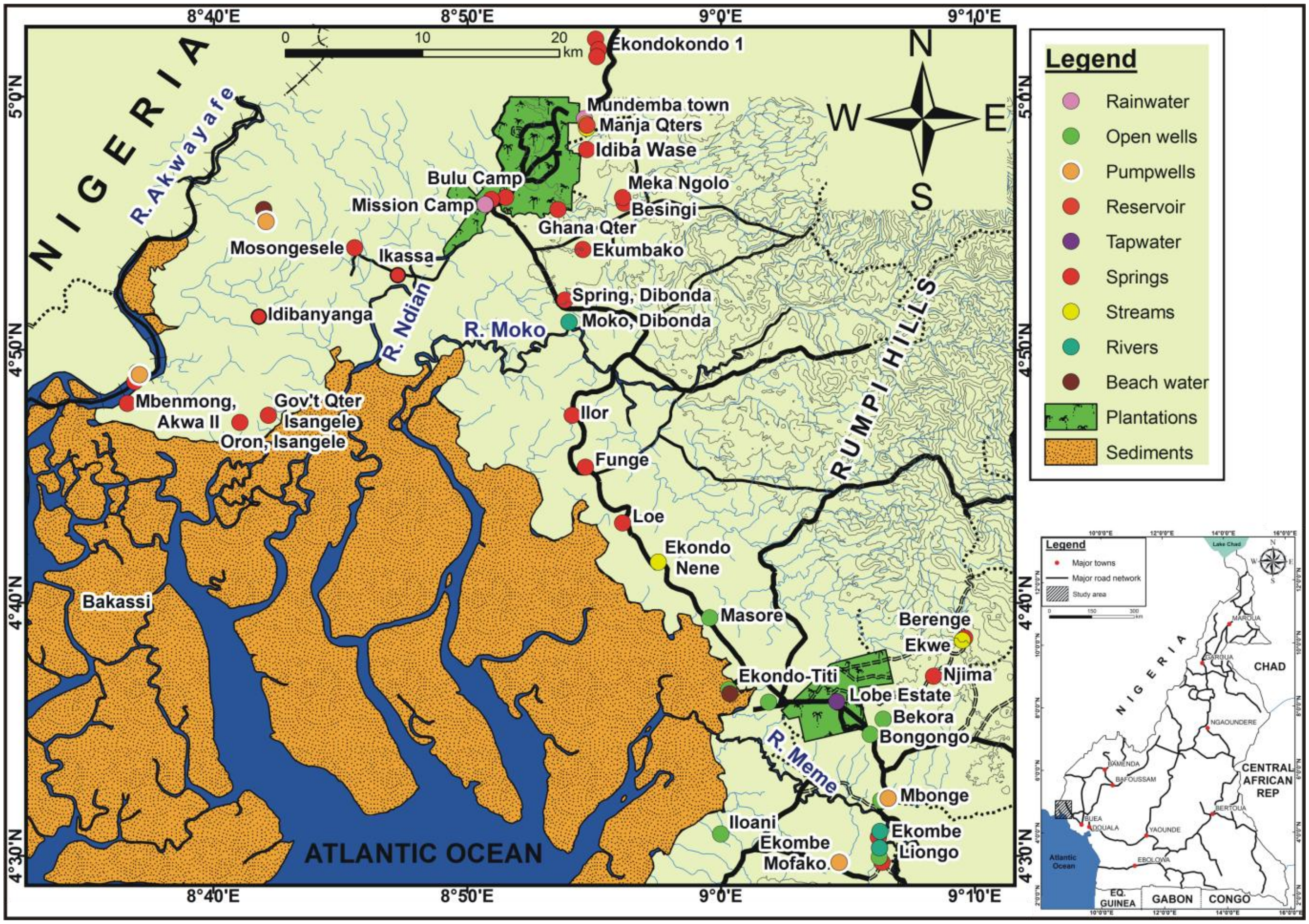

Figure 1. Geo-referenced map showing the location, drainage and sampling sites in the Rio del Rey Basin. Inset: Cameroon map showing study area (shaded rectangle).

the Cretaceous sedimentary rocks in this area as poorly sorted conglomeritic sandstones, dark micaceous siltstones, mudstones and shales. Directly overlying the Cretaceous sediments offshore is the lowest Tertiary unit known as the Isongo Formation, which is equivalent to the Akata Formation in the Niger Delta (Njoh and Petters, 2008).

This unit is composed mainly of dark grey marine shales ranging from Paleocene to Recent. The Agbada Formation is characterized by a lower shale section and an upper section, composed of an alternation of sandstones and shales. It ranges from Oligocene, Miocene to Recent. The Benin Formation forms the upper continental sequence in this basin and is composed of a few intercalations of shales towards the base, and rich in sands and sandstones.

The climate in this area is an Equatorial Cameroonian type (Etia, 1980) influenced by the meteorological equator. Two distinct seasons exist: a long rainy season of more than 8 months (March-October) and a dry season of four months (November-February; Gabche and Smith, 2002).

The study area is characterized by a high annual mean rainfall of over 5,000 mm (Zimmermann, 2000) subdivided into: 86 mm per month during the dry season and 326 mm per month during the rainy season (Gabche and Smith, 2002). The average annual variable temperature is 27°C (Ndian Meteorology, 2012). The coolest month typically occurs in August with mean monthly maximum temperatures of 25°C, while February is the hottest month with monthly mean maximum temperatures of 33°C.

Soils in the study area are ferralitic (Gavaud and Muller, 1980), yellowish in colour, and varying from clayey, silty, sandy to lateritic clay sub soils. Agricultural rich areas have been extensively cultivated for at least the last 200 years (Gartland, 1986). Large oil palm plantations of some 60 km^2 extent and belonging to the parastatal - PAMOL plantations Ltd - are found around Mundemba and Ekondo-Titi (Lawson, 1993).

MATERIALS AND METHODS

Water sampling and physico-chemical measurements

Fieldwork (January to February 2012) involved the collection of 51 water samples (38 groundwater, 9 surface water, 1 tap, 1 reservoir and two rainfall samples) and the measurement of physical parameters (pH, temperature, EC) *in situ*. The physical parameters were measured on-site due to their unstable nature to avoid unpredictable changes in characteristics as per the standard procedures (APHA/AWWA, 1998). The pH, temperature and total dissolved solids (TDS) were measured using the Hanna 98128 multi parameter type. Electrical conductivity (EC) values were measured using the Model 3301 conductivity meter. These meters were calibrated before and during fieldwork using buffer solutions as prescribed by the manufacturers. GPS Explorist 100 was used at each location to record the coordinates and altitudes to produce the sample location map (Figure 1).

At each sampling site, water from springs, streams, beaches and rivers was collected into a plastic collector after thorough rinsing with distilled water and the water to be sampled. Water from open wells was drawn from hand dug wells without any cement lining at depths that ranged from 3 to 10 meters using buckets tied with ropes. Hand dug pump wells were pumped before sampling for 5 to 10 min in order to purge any aquifer stagnant water to acquire fresh aquifer samples for analysis. Surface water was sampled from the edges of the water bodies as deep as possible along the flow path. Two sporadic rainfall samples were collected in different rainfall events in vessels cleaned with distilled water directly from the atmosphere. All samples meant for ion analyses were filtered through a 0.45 µm membrane filter which allowed the removal of particles and bacteria that could modify the contents (Atteia, 2005). For the samples meant for cation analysis, 1% nitric acid with a pH of less than two was added to keep metal ions in solution (Rodier et al., 2005).

