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Research Article

Origin of Mineralization of Groundwater in the Tongo Bassa Watershed (Douala-Cameroon)

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Abstract: The Tongo Bassa watershed is located in the Douala sedimentary basin with the equatorial humid (4000 mm/year) type climate. The groundwater is weakly to strongly mineralized with values of conductivity less than 1450 µS/cm. The water type that predominates in the study area is Na-Cl type during both seasons. The mineralization of the resource is more accentuated in the dry season than in wet season following the reduction of the water table due to low precipitation, over-exploitation and high temperature. Factor analysis was used to identify components (factors) which could explain the chemical characteristics of the aquifer. After rotation, three components could explain 84% of all the identified variables. The first component accounts for 61% of the variance and shows a high positive correlation of electric conductivity with Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, SO_2^{4-}, Br^-, NH^{4+} and HCO^{3-}. This component can be attributed to leaching of surface salts in soils as well as basic trading mechanisms. The second component is responsible for 13% of the variance. It is positively correlated with NO_3^- and negatively with pH. This is due to the nitrification of organic matter present on the ground. The third component was positively correlated with F^-, resulting from the dissolution of micas and representing 9.8% of the variance. The application of exploratory multivariate method identified the most relevant parameters that explain the mineralization of the water.

Keywords: Groundwater, mineralization, tongo bassa, watershed

INTRODUCTION

In many low-income cities, economic growth does not keep pace with the rise in urban populations. Underdeveloped countries do not have the resources to cope with the steady influx of migrants or with the explosive demographic growth of urban centers (Alirol *et al*., 2011; Aleon, 2008). Urbanization is steadily increasing without the development of environmental services such as solid waste disposal system, sewage treatment, industrial pollution control, basic water demands and basic water supplies (Diop and Tandia, 1987). In Sub-Saharan Africa, 37% of population doesn't have access to proper water supply. The underserved population has no other option to obtain water than from traditional wells, springs and boreholes which are the main water resource of 24% of the urban population in Africa (Banerjee *et al*., 2008). Naturally, groundwater is generally free from contamination and usually the best alternative to surface water. Monitoring of this resource, which is a prerequisite for its optimal management, is a real problem in these developing cities (Leduc and Loireau, 1997). Currently there is no array piezometric monitoring throughout the entire country of Cameroon and the monitoring of groundwater quality is not established with a view to characterize the resource (MINNEE, 2009). A perfect example of this environmental crisis is Douala, economic city in Cameroon where only 40% of the population is served by CDE (Camerounaise Des Eaux). The majority of population unserved takes water from the subsoil where it can be only in a few meters depth and mediocre quality (Ketchemen-Tandia, 2011; Takem *et al*., 2009). Hence, in order to assess the quality of groundwater consumption by human beings, it becomes necessary to understand the chemical characteristics of water by estimating relevant constituents (Kanan and Sabu, 2010). The work is done in a larger watershed of the rivers in the city of Douala which constitutes 27 districts.

In this study, the analysis factor is used to determine the chemical characteristics of water, to understand the process of mineralization, thus deduce the source of high concentrations of some chemical parameters of groundwater in the study area. Therefore effective decisions with regard to management of groundwater resources could then be taken when a clear picture of the actual or potential contamination issue and the relationships between variables and the quality of water is established.

Study area: The Tongo Bassa watershed lies between average longitude 9°46'00" N and latitude 4°4'00" E and occupies approximately the surface area of 4200

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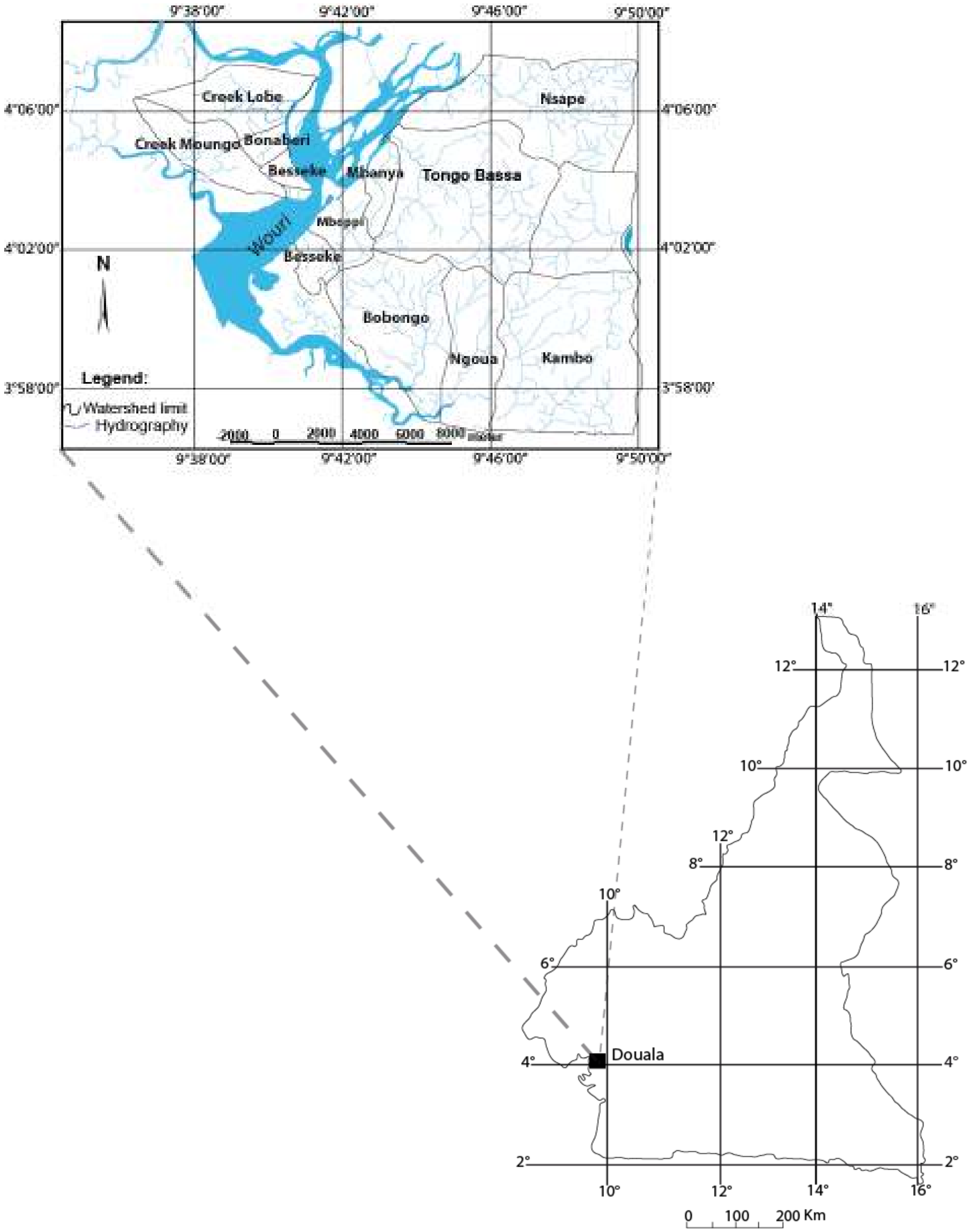


Fig. 1: Map of study area showing some of the prominent watershed

hm^2 (Fig. 1). It is one of the largest watershed basin among the 12 that make up the region of Douala and is therefore an experimental area for the hydro geological study in the region. The 27 districts that constituted the Tongo Bassa watershed have population density ranging from 25 to more than 350 inhabitants per hectare (MINUH, 1997). The Douala hydro geographical network is such that springs flow into streams that in turn flow into minor rivers like Tongo Bassa. The streams are in erosive phase on slopes and sedimentary in wetland areas or lowlands.

