



Evaluation of Trace Metals in Groundwater of Ekondo-Titi and Environs, Onshore Rio Del Rey, Cameroun

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Abstract

Ekondo-Titi and environs are found between 4.500 - 4.950N and 8.900 - 9.250E onshore Rio Del Rey Basin in Ndian and Meme Divisions of the South West Region in Cameroon. Evaluation of trace metals in groundwater is among the most important environmental issues related to contamination from anthropogenic and natural sources due to increased urbanization and intensive plantation agriculture in Ekondo-Titi and environs. The study investigated the trace metal content of groundwater sources; determined estimates of the health hazard and pollution risk indices; assessed the health hazard and level of risk to trace metal pollution in Ekondo-Titi and environs. Field measurement of physicochemical parameters and analysis of thirty-seven groundwater samples were analyzed to determine their trace metal content using Inductively Coupled Plasma Mass Spectroscopy ICP-MS. R-mode statistical analysis; Hierarchical Cluster Analysis (HCA) and Pearson's correlation analysis (PCA) of the trace metals with the physico-chemical parameters have been carried out. A risk is the chance, high or low, that the exposure to a hazard will actually cause harm. Four pollution hazards were estimated the average daily dose ADD, carcinogenic risks CR, non-carcinogenic risk hazard quotient HQ and hazard index HI. Six pollution risks were determined: the Degree of contamination DC, Enrichment factor EF, Ecological risk factor Er, Ecological risk index RI, Pollution load index PLI, and geo-accumulation index Igeo. The results show that the average abundance of trace metals concentrations in the groundwater is in the order: Fe > Ba > Mn > Zn > Sr > Ni > Cu > Co > Pb > Li > Cr > V > As > Cd. HCA distinguishes the trace metals into two

clusters: Cluster one; (01) element Fe; soluble; Cluster two (13) non soluble elements divided into two classes; class one (09) V, As, Cd, Cr, Li, Pb, Co, Ni, C; less enriched; Class two (04) Mn, Ba, Sr and Zn; enriched. PCA shows a very strong positive correlation between Cr/V, Ba/Li, Ba/Mn, Pb/Ni, Pb/Zn, Cu/Zn and a moderately strong correlation between Co/Mn, Ba/Co, Ba/EC and Ba/TDS. The values of groundwater pollution hazard indices range as follows; ADD (5E-06 - 0.078), CR (4.3E-06 - 0.002), HQ (3E-04 - 1.23) and HI (0.03 - 1.23). And those of the pollution risk indices are DC (-13.59 to -5.62), EF (0.79 - 843.94), Er (-29.84 - 0.19), RI (-62.07 to -45.53), PLI (-0.044 - 0.046) and Igeo (0 - 995.4). The groundwater pollution hazard indices ADD and CR are less than 1 in the categories of insignificant pollution health hazard, are below the acceptable guideline values whereas HQ and HI are above 1, likely to pose health hazards. The pollution health risk indices DC, EF, Er, RI, PLI, and Igeo are all below the acceptable guideline values. The enrichment factor EF showed that the sources of these metals are geogenic and anthropogenic processes. Barium is the most enriched element in the study area; this could be attributed to agricultural fertilizers. Igeo values indicate groundwater is no pollution to moderately pollution risk from Li, V, Cr, Co, As, Cd, Pb while groundwater has a strong pollution risk from Ba and extreme pollution risk from Mn, Sr, Fe and Zn, though the concentrations of the trace metals are below WHO guidelines. Thus, from the health hazard indices and pollution risk indices on trace metals, the groundwater in Ekondo-Titi and environs is safe for drinking. The severity of metal toxicity is governed by several factors, such as dose, nutrition, age, and even life style. Therefore, these low trends that indicate the absence of human health hazards and health risks, the groundwater, might not guarantee the complete and permanent absence of human health hazards and risks due to an increasing level of environmental pollution that might be imposed by the increasing plantation agriculture in this area. Groundwater sources might become a potential sink of contaminants; this is the reason for recommending a constant monitoring and implementation program in Ekondo-Titi and environs.

Subject Areas

Environmental Sciences, Hydrology

Keywords

Trace-Metal, PCA, HCA, Health-Hazard-Indices, Pollution Risks-Indices, Rio-Del-Rey, Ekondo-Titi, Cameroon

1. Introduction

Ekondo-Titi and environs are found between 4.500 - 4.950N and 8.900 - 9.250E as in **Figure 1**, in Ndiang and Meme Divisions of the South West Region in Cameroon; an agro-industrial zone of Cocoa, Banana, Rubber and Palm-oil plantations, all of which are exported and dependent on groundwater for processing.

The presence of agro-industries has led to unprecedented population growth and urbanization around this area resulting in a high demand for water that has now exceeded supply.