All samples were put in plastic bottles (100 and 1500 ml in two sets) thoroughly rinsed with distilled water and the water to be sampled. These bottles were rinsed several times to ensure that they were free from contaminants. The samples were preserved airtight in order to minimize oxygen contamination and the escape of dissolve gases. The samples were stored in ice-chest containers at about 4°C prior to laboratory analysis to exclude microbial activity and unwanted chemical activity. The 1500 ml of samples were transported to the Soil and Water Laboratory of the Institute of Agronomic Research for Development (IRAD) Ekona for Alkalinity test and to the Microbiology Laboratory of the Faculty of Science of the University of Buea for coliform counts test within 24 h. The 100 ml containers were transported to the Chemistry Laboratory, Tokai University, Japan for major ions analysis. Total alkalinity as bicarbonate (HCO_3^-) was measured within 8 h of sampling through titration using a volume of 0.02 MHCl to the sample and stirred with an automatic stirrer until endpoint, marked by a pH of 4.5.

Chemical analyses

Cations: sodium (Na^+), potassium (K^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}) were determined by the Flame Technique in a High Resolution Continuum Source AAS (ContrAA700). Details of the method used are described in Welz et al. (2006). Samples with EC values >100 µS/cm were diluted 5 or 10 times, to acquire an absorbance within the range of the used standards for Na^+, K^+ and Ca^{2+}. Measurements of the anions: chloride (Cl^-), phosphate (PO_4^{2-}) sulfate (SO_4^{2-}), nitrate (NO_3^{2-}), fluoride (F^-) and bromine (Br^-) were done using an Ion Chromatography (Dionex ICS-900). The charge balance for reliability of chemical measurements calculated after Domenico and Schwartz (1990) was within the acceptable limit of ±5%.

Microbial (total coliform analysis)

Microbial (total coliform count as bacteria indicator) analysis was performed by the most probable number (MPN) technique (APHA, 1992). Tubes of McConkey broth were inoculated with the water samples appropriately and incubated for 24-48 h at 37°C for total coliforms.

Data analysis

The SPSS 17.0 for windows statistical tool was used for Spearman correlation test, scattered plots and factor analysis to highlight indicators with high contribution that best explained the variability of state of water quality sampled. The WHO (2004) guidelines for water quality were used to evaluate the parameters analyzed for the purpose of drinking water. The water quality index (WQI) for the samples analysed was calculated using the methodology of the Canadian Department of Environment and Conservation (CCME, 2001) as described in Yidana et al. (2010). This method was used to characterize the usability of water resources for drinking purposes. The CCME (2001) was based on 3 factors: i) the scope which measures the percentage of the variables whose values deviate from the WHO (2004) value, ii) the frequency which measures the percentage of the samples that do not meet the standards and iii) the amplitude which measures the extent to which the non compliant parameters exceed the standards as described in Yidana (2010).

Agricultural suitability of groundwater samples was evaluated based on the following: Electrical conductivity (EC), the sodium percentage (Na %; equation 1), Wilcox diagram (Wilcox, 1955; Na % against EC), residual sodium carbonate (RSC; equation 2), sodium adsorption ratio (SAR; equation 3) and the United States Salinity Laboratory Classification (USSL) (Richard, 1954):

$$\mathrm{Na\,\%} = \mathrm{Na} \Big/ \mathrm{Na + Ca + Mg + K} \; \mathrm{x\,100} \qquad (1)$$

$$\mathrm{RSC} = (\mathrm{CO_2} + \mathrm{HCO_3}) - (\mathrm{Mg} + \mathrm{Ca}) \qquad (2)$$

$$\mathrm{SAR} = \mathrm{Na} \Big/ \sqrt{(\mathrm{Ca} + \mathrm{Mg})} \qquad (3)$$

RESULTS AND DISCUSSION

Physico-chemical composition of the groundwater sources

Results of the groundwater samples are presented in Table 1. The pH of springs, opens wells and pump wells sources ranged from 5.5 to 8. Sixty percent (60%) of these water samples were slightly acidic (5.5-6.4) and were different from the WHO (2004) standard for drinking water. EC values ranged from 3-274 µS/cm with a mean of 421.54 µS/cm. TDS of all groundwater sources ranged from 7.66 -248.30 mg/l with a mean of 54.30 mg/l. The chemical constituents analysed were low and were within the WHO (2004) guideline values except for high concentrations of NO_3^- (77.28 mg/l) and Br^-(0.08) in an open well source in the south east (Bekora) of the study area. The relative abundance of cations and anions (Figure 2a-d) were as follows:

$Na^+ > Mg^{2+} > K^+ > Ca^{2+}$ and $HCO_3^- > NO_3^- > Cl^- > SO_4^{2-}$ for

Table 1. Statistical summary of physico-chemical data of groundwater in the study area.

Parameter	Spring (n = 26)				Open well (n = 8)				Pump well (n = 4)				Summary of ground water samples (n = 38)		
	Mean	Min	Max	Std.	Mean	Min	Max	Std.	Mean	Min	Max	Std.	Min	Max	Mean
Water temperature (°C)	26.19	21.0	29.0	1.6	27.68	26.0	28.0	0.57	27.83	26.7	29.0	1.25	21.30	29.30	27.20
pH	6.72	5.64	7.61	0.55	6.12	5.5	7.2	0.54	6.78	5.87	8.0	0.99	5.5	8.00	6.60
EC	21.65	3.00	122.00	25.57	79.11	12.00	274.	90.23	95.63	7.00	171.5	82.04	3.00	274	41.54
Na^+ (mg/l)	1.93	0.33	5.28	1.47	6.21	1.19	20.8	6.65	5.09	2.19	9.06	3.06	0.33	20.80	3.17
K^+ (mg/l)	0.97	0.13	2.47	0.68	4.92	0.59	12.47	4.46	3.03	0.75	8.19	3.48	0.13	12.47	2.02
Ca^{2+} (mg/l)	0.31	0.03	1.66	0.34	1.53	0.02	6.88	2.22	2.85	0.16	8.6	3.87	0.02	8.60	0.83
Mg^{2+} (mg/l)	0.94	0.04	11.56	2.24	2.34	0.14	12.87	4.35	1.96	0.06	6.48	3.03	0.04	12.87	1.34
F^- (mg/l)	0.02	0.00	0.11	0.03	0.01	0.00	0.05	0.02	0.09	0.00	0.33	0.16	0	0.33	0.03
Cl^- (mg/l)	0.70	0.13	3.00	0.66	9.35	0.50	38.38	12.62	1.91	0.99	3.39	1.04	0.13	38.38	2.65
NO_2^-(mg/l)	0.00	0.00	0.00	0.00	0.01	0.00	0.08	0.03	0.01	0.00	0.04	0.02	0	0.08	0.007
Br^- (mg/l)	0.00	0.00	0.04	0.01	0.02	0.00	0.08	0.03	0.01	0.00	0.03	0.01	0	0.08	0.01
NO_3^- (mg/l)	1.10	0.00	8.10	1.79	17.67	0.00	77.28	25.35	3.57	0.00	8.5	3.80	0	77.28	4.85
PO_4^{2-} (mg/l)	0.04	0.00	0.39	0.11	0.01	0.00	0.05	0.02	0.00	0.00	0.00	0.00	0	0.39	0.02
SO_4^{2-} (mg/l)	0.82	0.20	2.39	0.69	2.33	0.19	11.20	3.66	2.44	1.29	5.58	2.09	0	11.00	1.31
HCO_3^- (mg/l)	19.22	4.88	118.34	21.75	91.94	75.56	106.20	9.80	52.92	10.98	101.26	47.44	4.88	118.34	38.08
TDS (mg/l)	26.07	7.55	144.52	26.32	136.34	98.62	248.30	49.29	73.90	19.69	124.01	56.43	7.55	248.30	54.32
SAR	0.4	0.09	1.40	0.30	0.76	0.22	1.99	0.69	0.53	0.36	0.83	0.20	0.09	1.99	0.56
Na/Cl	5.36	1.00	22.46	4.52	1.65	.84	4.78	1.29	5.87	1.49	14.06	5.82	0.84	22.46	4.29
Na/Ca	23.90	2.01	142.87	31.58	26.76	2.71	121.97	41.83	10.35	1.18	23.35	9.98	1.18	142.87	20.34
Na%	76.12	33.46	95.27	17.32	76.16	50.80	97.45	17.20	70.63	58.87	92.87	15.85	33.46	97.45	74.30
RSC	0.22	0.05	0.91	0.17	1.24	0.60	1.60	0.35	0.56	0.08	1.07	0.50	0.05	1.60	0.67
CAI1	-6.82	-26.8	-1.55	5.38	-2.13	-5.83	-0.05	1.71	-7.69	-15.8	-1.73	6.87	-26.8	-0.05	-5.55
CAI2	-0.27	-0.62	-0.05	0.15	-0.07	-0.15	-0.03	.05	-0.25	-0.26	-0.23	0.02	-0.62	-0.03	0.20
SI of Anhydrite	-6.26	-7.03	-4.86	0.52	-5.52	-6.58	-4.18	0.83	-4.95	-5.95	-3.71	0.93	-7.03	-3.71	-5.96
SI of Aragonite	-4.46	-7.27	-1.61	1.26	-4.91	-6.94	-2.39	1.38	-3.27	-5.39	-0.58	2.27	-6.94	-0.58	-4.37
SI of Calcite	-4.31	-7.12	-1.46	1.27	-4.77	-6.79	-2.25	1.38	-3.13	-5.24	-0.44	2.28	-6.79	-0.44	-4.23
SI of Dolomite	-7.33	-11.38	-1.71	2.46	-9.12	-12.25	-3.22	2.87	-6.19	-10.54	-1.47	4.58	-12.25	-1.47	-8.14
SI of Fluorite	-6.39	-7.92	-4.94	0.72	-6.43	-8.31	-4.55	2.66	-4.00	-4.41	-3.59	0.58	-8.31	-3.59	-5.22
SI of Gypsum	-6.04	-6.82	-4.65	0.51	-5.31	-6.36	-3.97	0.83	-4.75	-5.74	-3.51	0.92	-6.36	-3.51	-5.12
SI of Halite	-10.64	-11.37	-9.32	0.54	-9.32	-10.62	-7.66	1.04	-9.65	-9.93	-9.48	0.20	-10.62	-7.66	-9.43
PCO_2 (atm)	-2.77	-3.22	-2.29	0.26	-2.52	-2.69	-2.36	0.11	-2.50	-3.04	-2.22	0.37	-3.04	-2.22	-2.52