The Tongo bassa river network is dendritic and steady flows throughout the year. This river feed the major Wouri River that eventually join the Atlantic

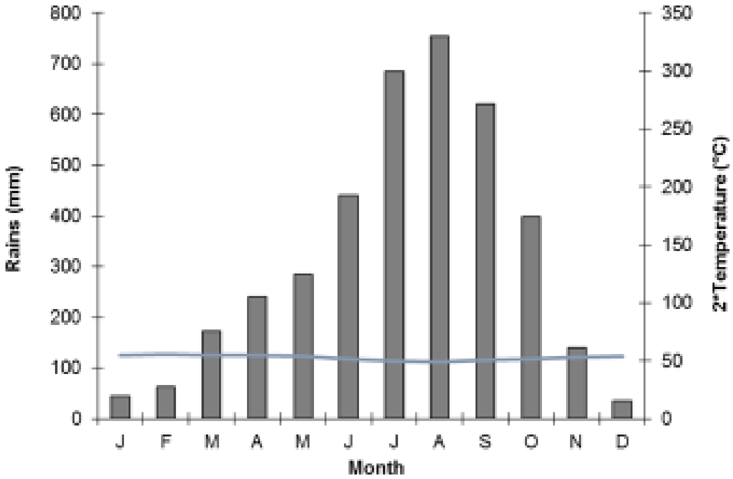


Fig. 2: Monthly rainfall and temperature pattern in Douala

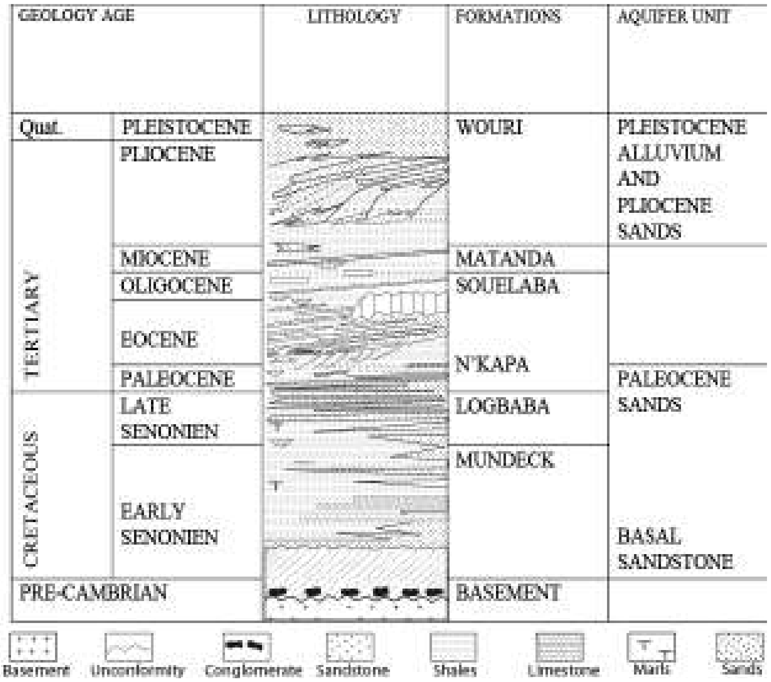


Fig. 3: Chronostratigraphic column of the Douala basin and major aquifer units

Ocean (Lafond, 1965). The topography is characterized by ridges separated by valleys with altitudes in the range of 5 to 60 m above mean sea level.

The regional climate is equatorial and the average annual precipitation from 1951 to 2012 is around 4000 mm (National meteorology). The humidity is influenced by the proximity of the sea about 30 km away and Mount Cameroon whose peak is at 4100 m. The area has two main seasons, a wet season (March to November) and a dry season (December to February). The maximum amount of precipitation is collected in July and August and the average is 754 mm. The lowest amount is collected in December where the monthly average is 35 mm over the same period. It should be mentioned that precipitations are widely distributed during the year (Fig. 2), creating altered conditions of leaching which is a characteristic of this zone (Regnoult, 1986). The monthly temperatures do not vary significantly from one season to another (26°C in August and 28.6°C in February) and the annual average is around 27°C. Evapotranspiration is very low relative to precipitation. The soil type varies from brown to black shallow sandy ferralitic to deep sandy clayey (Dumort, 1968).

Geological setting: The study area is part of Douala Sedimentary Basin, which covers an area of about 7,000 km^2 onshore and located at the center of the gulf of Guinea. Landforms variation is weak and height above sea level doesn't exceed 100 m (Dumort, 1968; Regnoult, 1986). It is one of the several divergent margin basins along the Southwest African Coast whose origin and structure are associated with the opening of the South Atlantic Ocean during the breakup of Gondwanaland (Tamfu and Batupe, 1995). The stratigraphy of the basin has been described by Dumort (1968), Regnoult (1986), Tamfu and Batupe (1995) and Manga (2008) and consists of Precambrian basement, uncomfortably overlain by a sedimentary sequence ranging in age from Cretaceous to recent (Fig. 3). The study area rests directly on the Mio-pliocene to recent alluvial sediments of this basin, which constitutes the Wouri Formation. It generally consists of unconsolidated fine-to coarse-grained sand and gravel mixed with silt and clay in various proportions. The alluvium is composed predominantly of quartz and kaolinite (Regnoult, 1986; Ndomè Effoudou-Priso, 2010) with a general thickness that ranges between 50 and 60 m (Takem *et al*., 2009; Djeuda-Tchapnga *et al*., 2001).

Hydrogeology: A generalized stratigraphic sequence of the major aquifer units of Douala sedimentary basin modified from Regnoult (1986) and Manga (2008) in Fig. 3. In Fig. 3 shows two shallow and deep aquifer units which have been identified in the Douala sedimentary basin by former national water company (SNEC, 1988).

The shallow aquifer is made up of the Mio-Pliocene sands and Quaternary alluvium whose boundaries are not known, so they are often confused (Ketchemen-Tandia, 2011). The Wouri formation, lies on top of the Miocene shale of the Matanda Formation and serves as an aquiclude. The lateral lithology variations that exist in this aquifer make it very complex. Several lentils of channel-filled sands, hosted in clay layers, occur within this main aquifer, which acts as perched aquifer. The shallow aquifer is a multilayer system with unconfined and confined groundwater which is mainly feeded by precipitation (Ketchemen-Tandia *et al*., 2007). Waste water from drainage channels could also infiltrate into this aquifer. Several streams drain the area and may also be recharge by the aquifer during the dry season. Average groundwater level fluctuation ranges between 0.3 m and 1.60 m during dry and wet seasons in unconfined shallow aquifer where hand dug wells have been sampled in the study area. This aquifer record water levels approximately 1-20 m and is highly exploited by hand dug wells. Many springs flow from valleys at the base of small cliffs where the topography intersects water table in the shallow aquifer. Their flow varies between 1.44 to 9 m^3/h and they are mainly used as drinking water in Douala. However, because of poor sanitation facilities, there are several potential sources of pollution mixing together at close proximity to springs. Bore-well discharges of 80 m^3/h/well have also been reported (Djeuda-Tchapnga *et al*., 2001**)** and most of the wells owned by private individuals, tap the Mio-Pliocene alluvial aquifer (confined system). The five selected bore wells (F1, F2, F3, F4 and F5) tap water from the confined aquifer system.