Water is one of the essentials that support all forms of animal and plant life [1] and it is generally obtained from surface water such as freshwater lakes, rivers and streams and groundwater such as springs and well water.

The study of trace metal deposition and accumulation is of increasing interest because of the awareness that trace metals present in groundwater may have negative consequences on human health and on the environment when they exceed the maximum contamination levels. Because of the absence of treatment of groundwater before drinking in Ekondo-Titi and environs, it is of great importance to assess the trace metal content. The assessment of trace metal quality of groundwater used by the inhabitants of this area is sparse. Environmental pollution by trace metals is due to both geogenic; natural processes such as weathering of minerals and anthropogenic activities related to industry, agriculture, burning of fossil fuels, vehicular emission, mining and metallurgical processes and their waste disposal.

Trace metals are naturally part of the environment and can be found in soils and rocks and also dissolved in rivers, streams and groundwater. Despite the natural occurrence of trace metal in the environment, the main sources of their accumulation in nature are human activities [2]. Trace metals are chemical components found in low concentrations, in mass fractions of ppm or less, in water, organisms and soil [3]. Some trace metals are essential as micronutrients Cu, Fe, Mn, Ni and Zn for life processes in plants and microorganisms, while others Cd, Cr and Pb have no known physiological activity, but are proven detrimental beyond a certain limit which is very much narrow for some elements like Cd 0.01 mg/L, Pb 0.10 mg/L and Cu 0.050 mg/L [4].

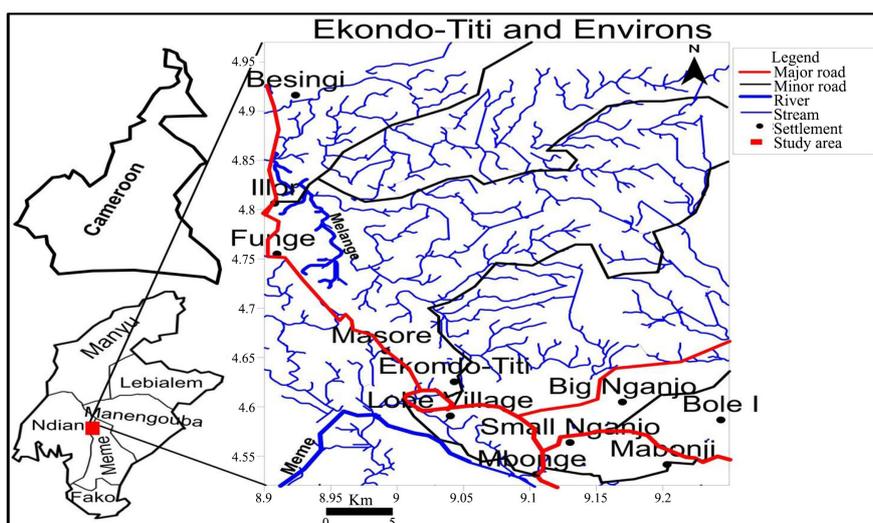


Figure 1. Location map for measurements and sample collection in Ekondo-Titi and environs.

A hazard is any agent that can cause harm/damage to humans or the environment. Risk is the possibility of danger or injury; an uncertain event/condition that, if it occurs, has an effect on the subject; the chance, high or low, that exposure to the hazard will actually cause harm. Health risk assessment encompasses four steps: Hazard identification, dose-response assessment, exposure assessment, and risk characterization.

The present study investigated the trace metal content of groundwater sources, determined estimates of the health hazard and pollution risk indices, assessed the health hazard and level of risk to trace metal pollution in Ekondo-Titi and environs.

1.1. Climate

This area is characterized by an equatorial climate, but its dominant lowland topography (exempting the highlands towards the northeast), and its proximity towards the sea ensures an equatorial maritime climate type along the Atlantic coast. The Climate is characterized by two seasons (rainy and dry) determine by the apparent movement of the overhead sun and seasonal tropical winds. Generally, annual rainfall is high. It ranges from 2000 mm on the lowlands and 4000 mm on the leeward slopes of Mount Cameroon and the Rumpi Hills [5].

1.2. Relief

The study area stands out as an area of gentle relief with lowlands in the south, west, and North West. Towards the east and North-East, the relief changes to hilly landscape. Some areas in the East have an altitude of up to 1000 m above sea level. Close to the Atlantic Ocean are the mangrove swamps, several creeks, and sand-spits that stretch from the muddy coast lines of Meme river delta in Mbonge, Ekondo-Titi to the Ndian River Basin.

1.3. Hydrology

The main rivers include rivers; Ndian, and Melange which both take their rise from the Rumpi Hills and River Meme from the flanks of Mt Cameroon and the Bakossi Forest Reserve and they flow into the Atlantic Ocean respectively.