SAR = Sodium absorption ratio, TDS = total dissolve solids, Na % = sodium percent, RSC = residual sodium carbonate, CAI = chloroalkaline indices, SI = saturation index, PCO_2 = partial pressure of carbondioxide in water.

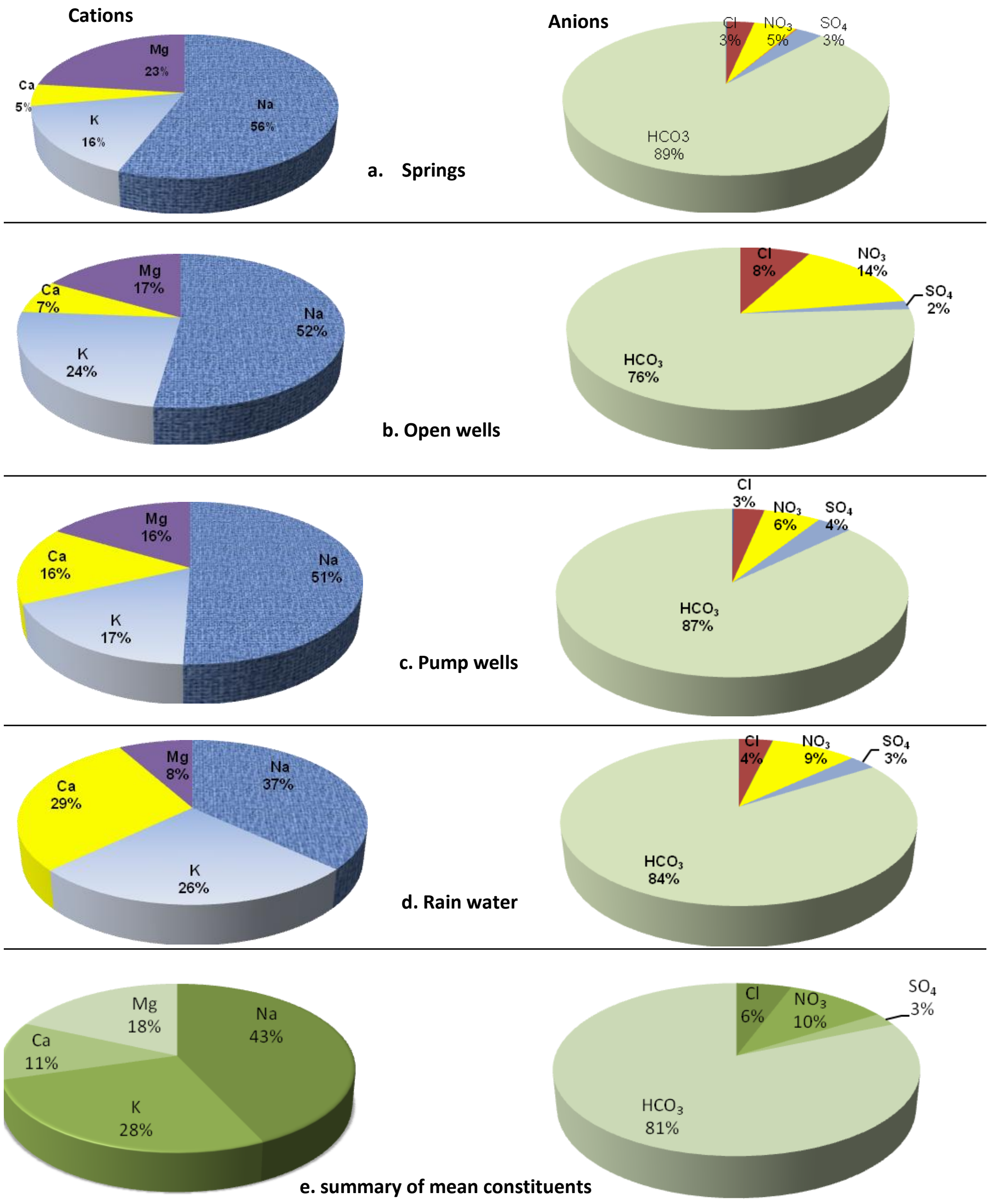

Figure 2. Pie charts of mean concentrations of ions (meq/l) for a) springs, b) open wells, c) pump wells and d) in rain water and e) summary of mean constituents showing dominant Na^+ and HCO_3^- in ground water sources.

springs; $Na^+ > K^+ > Mg^{2+} > Ca^{2+}$ and $HCO_3^- > NO_3^- > Cl^- > SO_4^{2-}$ for open wells; $Na^+ > Mg^{2+} > K^+ > Ca^{2+}$ and $HCO_3^- > NO_3^- > SO_4^{2-} > Cl^-$ for pump wells; $Na^+ > Ca^{2+} > K^+ > Mg^{2+}$ and $HCO_3^- > NO_3^- > Cl^- > SO_4^{2-}$ for rain water.

Sodium was the dominant cation and HCO_3^- the dominant anion (Figure 2e). This study has investigated the physico- (pH, temperature, EC) chemical (major: Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^-, SO_4^{2-}, NO_3^- and minor (F^-, Br^- ions) properties of some water sources (springs, open wells, pump wells) used by the local population as sources of drinking water and for agricultural purposes. According to Nduka and Orisakwe (2011), such surveillance of water quality to ensure safety is a vital public health function especially in developing countries.