The deep aquifer consists of the Paleocene sand of Logbaba Formation and basal sandstones of Moundeck Formation which is underlain by the Precambrian granites (Fig. 3). The Paleocene aquifer, with a thickness of about 200 m, is exploited by CAMWATER (which currently supplies drinking water to the city of Douala) and some industries within the Douala municipality. It discharges 250 m^3/h/well and **(**SNEC, 1988**)** the exact depths are not known.

MATERIALS AND METHODS

On site analyses were carried out for 428 hand dugs wells, boreholes and springs around and in the study area in order to characterize and estimate the degree of groundwater pollution. Representative water samples were collected from both private and public wells in the study area. A total of 30 hand dugs wells, 07 springs and 05 boreholes were available for sampling during dry season (December, 2010). Data analysis of dry season were used to characterize groundwater because the mixing effect with rainwater is limited. However in order to compare chemistry between the two seasons, samples were collected during the wet season (August 2011).The shallow groundwater samplings were analyzed for the concentrations of the major hydro chemical parameters. The samples were collected in 60 mL polyethylene clean bottles. All samples were filtered on site through a 0.45 μm syringe filter. The cations samples were acidified to a pH less than 2 with Ultra-pure nitric acid. On-site analyses were necessary for Electrical Conductivity (EC), pH, temperature and alkalinity because they are likely to change on transit to the laboratory. EC, pH and Temperature were measured using a WTW 330i HACH multiparameter. For each of these parameters, final readings were taken when the wells and boreholes were pumped until the values were stabilized. Alkalinity values were obtained through titration on site. This was done using a HACH Digital Titrator Model 16900. Sample for the majors ions were conducted in the laboratory of GYMAC (University of Bordeaux 1, France). The concentration of major ions (Na^+, Ca^{2+}, Mg^{2+}, K^+, $NH4^+$, Cl^-, HCO_3^-, NO^{3-} , SO_2^{4-}, PO_4^- and F^-) were analyzed using a double column Dionex Dx 120 ion chromatograph. The resulting data for the concentration of the major ions were subjected to internal consistency tests. The accuracy of the results was confirmed by employing the Charge Balance Error (CBE) (Salifu *et al*., 2013), where the concentrations of the anions and cations were expressed in

Table 1: Physicochemical parameters and major ions constituents in hand dug well (P), spring (SP) and bore well (F)

Name	EC µS/cm	pH	T ºC	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	NH4 (mg/L)	Br (mg/L)	Cl (mg/L)	F (mg/L)	SO4 (mg/L)	HCO3 (mg/L)	NO3 (mg/L)
P1	118.60	4.28	27.40	12.90	2.41	3.42	0.43	0.09	0.02	10.10	0.02	0.27	0.00	27.86
P2	119.50	4.20	27.60	15.26	1.38	0.65	0.19	0.23	0.03	8.23	0.11	0.35	0.00	29.81
P8	207.00	3.90	27.80	19.68	4.32	2.61	0.99	0.51	0.04	16.33	0.36	0.41	0.00	50.80
P10	28.00	4.42	27.20	1.80	0.17	1.40	0.14	0.18		3.40	0.07	0.96	0.00	4.00
P11	307.00	4.54	27.30	24.14	16.72	15.70	1.44	2.23	0.05	26.35	0.09	14.26	6.10	71.20
P12	177.80	4.30	27.60	16.43	6.11	2.93	0.71	2.45	0.03	13.38	0.04	0.40	0.00	46.46
P14	506.00	6.30	26.90	41.81	19.86	19.67	1.39	14.27	0.10	54.06	0.11	19.10	48.30	72.24
P18	332.00	5.40	27.80	32.21	12.15	14.61	1.60	8.24	0.07	40.38	0.04	5.74	21.00	71.98
P19	461.00	5.70	26.90	39.32	19.21	28.89	2.15	4.11	0.08	50.30	0.08	14.90	9.00	111.21
P20	510.00	4.09	27.50	48.05	16.69	17.43	2.31	4.26	0.09	50.63	0.06	1.25	0.00	146.13
P21	345.00	5.80	27.20	25.48	14.16	26.49	1.73	6.05	0.05	34.91	0.11	18.48	42.80	60.37
P24	130.20	4.30	27.60	15.33	3.59	6.12	0.64	0.93	0.06	14.05	0.04	3.00	0.00	37.24
P26	129.70	5.00	27.00	11.07	3.30	5.39	0.64	0.34	0.03	7.49	0.05	1.15	2.70	41.63
P28	140.80	4.60	27.50	14.65	2.42	2.81	0.48	0.45	0.03	9.69	0.18	0.63	0.00	35.20
P29	184.60	4.17	27.80	21.80	3.59	2.50	0.42	0.86	0.04	13.49	0.06	0.31	0.00	50.17
P30	94.20	4.20	27.50	9.24	2.62	1.97	0.24	0.07		6.86	0.06	0.70	0.00	21.15
P32	254.00	4.69	27.40	23.33	8.02	12.80	0.34	0.59	0.04	25.00	0.19	14.90	6.00	42.41
P34	408.00	5.40	27.60	29.84	10.94	23.24	1.69	4.59	0.06	36.09	0.22	6.12	7.40	102.19
P36	136.40	5.30	26.80	14.51	3.48	5.15	0.44	0.81	0.03	15.94	0.09	0.69	9.00	26.20
P37	234.00	6.10	27.30	10.76	6.49	25.01	0.63	0.08		12.63	0.06	31.35	39.80	5.76
P38	128.00	5.60	27.20	8.81	5.94	5.74	0.86	1.22	0.05	7.65	0.02	2.56	2.80	36.00
P39	75.70	5.60	27.30	5.94	1.10	8.06	0.30	0.19	0.02	12.50	0.04	0.31	7.60	18.29
P40	135.70	4.20	27.50	11.16	3.63	3.52	0.51	1.33	0.03	9.09	0.09	1.52	0.00	32.39
P41	46.90	4.30	27.40	3.45	2.74	1.52	0.15	0.70		2.92	0.09	1.20	0.00	15.27
P42	475.00	5.70	27.50	48.53	15.61	17.71	2.32	4.74	0.15	73.11	0.03	18.08	40.10	24.70
P43	464.00	4.70	27.60	37.98	14.42	27.86	1.77	6.25	0.08	31.32	0.06	6.02	3.20	196.81
P44	155.00	4.80	27.60	11.99	5.33	10.25	0.61	0.67	0.03	13.45	0.09	8.18	8.00	28.09
P45	230.00	4.40	27.50	26.76	3.48	10.52	1.01	0.51	0.04	24.27	0.08	1.33	0.00	62.44
P46	337.00	5.10	27.30	57.99	2.83	4.02	0.60	0.55		78.56	0.11	2.78	4.00	16.25
P47	337.00	4.20	27.20	27.75	10.18	15.22	1.29	1.95	0.05	23.59	0.15	15.75	0.00	78.36
SP3	123.10	3.97	27.30	10.68	2.04	1.13	0.20	1.21	0.02	7.59	0.12	0.67	0.00	24.95
SP13	366.00	4.50	27.50	34.29	13.29	13.88	1.57	5.81	0.07	40.62	0.13	4.66	0.00	90.86
SP22	200.00	4.05	27.20	14.60	5.45	6.86	0.85	1.00	0.06	13.77	0.06	2.77	0.00	42.50
SP27	138.80	4.36	27.50	12.57	2.26	5.70	0.54	0.67	0.02	10.42	0.04	0.52	0.00	37.03
SP31	505.00	5.73	28.00	34.32	12.65	30.61	2.48	7.94	0.27	42.00	0.03	20.05	15.40	126.30
SP33	102.20	4.30	27.40	9.55	2.85	2.51	0.36	0.56		7.87	0.15	2.29	0.00	20.66
SP35	95.20	4.35	27.20	9.08	1.39	1.14	0.24	0.54	0.02	5.18	0.05	0.37	0.00	20.78
F1	947	6.96	28.4	20.6	14.9	86.8	49.1			324.7		0.1	90.0	8.0
F2	31	3.88	27.3	1.0	0.2	1.4	0.4			2.0		2.4	0.0	3.0
F3	42	4.54	27.6	1.2	2.6	3.0	1.1			1.4		8.7	5.8	6.3
F4	37	4.75	28	1.7	1.5	2.4	4.6			1.1		6.5	25.6	1.3
F5	110	5.51	27	2.7	4.0	8.6	5.5			2.5		8.0	50.2	0.7