The slightly acidic nature of the water sources are linked to the formation and dissolution of minerals and also influenced by biochemical processes in solution (Freeze and Cherry, 1979; Williams and Benson, 2010; Nduka and Orisakwe, 2011). The slight acidic nature of some of the potable water sources (Table 1) may possibly be attributed to the lateritic soils and organic litters from mangroves in the area (Williams and Benson, 2010). These processes involve groundwater reaction with lateritic soils and humic acids from the decomposition of organic matter in the infiltration zones leading to acidification from dissolved carbondioxide (CO_2). This is supported by the higher calculated partial pressures of carbondioxide (PCO_2), with which waters equilibrated in the infiltrating water ($10^{-3.04}$ - $10^{-2.22}$atm) (Table 1) compared to atmospheric air ($10^{-3.5}$ atm) which suggests that the waters have gained CO_2. The slightly acidic nature of the groundwater sources may also lead to the breakdown of HCO^-_3 releasing free hydrogen and carbondioxide.

Ako et al. (2011) and Fantong et al. (2009) obtained similar findings in groundwater sources along the Cameroon Volcanic Line and attributed the presence of dissolved CO_2 to root respiration, decay of organic matter or dissolution of carbonate minerals. According to Chapman (1996), marked spatial variations of groundwater temperature are largely the result of groundwater flow pattern and particularly the extent to which vertical movement occurs.

The lower mean groundwater temperature (27.20°C) (Table 1) relative to the air temperature (28.4°C) suggests that the depth of circulation (3-10 m deep) is short as in Local Systems and in close proximity to recharge areas with quick infiltration (Chapman, 1996). Studies carried out by Gnazou et al. (2011) in coastal aquifers in Togo (along the Gulf of Benin) indicated higher water temperatures (29-34°C) to relative lower air temperature (27°C) to confined aquifers with depths of 50 to ≥ 200 m. Following this, the lower mean water temperatures in the ground-water sources relative to the mean air temperatures as observed are associated with the unconfined nature of the aquifers. This fact is supported by evidence from field observations where aquifers are typically shallow, unconfined and characterised by depths of 3 to 10 m.

The EC values (3.00-274 us/cm) (Table 1) represent waters experiencing slight mineralization (Gnazou et al., 2011). The EC for open wells (Table 1) where slightly higher than those for springs and pump wells, probably due to increased value of nitrate (77.28 mg/l) from fertilizers in some of the open wells like those in Bekora. There is a relationship that exists between EC and nitrate (Das et al., 1999; De Neve et al., 2000). A positive correlation (r^2 = 0.69) (Table 2) which indicates a relationship exists between EC and NO_3^-. The EC values recorded are slightly lower than those obtained (27.80. to 899. μS/cm) in some localities in Douala (Eneke et al., 2011). In Togo where EC values in coastal aquifers were shown to exceed 1000 μS/cm in some areas (Gnazou et al., 2011), this was attributed to high sulphate content released from evaporites (gypsum) present in the surrounding geological formations. Low sulphate values (Table 1) obtained from groundwater sources in study area confirm low mineralization and the non-contribution from evaporites. According to Freeze and Cherry (1979), TDS values <1000 mg/l represent fresh water. Based on Table 1, TDS values for groundwater sources were below 248 mg/l, thus considered as fresh water.

Nitrate levels for groundwater sources varied from 3.80-77.28 mg/l (Table 1). There is a strong correlation between NO3- and Cl- (r2 = 0.97) (Table 3) which suggests an anthropogenic source of NO3- from the use of agrochemicals in the surrounding plantations and inputs from domestic waste that infiltrates into the groundwater sources. The ionic constituents of Ca2+ and K+ are slightly higher in the sporadic rain samples with lower values of Na+ and Mg2+ than the groundwater samples. The ionic constituents of Ca2+ and K+ are higher in rain samples because these were early rains which have shown to be enriched in major ions in tropical areas (Freeze and Cherry, 1979). The early rains enriched in dissolved ions would lead to the leaching of the base forming ions (Ca2+, Na2+, Mg2+ and K+) from the soils chemically enriching the water during infiltration in the subsurface (Apello and Postman, 1993; Feng et al., 2005; Eneke et al., 2011). The Na+ concentration in the aquifer system probably arises from the gneisses, basalts, sediments and clay units that exist in the study area.

Ternary plots (Piper, 1944) for major cations (Mg2+, Ca2+, Na+ and K+) and anions (SO42-, HCO3- and Cl-) in all the water samples revealed different water types with different proportions (Figure 3). According to Xu and Usher (2006), when fresh water is enriched by Ca2+ and depleted in Na+, an initial sodium chloride facies becomes calcium chloride in nature as in the study area (Ca-Mg-Cl) in a process of inverse cation exchange. Such changes in facies suggest freshwater contamination by sea water (Banton and Bangoy, 1997). The negative values of CAI and CAI2 (Table 1) also indicate that Na+ + K+ in rocks is exchanged for Ca2+ + Mg2+ in water. This facie (Ca-Mg-Cl) was highly mineralized with TDS content that reflects pollution due to anthropogenic activities in the area.

Main sources of ions and water mineralisation processes

The molar ratios of Na/Cl for groundwater sources ranged from 0.84 to 22.5 (Table 1). Meybeck (1987) used Na/Cl molar ratios to study silicate weathering reactions and showed that Na/Cl molar ratio >1 reflects Na^+ released from silicate (feldspar) weathering in the process of exchange of magnesium and calcium in water with sodium and potassium in rock (cation-anion exchange reaction) (Equation 4) (Utom et al., 2013):

$$2NaAlSiO_3O + Ca^{2+} \leftrightarrow CaAlSiO_3O + 2Na^+ \qquad (4)$$

Values of Na^+/Cl^- < 1 (0.84 mg/l) recorded in an open well (Table 1) implies that another source is contributing

Table 2. Correlation coefficient matrix between chemical variables for groundwater in the Rio del Rey Basin.

	Temperature (°C)	pH	EC	TDS	Na^+	K^+	Ca^{2+}	Mg^{2+}	F^-	Cl^-	NO_2^-	Br^-	NO_3^-	PO_4^{2-}	SO_4^{2-}	HCO_3^-
T°C	1															
pH	-0.14	1														
EC	0.26	0.17	1													
TDS	0.37	-0.06	**0.84**	1												
Na^+	0.26	-0.05	**0.89**	**0.80**	1											
K^+	0.37	0.04	**0.89**	**0.81**	**0.84**	1										
Ca^{2+}	0.31	0.19	**0.78**	**0.64**	**0.65**	**0.74**	1									
Mg^{2+}	0.12	0.36	**0.59**	**0.55**	0.35	0.39	0.23	1								
F^-	-0.10	0.21	0.39	0.14	0.30	0.04	0.14	0.20	1							
Cl^-	0.24	-0.31	**0.73**	**0.73**	**0.89**	**0.80**	**0.57**	0.16	0.00	1						
NO_2^-	0.26	0.06	0.19	0.27	0.07	0.31	0.05	**0.55**	-0.13	0.06	1					
Br^-	0.25	-0.11	**0.60**	**0.60**	**0.65**	**0.78**	0.34	0.47	-0.10	**0.69**	**0.65**	1				
NO_3^-	0.21	-0.33	**0.69**	**0.69**	**0.87**	**0.74**	**0.60**	0.09	0.00	**0.97**	0.02	**0.62**	1			
PO_4^{2-}	-0.13	0.49	0.25	0.18	0.14	0.04	0.02	**0.51**	-0.04	-0.04	-0.01	0.00	-0.08	1		
SO_4^{2-}	0.33	0.30	0.46	0.43	0.22	**0.56**	0.40	**0.65**	0.00	0.10	**0.71**	**0.57**	0.03	0.06	1	
HCO_3^-	0.35	0.03	**0.65**	**0.91**	**0.53**	**0.58**	0.46	**0.59**	0.16	0.39	0.28	0.37	0.35	0.24	0.44	1

Bold values indicate highly correlated and shows evidence of observed water composition.

chloride to the groundwater (Edet et al., 2011?). Water containing significant amount of chloride (38.38 mg/l) (Table 1) in the open well at Bekora whose drainage has less salty rocks or evaporite is considered to be derived from the atmosphere (Al-Mikhlafi et al., 2003). Ninety six percent of Na/Cl molar ratio of the analysed groundwater and surface water samples were greater than that of seawater (0.86) and 4% was less than 0.86 possibly indicating sea water intrusion due to its proximity to the Gulf of Guinea (Yidana et al., 2010).