Table 2: Seasonal variation of the chemical content in hand dug well (P) and spring (SP). Ao = August (wet saison) and Dec = December (dry saison)

Name	EC (µS/cm) De.	Ao.	Ph De.	Ao..	Na^+ De.	mg/l Ao.	K^+ De.	mg/l Ao.	Ca^{2+} De.	mg/l Ao.	Mg^{2+}De.
P2	119.5	115	4.2	4.4	15.3	14.2	1.4	1.6	0.7	1.7	0.2
P8	207.0	208	3.9	6.2	19.7	10.4	4.3	4.3	2.6	25.7	1.0
P10	28.0	20	4.4	5.3	1.8	1.4	0.2	0.3	1.4	1.7	0.1
P12	177.8	208	4.3	4.2	16.4	10.5	6.1	6.3	2.9	2.4	0.7
P14	506.0	535	6.3	6.6	41.8	38.4	20.0	20.8	19.7	24.0	1.4
P18	332.0	326	5.4	6.2	32.2	25.6	12.2	11.5	14.6	19.0	1.6
P19	461.0	490	5.7	6.0	39.3	43.8	19.2	9.9	28.9	27.1	2.2
P20	510.0	373	4.1	5.5	48.1	28.1	16.7	16.9	17.4	23.4	2.3
P21	345.0	367	5.8	6.2	25.5	33.3	14.2	11.2	26.5	22.9	1.7
P24	130.2	115	4.3	4.5	15.3	12.6	3.6	2.1	6.2	2.7	0.6
P26	129.7	113	5.1	4.4	11.1	7.7	3.3	2.9	5.4	4.5	0.6
SP3	123.1	117	4.0	4.2	10.7	31.1	2.4	11.8	1.1	14.3	0.2
SP13	366.0	362	4.5	5.1	34.3	10.4	13.3	2.0	13.9	1.7	1.6
SP22	200.0	193	4.1	4.2	14.6	13.9	5.5	5.2	6.9	6.9	0.9
Name	mg/l Ao.	NH_4^+ De.	mg/l Ao.	Cl^- De.	mg/l Ao.	NO_3^- De.	mg/l Ao.	SO_4^{2-} De.	mg/l Ao.	HCO_3-De.	mg/l Ao.
P2	0.4	0.2	0.1	8.2	9.5	29.8	36.2	0.4	0.0	0.0	0.0
P8	1.3	0.5	0.1	16.3	7.1	50.8	57.4	0.4	6.4	0.0	25.1
P10	0.1	0.2	0.0	3.4	1.1	4.0	4.1	1.0	0.6	0.0	1.5
P12	0.7	2.5	1.3	13.4	9.9	46.5	43.6	0.4	0.5	0.0	0.0
P14	1.8	14.3	25.9	54.1	35.5	72.2	76.9	19.1	30.3	48.3	63.4
P18	1.5	8.2	8.2	40.4	25.2	72.0	49.8	5.7	13.2	21.0	40.3
P19	2.8	4.1	8.1	50.3	45.2	111.2	57.1	14.9	15.0	9.0	47.4
P20	2.3	4.3	0.7	50.6	32.7	146.1	97.6	1.3	15.8	0.0	0.5
P21	1.4	6.1	4.9	34.9	27.3	60.4	67.4	18.5	32.1	42.8	18.8
P24	0.4	0.9	0.1	14.1	9.8	37.2	32.2	3.0	0.0	0.0	0.0
P26	0.6	0.3	0.1	7.5	7.8	41.6	29.3	1.2	1.3	2.7	0.0
SP3	1.6	1.2	5.0	7.6	34.9	25.0	100.2	0.7	7.00	0.0	1.4
SP13	0.3	5.8	0.9	40.6	7.9	90.9	36.2	4.7	1.7	0.0	0.0
SP22	1.00	1.0	0.2	13.8	14.1	42.5	54.8	2.8	4.4	0.0	0.0

meq/L. It is observed that although some of the samples were associated with CBE values higher than the recommended 5%, the computed CBE values are nevertheless within ±10%. As a result of this, all the samples passed the internal consistency test and were used for the next stage of the research (Table 1 and 2). The Charge Balance Error superior to ±5% for some sampling is due to the low salinity which characterizes groundwater in Douala sedimentary Basin. Locations of selected sampling sites were fixed using Garmin GPS (Fig. 4).

Statistical and graphical analyses of data: The resulting data on the hydrochemical parameters were subjected to internal consistency checks, after which advanced multivariate statistical and conventional graphical techniques were applied. Statistical analyses were carried out using the statistical software SPSS Statistics, version 17.0.

Principal components were selected as the extraction method whilst the Kaiser criterion (Salifu *et al*., 2013) was used to ward off redundant or no-unique factors resulting from the analyses. Practically, one can obtain as many factors in the factor analysis as there are parameters/variables in the dataset. Factors analyses performed in this fashion will lead to the complete factor model with so many redundant factors which cannot be interpreted. As a result, the original objective of the process as a data reduction scheme would have been defeated. The Kaiser criterion ensures that only factors with Eigen values greater than or equal to 1 were retained in the final factor model. This is based on the assumption that a unique process or worthy factor should be able to account for the variance of at list one variable. The communalities were used to sort and remove variables which had no contribution to the factor model. Those variables outside of this range were dropped since their inclusion would cloud the result of the analyses. In this way, the final factor model would contain only variables whose contributions to the determination of the significant process influencing the entire hydrochemistry would be highlighted (Salifu *et al*., 2013).

RESULTS AND DISCUSSION

The results of chemical analyses of shallow groundwater used for this study are present in Table 1.

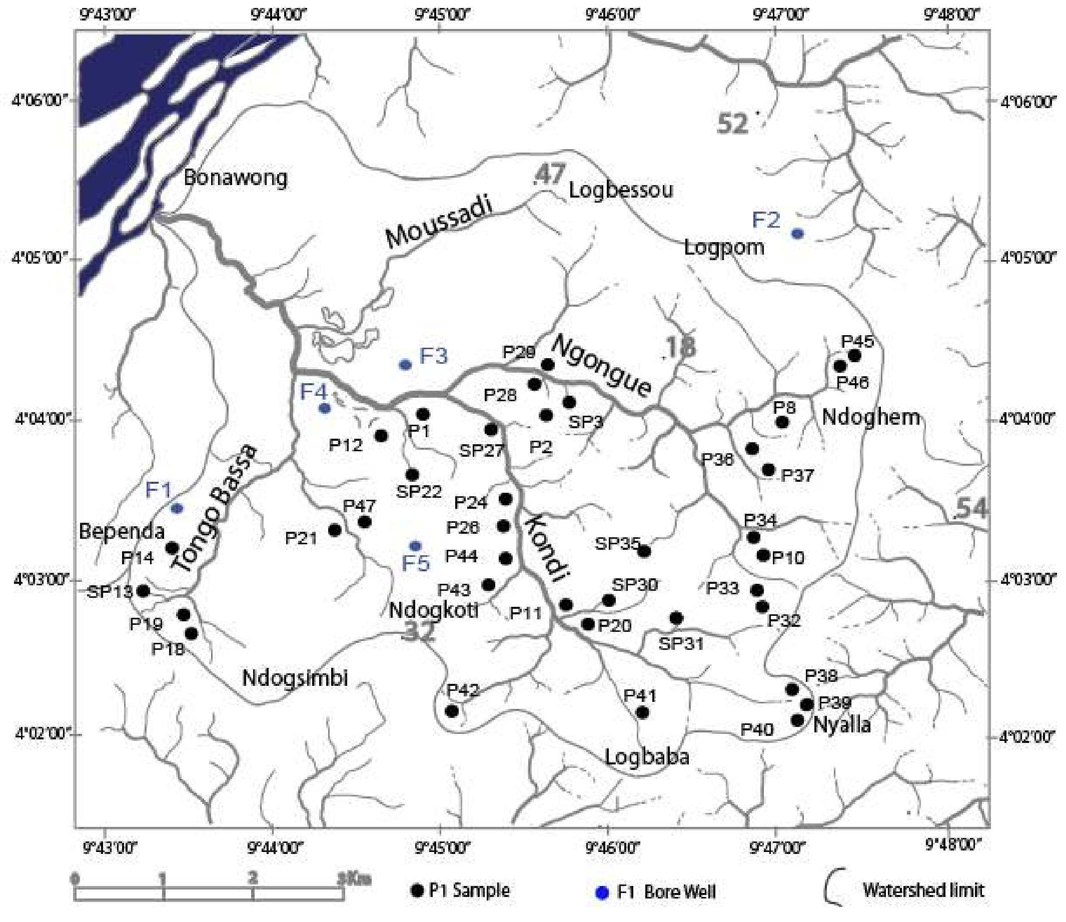


Fig. 4: Location of groundwater samples

The temperature of the groundwater samples is generally room temperature and ranges between 26.9 and 28°C. According to Ketchemen-Tandia (2011) the low temperature suggests quick infiltration and a shallow flow-path. Groundwater is acidic, as the pH values range from 3.9 to 6.3 with a mean of 4.7 and 4.2 to 6.6 with a mean of 5.21 respectively during the dry and wet season. In the bore wells, pH values varies between 3.9 and 7 and 95% of these samples show pH values less than those recommended by the WHO (6.5 - 8.5) (WHO, 2004). The low pH indicate that there are several factors contributing to groundwater acidity in the area. Analyses of rainwater in study area show average pH value equal 5.5, this is according to Berner and Berner (1987) that under normal atmospheric conditions, pH of rainwater is approximately 5.7 units. Moreover, natural groundwater pH unaffected by anthropogenic processes is not expected to be less than 4.6 (Appelo and Postma, 1999). However, values ranging up to 3.9 are observed. The acidic nature of the groundwater in Tongo Bassa Basin accompanied by low EC and sulphate suggest that the acidity is apparently produced on one hand by natural processes view the silicate nature of aquifer and on the other hand dissolution of the soil generating CO_2 and probably quantities of dissolved organic acids. Evidence of the abundance of organic matter in the soil of Tongo Bassa basin is the brown coloration of river.

The spatial distribution of the values of Electrical Conductivity (Fig. 5) shows that the values are increasing from the north east section of the study area where there is a weak population density (25 to 150 people per km^2) and little human activity, to the south west where conductivity values exceed 1000 µS/cm and population density is between 150 to 350 people per km^2. To characterize the seasonal variation, EC values for wet and dry seasons were carried out. The EC ranged from 28 (P10) to 510 µS/cm (P20) with a mean of 259.7 and 20 (P10) to 535 µS/cm (P14) with a mean of 253.0 µS/cm for dry and wet season respectively. Those close averages show that the EC values does not change much from one season to another with a slight decrease in the wet season.

The lower average value of EC in wet season suggests the decrease in concentration of salt due to dilution of groundwater by rainwater. The close and high standard deviations in EC for dry (158.4 µS/cm) and wet season (156.5 µS/cm) suggest local variation in point sources due to anthropogenic activity and multiple aquifer system.