According to Rogers (1989), if silicate weathering is the possible source of Na^+, then these water sources will have HCO_3^- as the most abundant anion. This is because of the reaction of silicate minerals with carbonic acid in the presence of water, which releases HCO_3^- (Elango et al., 2003) as in Equation 5 (Tay, 2012):

$$2NaAlSi_3O_8 + 2CO_2 + 11H_2O = Al_2Si_2O_5(OH)_4 + 2Na^+ + 2HCO_3^- + 4H_4SiO_4 \quad (5)$$

(Albite) (Kaolinite)

This confirms the dominance of HCO_3^- in the groundwater sources as a result of weathering reactions on rocks in the study area by percolating groundwater. Where silicate mineral weathering is the major controlling process, concentrations of the major physico-chemical parameters are relatively low as with the case of the study area (Yidana et al., 2010). Yidana et al. (2010) indicated that the wells within the weathered gneisses in the Keta Basin, delivered relatively fresh groundwater whose quality is controlled by the weathering of silicate minerals and present the fresh water types.

Correlations between major ions in groundwater within the study area were carried out using Spearman's correlation analysis (Table 2). The results showed statistical, regression analysis between TDS-HCO_3, EC-Na, EC-K, Na-Cl with very strong positive relations with r^2 values of 0.91, 0.89, 0.89 and 0.89, respectively suggesting that the different aquifer chemistry is controlled by these parameters (Odoh et al., 2012). The correlation between Cl^--NO_3^- (r^2=0.97) and K-NO_3 (r^2 = 0.74) suggests the application of fertilizers and poor sanitation conditions. Other moderately inter-relationships exists as shown in Table 2.

Factor analysis was further used to establish the

Table 3. Factor analysis after varimax rotation on the physico-chemical data of groundwater sources.

Parameter	Factor			
	1	2	3	4
Water T°C	0.40	-0.01	-0.39	0.44
pH	0.02	0.68	0.46	0.02
EC	0.93	0.04	0.30	0.07
TDS (mg/l)	0.93	-0.01	0.07	0.02
Na^+ (mg/l)	0.90	-0.28	0.24	-0.06
K^+ (mg/l)	0.93	-0.08	-0.07	0.01
Ca^{2+} (mg/l)	0.74	-0.10	0.21	0.26
Mg^{2+} (mg/l)	0.58	0.69	0.06	-0.14
F^- (mg/l)	0.15	0.09	0.58	0.54
Cl^- (mg/l)	0.81	-0.51	-0.01	-0.21
NO_2^- (mg/l)	0.38	0.53	-0.64	-0.04
Br^- (mg/l)	0.78	0.04	-0.42	-0.26
NO_3^- (mg/l)	0.77	-0.57	0.03	-0.19
PO_4^{2-} (mg/l)	0.15	0.50	0.47	-0.57
SO_4^{2-} (mg/l)	0.56	0.61	-0.37	0.20
HCO_3^- (mg/l)	0.72	0.23	0.08	0.13
Eigen values	7.30	2.59	1.86	1.10
% total variance	45.63	16.17	11.64	6.86
Cumulative %	45.63	61.80	73.44	80.30

relationship between variables for the physicochemical data of groundwater sources (Table 3). Four factors were found to be responsible for the variation of groundwater quality. Factor 1 accounted for 45.63% of the total variance. It included high values of EC, TDS, Na^+, K^+, Ca^{2+}, Cl^-, Br^-, NO_3^- and HCO_3. Factor 2 accounted for 16.17% of the total variance. It included high values of pH, Mg^{2+} and SO_4^{2-}. Factor 3 accounted for 11.25% of the total variance and factor 4, 6.86% of the total variance and were associated with F^-. Factors 1 and 2 suggest mineralization of dissolved ions as a result of chemical weathering (Equation 5) and cation exchange processes at soil water interface due to the contribution of the major cations (Na^+, K^+, Ca^{2+} and Mg^{2+}) and Na^+-bearing minerals (Singh et al., 2005; Ganyaglo et al., 2012); where Na^+ is expected to exchange for Ca^{2+} (Utom et al., 2013) as in Equation 4.

The major (Cl^-, SO_4^{2-}) anions may have resulted from atmospheric inputs. Factors 3 and 4 are attributed to geogenic sources. Chloro-alkaline indices, CAI 1 = Cl-(Na+K) / Cl and CAI 2 = Cl - (Na+K) / SO_4+HCO_3 + CO_3 + NO_3 (Schoeller, 1965) were used to constrain the possible ion exchange reactions between groundwater and the host aquifers.

All groundwater samples had negative values for both indices (Table 1). CAI values suggest that Mg^{2+} and Ca^{2+} from water are exchanged with Na^+ and K^+ in rock favouring cation-anion exchange reactions (chloro-alkaline disequilibrium) (Gupta et al., 2009). The CAI ratio is negative when $Na^+$and K^+contents are high. This situation occurs when groundwater has been strongly in contact with minerals able to yield these interchangeable cations easily (Abderamane et al., 2013). This exchange is common with alumino-silicated clays formed by layers whose cohesion is ensured by the existence of interlayer cations and water. The surface of the layers is negatively charged thus promoting the possibility of cation exchange with those of groundwater.

In unconsolidated sediments of an aquifer system, there is always a considerable amount of clay minerals that adsorbs some of the cations in their pore spaces. This allows some species of cations in the groundwater to be replaced by other cations from the aquifer (Ma et al., 2013).

When there is an exchange between Na^+ and K+ in water sources with Mg^{2+} or Ca^{2+} in the aquifer material, both chloro-alkaline indices (CAI_1 and CAI_2) are positive, indicating reverse ion exchange (Jankowski et al., 1998). If the exchange takes place between Ca^{2+}or Mg^{2+} in groundwater with Na^+ or K^+ in the aquifer material, the indices will be negative, indicating ion exchange (Schoeller, 1967; Kumar et al., 2007) as observed in the study area.

Based on the geology of the area, the results of saturation indices (SI) of carbonates, sulfates, fluorite, halite minerals and partial pressures of CO_2 (P_{CO2}) calculated using PHREEQC, are presented in Table 1. Saturation indices express the extent of chemical