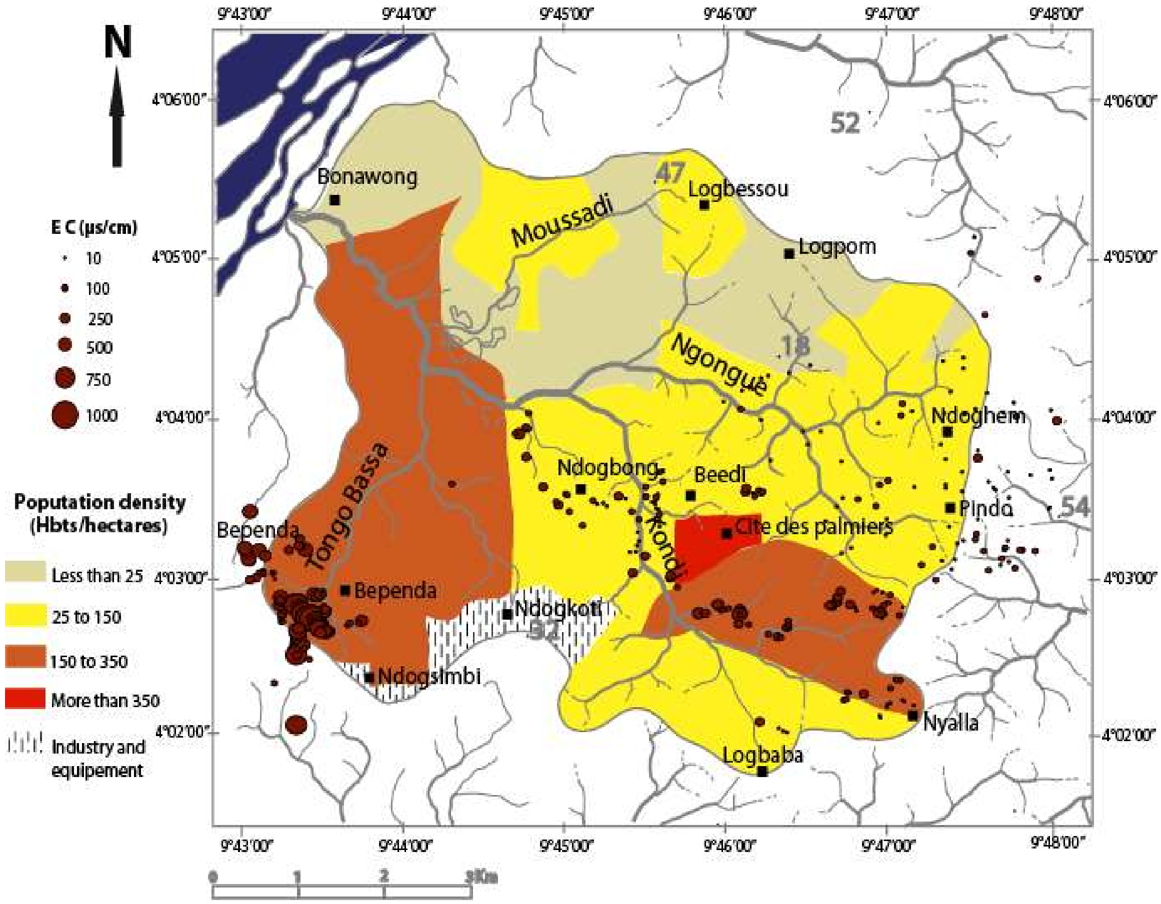
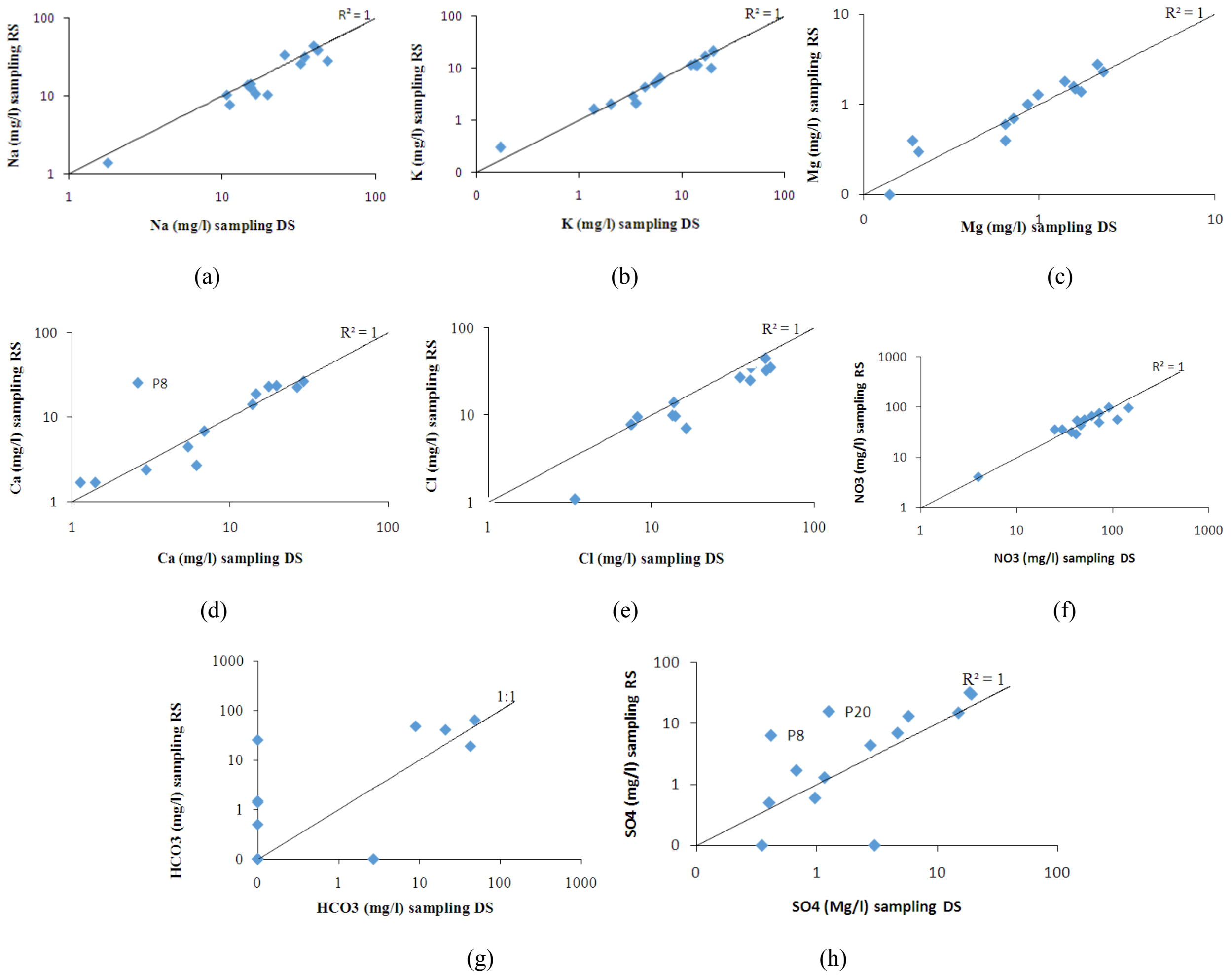


Fig. 5: Spatial distribution of Electrical Conductivity (µS/cm) and population density

The springs have shown high conductivity (123 to 366 µs/cm) than bore wells (31 µs/cm in F2 to 110 µs/cm in F5 excluding bore well F1) where a background EC of 50 µs/cm was reported by Kamta (1999). According to Djeuda-Tchapnga *et al*. (2001) and Takem *et al*. (2009), bore wells and spring are tapping the Mio-Pliocene shallow aquifer. Though, according to the present study, bore wells appear to be tapping water from greater depth in confined aquifer, while the springs are tapping water from unconfined aquifer like hand dug wells. This is explained by the fact that the spring are directly affected by seasonal variations in flow measurement and chemistry in both seasons and high levels of dissolved ions relative to bore wells, with the exception of F1(937 µS/cm) according to Takem (2009) in the same area of this sample. Bore well F1 is located in a district (Bependa) which will constitute a public discharge and where cholera epidemic continues to decimate populations (Guevart *et al*., 2006).

The two sets of chemical data on the same well (Table 2) between the dry season and the wet season allow a direct comparison. Line 1:1 represents the state of the same concentration. Relative to the line1:1, it is observed in Fig. 6 that:

- No significant variation for potassium (K^+), magnesium (Mg^{2+}), calcium (Ca^{2+}) and nitrates (NO_3^-) between the two seasons (Fig. 6b to f). The filtration process which occurs during groundwater recharge could account for the absence of a significant seasonal variation in these parameters.
- Noticeable dispersion for bicarbonates (HCO_3^-) and sulfates (SO_4^-) in Fig. 6(g and h) showing that values are not related to the change of seasons.
- The majority of the points are to the right of the line 1:1 (Fig. 6a and e), indicates an increase in the concentration of sodium (Na^+) and chlorides (Cl^-) in the dry season respectively 23.29 and 25.37 mg/L compared to 20.1 and 19.14 mg/L recorded in the wet season. According to the same result in Nigeria (Makwe and Chup, 2013), this could be due to the reduction in groundwater recharge resulting from low precipitation, over-exploitation and higher temperature during the dry season.



(a) (b) (c)

(d) (e) (f)

(g) (h)

Fig. 6: Plot of parameters between Dry season (DS) and Wet Season (RS)

Table 3: Correlation matrix of chemical variables

EC		pH	T	K	Na	Ca	Mg	NH4	Br	Cl	F	SO4	HCO3	NO3
EC	1													
pH	0.52	1												
T	-0	-0.4	1											
K	0.94	0.45	-0.1	1										
Na	0.97	0.43	0.06	0.89	1									
Ca	0.85	0.4	0.04	0.84	0.8	1								
Mg	0.92	0.41	0.14	0.89	0.91	0.87	1							
NH4	0.8	0.59	-0	0.77	0.76	0.62	0.61	1						
Br	0.83	0.42	0.09	0.75	0.91	0.56	0.82	0.63	1					
Cl	0.89	0.49	0.08	0.8	0.95	0.65	086	0.65	0.95	1				
F	0.42	0.23	-0	0.31	0.24	0.5	0.27	0.3	0.01	0.13	1			
SO4	0.83	0.53	-0.2	0.88	0.76	0.71	0.77	0.65	0.7	0.75	0.28	1		
HCO3	0.62	0.64	-0.1	0.57	0.62	0.4	0.49	0.74	0.65	0.64	0.11	0.77	1	
NO3	0.56	0	0.15	0.58	0.52	0.77	0.58	0.46	0.29	0.33	0.35	0.23	-0.1	1

The concentration (mg/L) of individual ions in the dry season vary as follows: Na^+ from 1.80 to 57.99; K^+ 0.17 to 19.86; Ca^{2+} 0.65 to 28.89; Mg^{2+} 0.14 to 2.48; NH_4^+ 00.9 to 14.27; Cl^- 2.92 to 78.56; SO_4^{2-} 0.27 to 20.05; HCO_3^- 0 to 48.30 and NO_3^- 4 to 196.81. The chemical composition reflects a low mineralization of groundwater due to the sandy nature of sediments, which allows a rapid and short residence time for groundwater; couple with the resistant nature of sediments to dissolution, limiting the contribution from water rock interactions (Hem, 1985). Another comparison is the trend during the two seasons. In dry season, no cation exceeds 50% of the total cations in all the groundwater samples. The order of the relative abundance of major cations expressed in percent of meq/L in dry season, is Na^+ (49.36)> Ca^{2+} (22.42)> K^+ (18.43)> NH_4^+ (7.51)> Mg^{2+} (2.29) while that of the anions is NO_3^- (60.02)> Cl^- (25.68)> HCO_3^- (8.95)> SO_4^{2-} (5.34). In wet season the order is: Na^+ (44.11)> Ca^{2+} (27.91)> K^+ (16.73)> NH_4^+ (8.71)> Mg^{2+} (2.53) for cations and NO_3^- (55.53)> Cl^- (20.03)> HCO_3^- (14.83)> SO_4^{2-} (6.49) for the anions. The two seasons show the same pattern. Na^+ and Ca^{2+} are the dominant cations. The concentration of Na^+ could be attributed to atmospheric deposition by sea spray since the area is located close to the coast (Appelo and Postma, 1999). Water interactions with the alluvial sediments, principally the weathering of feldspar (plagioclase), could be another possible source of the cations Ca^{2+} and Na^+ in ground water. NO_3^- and Cl^- are dominant anions. There is no known geologic source of chloride in the study area. Moreover the concentration of chloride in sample P10 from slope tableland and bore wells are between 1.1 to 3.4 mg/L except bore well F1 which else supports the fact that the source of chloride is not from any of the geological formations. Like Na^+, the source of chloride could thus be related to salts from sea spray and probably from anthropogenic inputs, such as animal wastes and individual pollutants (Djeuda-Tchapnga *et al*., 2001; Ketchemen-Tandia *et al*., 2007; Takem *et al*., 2009; Ngo Boum-Nkot, 2004). 41% of water points have concentrations in nitrates exceeding the WHO standards in all water sample and it was generally high in hand dug wells loan from the valley along Tongo Bassa river to P30 (21.15 mg/L) from P43 (196.82 mg/L) because high density of population add to the low water table. Nitrate contamination of a well is often regarded as a first sign of deteriorating groundwater quality. Sources of excess nitrate in water include septic systems, wastewater effluent, animal wastes, excreta disposal in the environment and industrial wastes. Organic pollution from onsite sanitation has been reported to be a major cause of nitrate contamination of shallow groundwater in many semi-urban settlements (in Burkina Faso (Greon *et al*., 1988), Niger (Joseph and Girard, 1990), Senegal (Collin and Salen, 1989), Cote D'ivoire (Faillat, 1990), Tanzania (Nkotagu, 1996) and India (Maheshwari *et al*., 2012). Previous studies in the same area (Takem *et al*., 2009) shows that there is a weak correlation between the nitrate levels and levels of fecal indicator bacteria. This can confirm the fact that the contamination comes from many sources. Nitrate concentration in sample P10 and bore wells was between 0.7 to 4 mg/L. The low level of nitrate contamination could be due to selective removal of nitrates during infiltration through the soil (Lewis *et al*., 1980). Another possible reason for relatively low levels of nitrate in some of the sampling sites could result from the reduction of nitrate by organic matter, thereby producing NH_4^+ (Stumm and Morgan, 1996) which is present in groundwater.

The correlations analysis was initially performed before conducting the factor analysis in order to modify the interpretation obtained from the components analysis (Melloul and Collin, 1992). Positive correlation is obtained between EC and Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, Br-, NH_4^+ and SO_4^{2-} (Table 3). However, Na^+, K^+, Mg^{2+}, Cl^-, show the strongest correlations with EC indicating that the mineralization is derived primarily from the dissolution of the surrounding sandy clay consisting essentially of minerals such as alkali feldspars and micas (Ndomè Effoudou-Priso, 2010) which provide the ions Na+, K+, Mg $^{2+}$. Chloride ions in turn come from another source that can be human action. Indeed, the owners of the wells treat the water by adding bleach and sodium chloride. This is corroborated by strong correlation between Na^+ and Cl^- (Table 3) and obliterates the chemical profile natural water. The trilinear plot of all samples expressed in