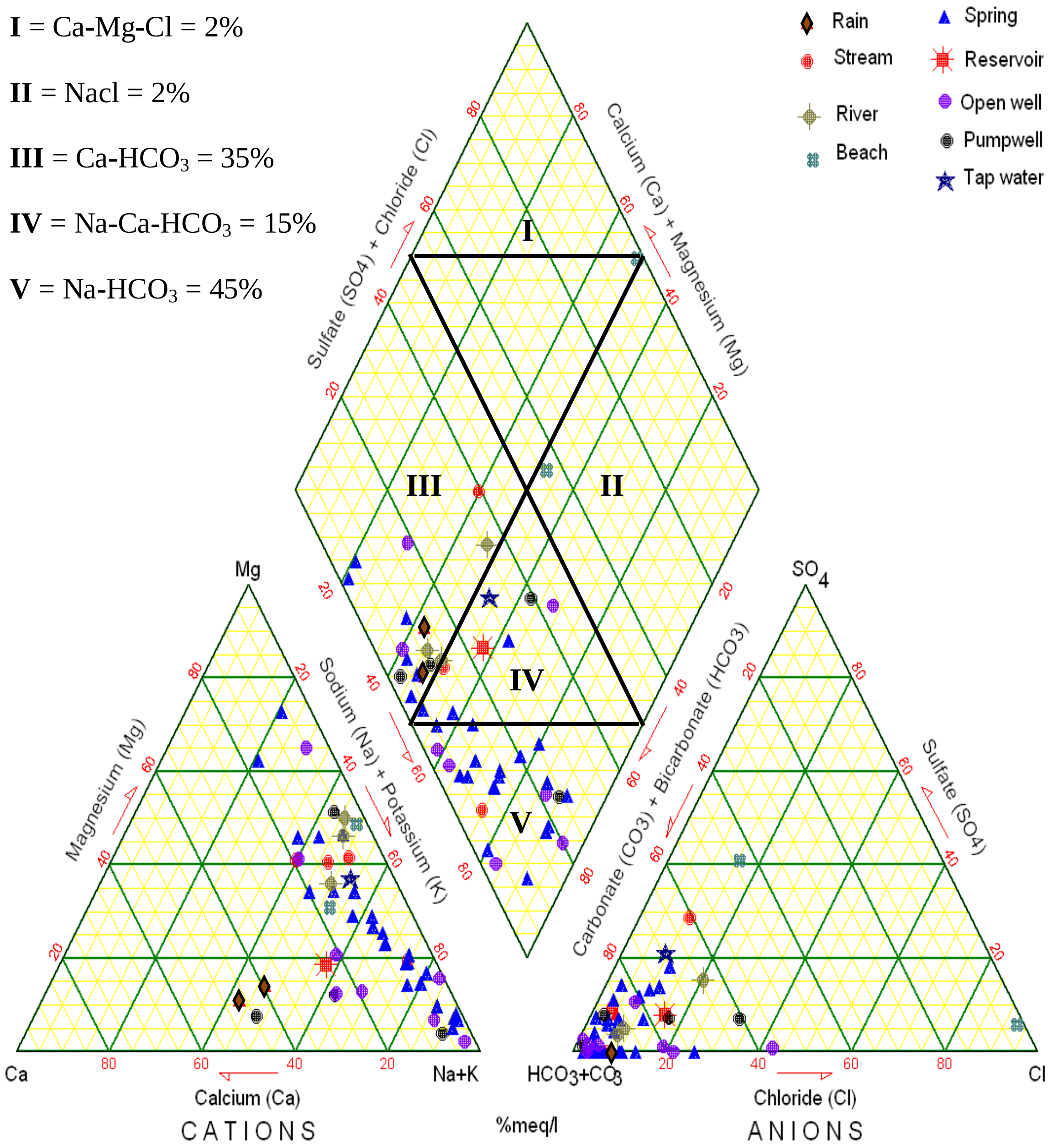

Figure 3. Piper diagram showing the water types with proportions in the Rio del Rey Basin. Alkali metals (Na^+ + K^+) exceed alkali earth metals (Ca^{2+} + Mg^{2+}). Weak acids (CO_3 + HCO_3) greatly exceed strong acids (SO_4 + Cl^-).

equilibrium between water and mineral phases in the matrix of the aquifers (Yidana et al., 2010) and could be used to evaluate the contribution of mineral dissolution and/or precipitation processes relating to the water-rock interaction (Drever, 1997; Ako et al., 2011). An index of SI<0, indicates that groundwater is under-saturated with respect to the particular mineral (Appelo and Postman, 1993). From the results obtained, all the groundwater sources were under-saturated with respect to calcite, dolomite, aragonite, gypsum, anhydrite, fluorite and halite.

The negative values registered for all the water samples could reflect the character of water from a formation with insufficient amount of the mineral in solution. The under-saturation of the sulphate minerals suggests that soluble sulphate mineral phases are absent in the host rocks (Gnazou et al., 2011). The influence of these sulphate minerals, on the chemistry of the groundwater was also less significant.

Gibbs (1970) was used to provide information on the mechanisms that actually controlled the groundwater chemistry. Figure 4a and b showed that the groundwater

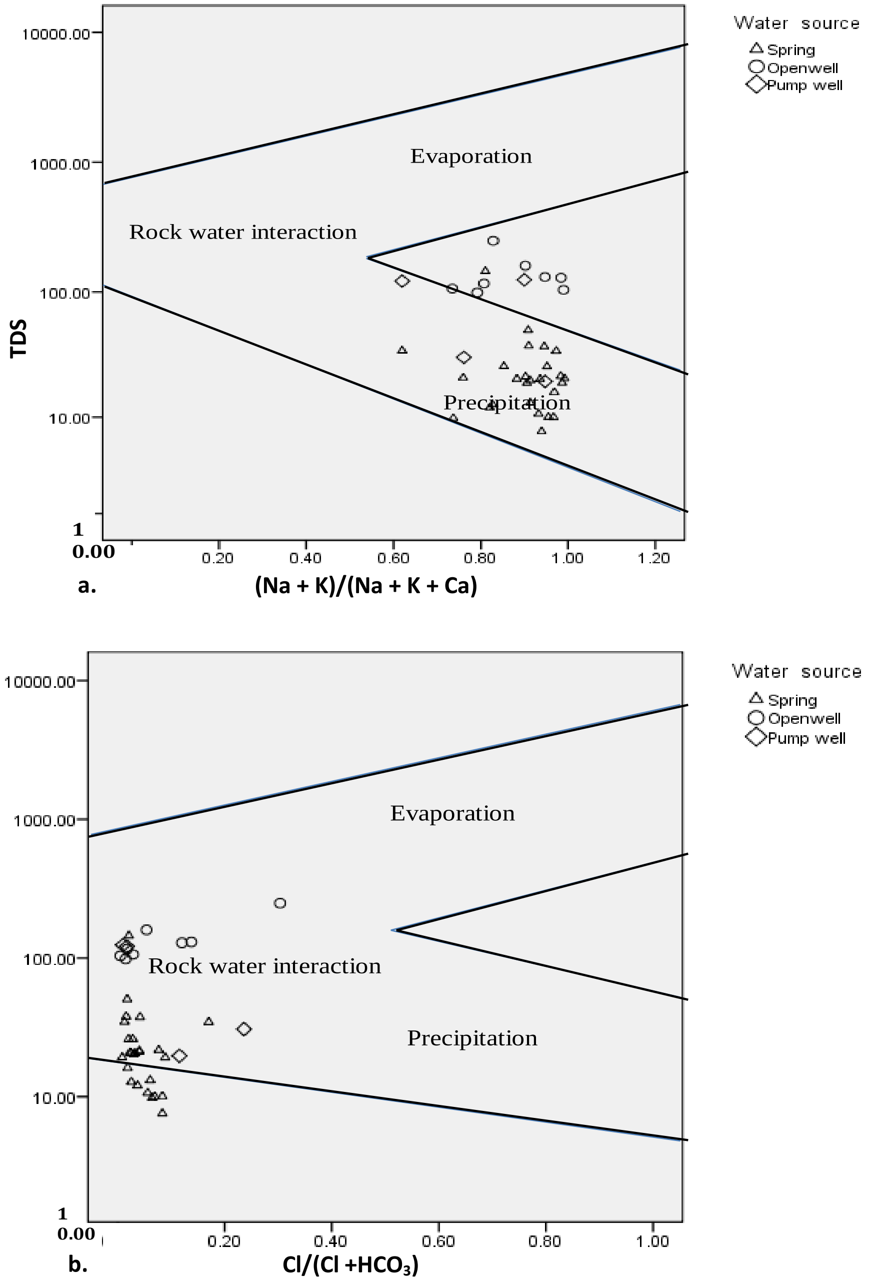

Figure 4. Mechanisms controlling the chemistry of groundwater (after Gibbs, 1970) a. Na+K/Na+K+Ca and b. Cl/Cl+HCO_3 respectively.

samples plotted in the water-rock interaction zone confirmed that rock dissolution is apparently the dominant process influencing the groundwater hydrochemistry.