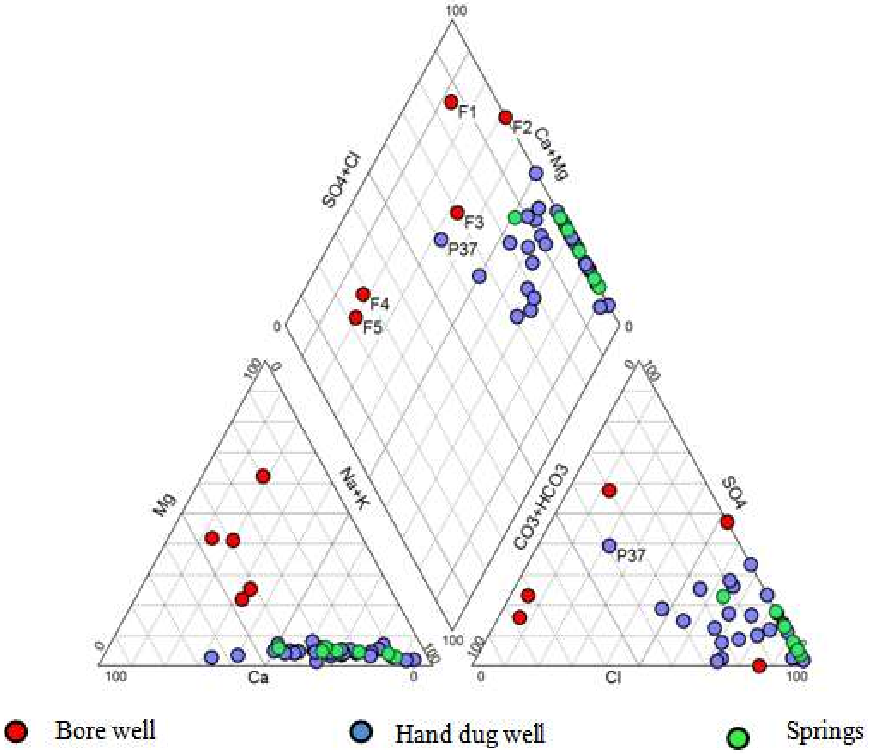


Fig. 7: Representation of groundwater chemical data on trilinear diagram

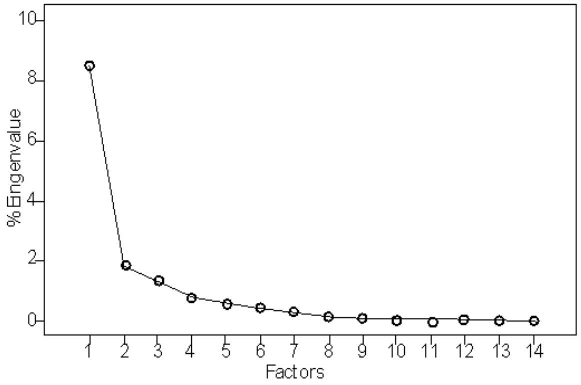


Fig. 8: Principal components and Eigenvalues

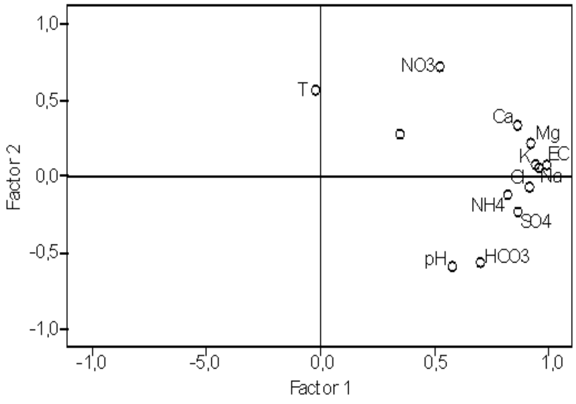


Fig. 9: Relationship between Factors 1 and 2

Table 4: Correlation matrix on the three extracted rotated factors

Variable	Factor 1	Factor 2	Factor 3
EC	0.987	0.078	0.039
Na	0.959	0.07	-0.171
K	0.945	0.078	0.069
Mg	0.922	0.211	-0.117
Cl	0.904	-0.068	-0.301
SO4	0.868	-0.229	0.037
Ca	0.854	0.348	0.244
Br	0.853	-0.107	-0.413
NH4	0.824	-0.119	0.1
HCO3	0.701	-0.555	-0.116
NO3	0.525	0.715	0.227
pH	0.576	-0.581	0.32
F	0.347	0.281	0.681
T	-0.018	0.563	-0.592

mg/l on both periods shows also Na-Cl hydrochemical type dominated groundwater composition (Fig. 7).

Statistical analysis of physicochemical data (14 variables and 37 individuals) was conducted by the PCA (Principal Component Analysis) using in SPSS Program. The correlation matrix gives us the first idea of associations between different variables. The eigenvalues of the correlation matrix measures the percentage of variance explained by each component (Yidana *et al*., 2010). Significant attention is given to variables with strong positive or negative contribution to the factorial axis which is easier to understand the source of variability explained by the factor. Only three factors whose eingenvalues are greater than 1.0 (Fig. 8) were initially extracted (Table 4) representing 84% of total variance. The relationship between factors 1 and 2 is shown in Fig. 9.

Factor 1: Usually is the most important process or combination of processes that control water chemistry and on the other hand the higher eigenvalues and the highest variance between components (Nkotagu, 1996). In the current study, Factor 1 accounted for 61% of the variance and is positively correlated with EC, Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, Br^-, NH_4^+ and SO_4^-. It is attributed to natural weathering reactions and exchange between the cations. In this case, it is the dissolution of alkali feldspar and mica and the mixture of salt leaching to the soil surface. Indeed, the discharge of wastewater is basically raw sewage returned into the environment.

Factor 2: It is positively correlated with NO_3^- and negatively correlated with pH. The negative loading of pH on factor 2 with NO_3^-indicates nitrification to be taking place according to the equation [36]:

$$NH_4^- + 1,5O_2 \leftrightarrow NO_2^- + 2H^+ + H_2$$

Then $NO3^-$ is formed through the oxidation of the NO_2^- following the equation:

$$NO_2^- + 0,5O_2 \leftrightarrow NO_3^-$$

The low pH values and high values of NO_3^- concentration suggest in some well the presence in water of high concentrations of NH_4^+. Fertilizers are not widely used in the catchment of the Tongo Bassa River, which suggests that the nitrification process can be mainly attributed to discharges of organic waste matters of humans and animals alike that are prevalent in nature. The infiltration being facilitated through the sandy clayey nature of the soil.

Factor 3: This factor is positively correlates with fluorine and correlates negatively with temperature. Fluoride occurs naturally in water at concentrations of 1 mg/L. But in the groundwater, these levels are rather low because of between 0.02 and 0.22 mg/L. It would be expected to have higher value of fluorine concentration (found in micas) view the temperature of the water (28°C) that accelerates the water-rock interaction favoring the presence of concentrations of fluoride ions in solution. This may be due to the dilution effect of rainwater.

CONCLUSION

Interpretation of the hydro chemical analysis of groundwater samples reveals that shallow groundwater in Tongo Bassa watershed has low mineralization. High EC and nitrate in some samples indicate that human activity have significant impact on the groundwater quality. The pH values reveal that the groundwater has an acidotic nature. The sequence of the abundance of the major ions is in the following order (expressed in percent of meq/l) in both dry (December 2010) and wet (August 2011) seasons: $Na^+ > Ca^{2+} > K^+ > NH_4^+ > Mg^{2+} = NO_3^- > Cl^- > HCO_3^- > SO_4^{2-}$. The concentrations of major ions in groundwater are within the permissible limits for potable water except for NO_3^-. The water type that predominates in the study area is Na-Cl type during both seasons. The results show also that the concentrations do not change much from one season to another. Nevertheless the fact that for certain elements such as Na^+ and Cl^- slightly higher concentrations in the dry season, supports the view that mineralization of the resource is more accentuated in the dry season than in wet season following the reduction of the water table due to low precipitation, over-exploitation and high temperature. Factors analysis helped to establish the cause and relationship of the mineralization of the groundwater in the Tongo Bassa watershed. Three factors with an Eigenvalue each greater than 1 explain 84% of all the identified variables. The phenomena is attributed to natural weathering reactions and exchange between the cations. In this case, it is the dissolution of alkali feldspar and mica and the mixture of salt leaching to the soil surface. Indeed, the discharge of wastewater is basically raw sewage returned into the environment.

Based on the hydro chemical results, it is concluded that though waters of the shallow aquifer are weakly mineralized, require the proper treatment methods to make them more safe and fit for human consumption. Hydro chemical groundwater characterization and evaluation should be used. Routine monitoring and quality testing of periodic water is also recommended.

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