Suitability of the water sources for drinking and agricultural purposes

The suitability of groundwater for drinking purposes was based on WHO (2004) limits (Table 4). Sixty percent (60%) of the groundwater samples had pH values different from the WHO (2004) guideline limit (Table 4) suitable for drinking water. The EC, TDS, cations, bicarbonate and sulphate of the groundwater sources are within the desirable limits of WHO (2004). Concentrations of Br^- (16%) and NO_3^- (10%) (Table 4) of the groundwater sources exceeded the WHO (2004) guidelines for drinking water.

The present study indicates low flouride values (0-0.33 mg/l) (Table 1) similar to those of the Ndop plain (0-0.39 mg/l) investigated by Wirmvem et al. (2013). Flouride

Table 4. Groundwater quality and compliance with WHO (2004) drinking water standards.

Parameter	Ground (N=38)			WHO (2004) limit	Sample above (or out of) WHO guideline limit (%)
	Min	Max	Mean		
pH	5.50	8.00	6.60	6.5-8.5	60.00
EC	3.00	274	41.54	750	0
Ca^{2+} (mg/l)	0.02	8.60	0.83	75	0
Mg^{2+} (mg/l)	0.04	12.87	1.34	30	0
Na^+ (mg/l)	0.33	20.80	3.17	200	0
K^+ (mg/l)	0.13	12.47	2.02	100	0
Cl^- (mg/l)	0.13	38.38	2.65	250	0
NO_3^- (mg/l)	0	77.28	4.85	10	10.00
SO_4^{2-} (mg/l)	0	11.00	1.31	250	0
PO_4^{2-} (mg/l)	0	0.39	0.03	0.30	0.50
HCO_3^- (mg/l)	4.88	118.34	38.08	200	0
Br^- (mg/l)	0	0.08	0.01	0.01	16.00
F^- (mg/l)	0	0.33	0.03	1.50	0
TDS (mg/l)	7.55	248.30	54.32	500	0
Total hardness (TH)	0.22	57.00	7.61	100	0
Total Coliform Counts (cfu/100 ml)	0	2400	1316.16	0	97.00

Table 5. Classification of water quality after CCME (2001).

CCME (2001) ranges for WQI (%)	No of samples	WQI (%)	Type of water
95-100	46	90	Excellent quality
80-88	3	6	Good quality
65-79	0	0	Fair quality
45-64	1	2	Marginal quality
0-44	1	2	Poor quality
Total	51	100	

is a health concern because of its effect on teeth and gums. Flouride concentration of ~1 mg/l is considered to be beneficial in preventing tooth decay. Flouride values >4 mg/l may cause dental fluorosis or mottling of permanent teeth and bone damage in children between the ages from 0 (birth) to 13 years (WHO, 1989). At low concentrations (< 0.2 mg/l), F^- in drinking water may result in dental caries (Edmunds and Smedley, 1996). Fantong et al. (2009) reported higher fluoride concentrations (>1.5 mg/l) in groundwater samples occurring in granitic terrain alongside the plain alluvium and the Limani-Yagoa ridge regions in north Cameroon which have caused severe cases of fluorosis as diagnosed by medical doctors (Fantong et al., 2013). Table 5 present the WQI range, water type and the calculated WQI for the analysed data. The water quality index is a rating technique that provides the composite influence of individual water quality parameters on the overall quality of water for human consumption (Mitra and ASABE Member, 1998). The WQI calculated using the adjusted form of CCME (2001) based on the major and the chemical parameters (TDS, pH, F^-, Br^-) for the groundwater and surface water data indicated that 90, 6, 2 and 2% (Table 5), provided excellent, good, marginal and poor water quality respectively for drinking purposes.

The excellent water quality (Table 5) implies that the water is very close to pristine conditions (CCME, 2001). Good quality water (Table 5) reflects water with minor incidences of impairment. Marginal water in the study area (open well at Bekora) had a high NO_3^- concentration characterised by a similar composition as marginal groundwater sources studied in the Keta Basin (Ghana) by Yidana et al. (2010). Elevated concentrations (> 5 mg/l) of nitrate in waters are an indication that the waters are at the risk of pollution (Edet et al., 2011) due to anthropogenic sources of fertilizers used in surrounding plantations and domestic waste discharge that penetrate into the subsurface.

High nitrate levels in water have been associated with methemoglobinemia, gastric ulcer (Canter and Knox, 1985), cancer and urinary tract diseases (Edet et al., 2011). In Douala, higher NO_3 (49.8-53.8 mg/l) concentra-

Table 6. Groundwater classification based on total hardness (TH) after Driscoll (2009).

Total hardness (TH) as $CaCo_3$ (mg/l)	Water type	No of groundwater samples	Percentage of groundwater samples
<9	Soft	30	82
9-60	Slightly hard	8	18
60-120	Moderately hard	-	-
120-180	Hard	-	-
>180	Very hard	-	-
Total		38	100

tion was obtained in groundwater sources associated with organic nitrogen leached from pit latrines and solid waste dumps (Takem et al., 2010).

Based on the classification scheme by Driscoll (2009), 81% of the groundwater sources were classified as soft water, while 18% of groundwater sources were categorised as slightly hard water (Table 6). Hardness of the water is attributable to the presence of alkaline earths, that is, Ca^{2+} and Mg^{2+}. These ions react with soap to form precipitates (Jalali, 2006). Hardness of water supply intended for human consumption is between 80 and 100 mg/l (Discoll, 2009). The hardness of the groundwater sources were within the permissible limit of the WHO guideline of 100 mg/l (Ako et al., 2011).

Endeley et al. (2001) reported that 26 of the 31 (84%) water samples analyzed from sources around Mount Cameroon were soft waters. There is a link between water hardness and cardiovascular diseases. Dissanayake et al. (1992) found a negative correlation between water hardness and various forms of cardiovascular diseases and leukemia in Siri Lanka. The British committee on medical aspects of food policy (COMA, 1994) also found a weak inverse relationship between water hardness and cardiovascular disease death. This implies that people consuming soft waters have the likelihood to suffer from cardiovascular diseases than those consuming hard waters. Eighty-two (82) percent of the groundwater sources were soft waters meaning that people living in the Rio del Rey basin whose only source of drinking water are the groundwater sources have a high risk of contracting cardiovascular diseases.

The total coliform bacteria ranged from 0 to 2400 MPN/100 ml for groundwater sources (Table 4). From the results, all the water sources were polluted with the exception of the reservoir source in Mundemba town and a spring at Ekombe Liongo with values of 0 MPN/100 ml. According to the WHO (2004) guideline, 97% of groundwater sources were polluted water sources (Table 4). Based on the MPN count of total coliform bacteria following the classification by Cheesbrough (1992), the majority of the water sources were grossly polluted (75-2400 MPN/100 ml). Bacterial contamination in these water sources may possibly cause water-borne diseases such as cholera, typhoid fever and diarrhoea (WHO, 2004). The high total coliform counts were indicative of poor sanitary handling and/or environmental conditions of most of the water sources because they are not specific faecal matter indicators (Ejechi et al., 2007).

Sodium absorption ratio (SAR) values >10 are inacceptable for agricultural purposes (Yidana et al., 2010). EC values of the groundwater sources were <250 µs/cm and SAR <6 (Table 1) thus classifying the waters into low salinity hazard class (CI) and low sodium hazard class (SI; USSL, 1954) (Figure 5a). On the plot of SAR against EC, 99% of the water sources plotted in the low category (Figure 5a). The samples that plotted on the excellent to good curve (Figure 5b) had low salinity and sodium content and were the best water types for irrigation (Yidana et al., 2010). Five percent (5%) plotted on the good to permissible, 45% permissible to doubtful and 5% doubtful to unsuitable (Figure 5b). Based on residual sodium carbonate (RSC) values (Table 1), all the groundwater sources are suitable for irrigation with values that ranged from 0.05 to 1.07 with the exception of the open well at Bekora (Table 1) classified as marginal due to high values of 1.60.

High Na^+ waters are not suited for irrigation activities because Na^+ ion adsorbs onto cation exchange sites reducing soil permeability (Yidana et al., 2010). This implies that the studied water sources are suitable for irrigational practices due to their low salinities and Na %. Low salinity water (C1 class with EC < 250 µS/cm) (Figure 5a) can be used for most crops on most soils with little likelihood of soil salinity development (Richards, 1954). The relatively low SAR values imply that these groundwater sources would pose no Na^+ effect when used for irrigation (Yidana et al., 2010). Low salinity water (SAR < 6) can also be used for irrigation on most soils with little danger of developing harmful levels of exchangeable sodium (Richards, 1954).

Conclusions

A baseline study of the hydrogeochemical parameters of natural and anthropogenic influences on groundwater quality for drinking and agricultural uses in the Rio del Rey Basin within the remote Bakassi Peninsular has been generated for the first time. Sixty percent (60%) of the groundwater samples were slightly acidic (5.5-6.4) and out of the WHO (2004) standard for drinking water.

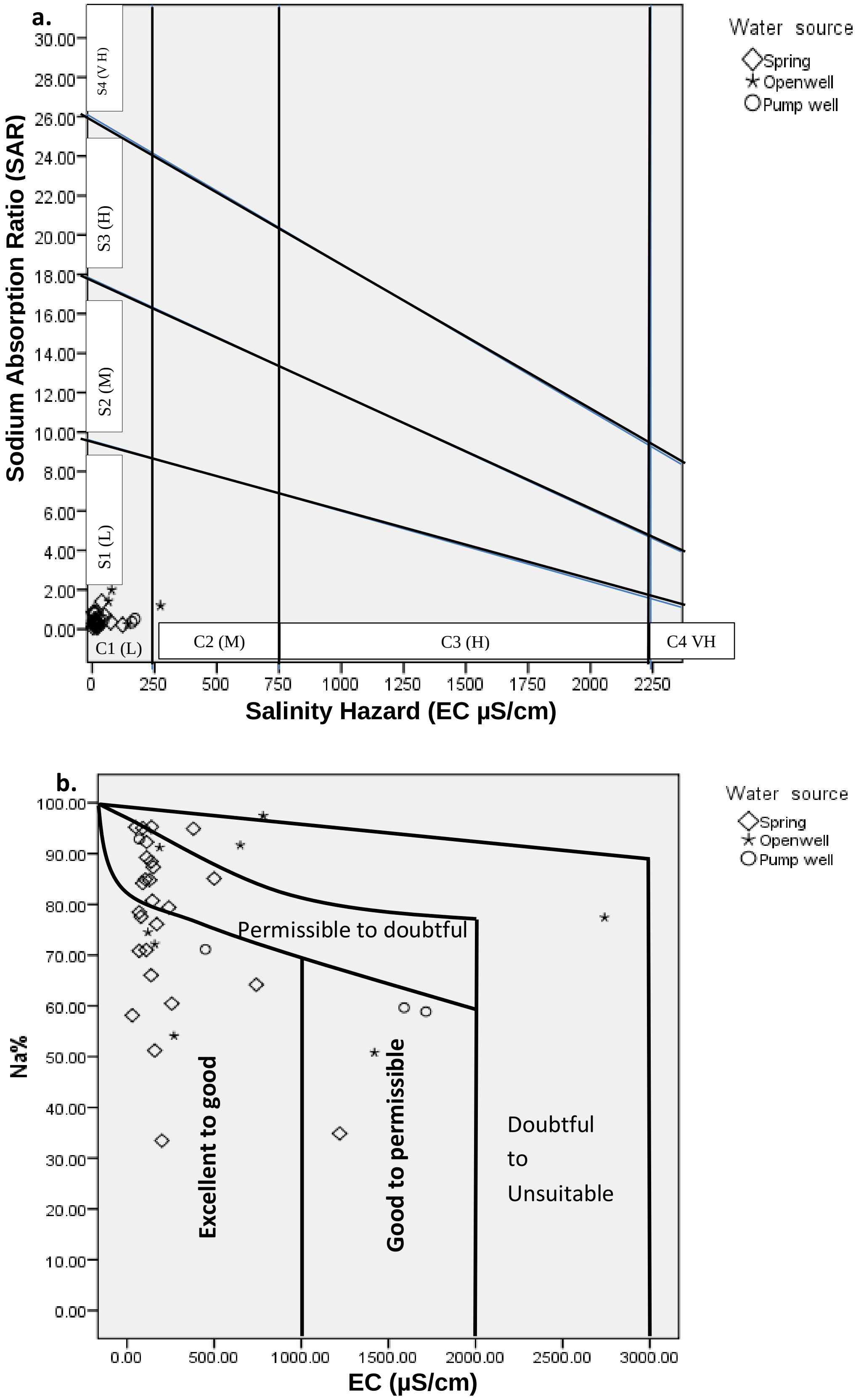

Figure 5. Classification of groundwater for irrigation. a. United States Salinity Laboratory (USSL) diagram after Richard (1954) and b. Wilcox diagram after Wilcox (1955) showing irrigational suitability in the study area.

The major ions of the groundwater sources were within the WHO (2004) guideline values for drinking water except for high concentrations of NO_3^- (77.28 mg/l) and Br^- (0.08) ions in a water source in the south east (Bekora) of the study area which increases the risk of the population here to diseases such as methemoglobinemia, gastric ulcer, cancer and urinary tract diseases. Sodium (Na^+) was the dominant cation, while HCO_3 was the dominant anion for all the groundwater sources. The relative abundance of cations and anions in the groundwater sources were as follows: $Na^+ > K^+ > Mg^{2+} > Ca^{2+}$ and $HCO_3^- > NO_3^- > Cl^- > SO_4^{2-}$, respectively.

The groundwater sources were fresh water with relatively low mineralisation of 7.6-248.mg/l TDS. The main sources of ions were from mineral dissolution of gneisses, basalts, sediments and clay units which constitute the geology of the area.

The water types in the area were: Na-HCO_3 (45%), Ca-HCO_3 (35%), Na-Ca-HCO_3 (15%), Ca-Mg-Cl (2%) and Na-Cl (2%). The main hydrogeochemical processes that influenced the chemical composition of the water sources were incongruent silicate dissolution and cation exchange. Mineral saturation indices suggest that the dissolution of carbonates, sulphates, halites and fluorides were insignificant in the groundwater.

The slightly acidic groundwater sources might lead to the dissolution of heavy metals in rocks in the study area. The majority of the groundwater sources were soft waters. Water quality index calculated using the adjusted form of CCME (2001) based on the major and minor ions (F^-, Br^-) suggested that 90, 6, 2 and 2% provided excellent, good, marginal and poor water quality respectively for drinking purposes.

However, based on the total coliform counts, 97% of these water sources were polluted and classified as polluted water sources due to poor hygienic practises of the population which predisposes these water sources to bacterial contamination thereby exposing the population to water-borne diseases such as typhoid, cholera, dysentery, diarrhoea and scabies. Based on EC, Na %, SAR, USSL classification and RSC, 90% of the ground-water sources were considered suitable for agricultural purposes.

Hydrochemical evaluation of potable water sources during the rainy season is necessary to check NO_3^- contamination which may arise from domestic waste discharges and agrochemicals into shallow groundwater. Due to the microbial contamination of the water sources it will be necessary to treat the waters before consumption.

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