1.4. Geology

Cameroon's geology is made of different rock types;

- 1) Precambrian basement rocks covering about 77% of Cameroon and underlie,
- 2) Sedimentary rocks covering 9% are of Cretaceous to the Cenozoic Era intruded in some areas by,
- 3) The Tertiary to recent volcanics covering 10% found generally along the Cameroon Volcanic Line (CVL),
- 4) Over a, b and c, above along major river channels, deltas and seashores are recent alluvium that make up some 4%.

Bakassi Peninsula is found in the Rio Del Ray basin (Coastal basin) which is one of the Equatorial Atlantic marginal basins in the Gulf of Guinea, covering 2500 km² and dipping ocean-wards with about 6000 m thick of sediments ranging from Cretaceous to Recent. The basin proper is bordered to the west and northwest by the contemporaneous Niger Delta Basin, limited to the south by the Island of Bioko, the north by the Rumpi Hills and to the east by the Cameroon Volcanic Line (CVL) separating the Rio Del Ray basin from the Douala Basin.

The Rio Del Ray basin and the Douala basin are genetically related and were linked together constituting one composite basin, which was itself attached to the Niger Delta in Nigeria. There are four Formations of the Rio Del Ray basin; Akata, Agbada, Benin and the Isongo formations averaging a depth of 2.5 km.

The Akata Formation is about 600 m - 6000 m thick. The sands are continental slope channel-fills and turbidities.

The Agbada Formation overlies the Akata Formation and consists of interbedded sand and shales with thickness of about 300 m - 4500 m. The coarse clastic beds are the oil reservoirs of up-to-date discovered oilfields.

The Benin Formation is the topmost Tertiary sequence of the Niger Delta and continues eastwards into the Rio Del Ray basin as a fringe zone of shales diapirs, sandy clays, dark-green sandstones, lignites and fragments of volcanic rocks. The Benin Formation has a thickness of about 1890 m - 2300 m at the center.

The Isongo Formation is encountered mostly south-east of the Rio Del Ray basin and represent a mixed phase of marine shales and fan sands.

The Formations in the Rio Del Ray basin that outcrops onshore are Aptian to Albian Mundeck, coarse fluvial sandstone and the late cretaceous Mungo and Logbaba, shallow marine limestones, sandstones and shales which are overlain unconformably by Tertiary non marine sands and silts. Offshore the sequence above the unconformity is Eocene to recent, the Akata Formation, diachronous pro-deltaic shales are overlain by the Agbada, deltaic front sandstones, shales and the Benin, fluvial sands. The Rio Del Ray basin also contain some features of the Cameroon Volcanic Line (CVL), an alignment of volcanic massifs trending north-south from the island of Pagalu to lake Tchad, consisting of a hosts and grabens and is an example of intraplate volcanism as discussed in [6] [7] [8] [9]. The CVL is a "Y" shape long chain of Tertiary to Recent Volcanic complexes with a general NE-SW orientation and spreads from the South Atlantic into the interior of Africa. Amongst the 60 volcanic craters that litter the CVL, Mount Cameroon is the most active. The CVL extends more than 900 km across Cameroon from Bui and Adamawa plateau in the north of mount Cameroon and Equatorial Guinea [10], it then continues for another 700 km through the Atlantic island of Principe, Sao Tome and Palagu [11]. The CVL was initiated by an upwelling mantle plume since the onset of the continental breakup in the early cretaceous. It generally consists of basalts to rhyolite nephelinites, phenolites and trachytes with volcanic rocks found within the volcanoes [8]. The continental

volcanoes are Mount Fako, Rumpi hills, Manengouba, Bambuotus, Oku and the volcanic rocks of Kapsiki plateau and the Benue valley [12]. The oceanic part is made up of Annabon, Sao-Tome, Bioko and Principi [13]. The continental sector of the CVL seems to follow old suture zones between two seismically and paleomagnetically distinct lithospheric blocks [14] [15]. The major rock formations in Bakassi Peninsular onshore around Ekondo-Titi and environs are; gneiss, meta-sediments (Cretaceous; Tertiary sediments) and Recent volcanics as in **Figure 2**.

The Cretaceous-Tertiary sediments vary according to the environment of deposition and are essentially clastic, consisting of sands, sandstone, and conglomerates with subsidiary clays, shales, marls and lignites outcropping beyond the southern catchments' limits with a thickness of about 68 meters. The Tertiary-Quaternary basaltic lavas associated with the Cameroon Volcanic Line, as part of the major Fouban shear zone, intruded the sediments during the Miocene [16]. This magmatic activity resulted in extensive lava flows that formed the Rumpi hills in the north and intruded the sediments in the south. These extrusive events lapsed for sufficient time allowing a substantial layer of ash and basaltic lava flows to become interbedded with the extensive alluvium, deltaic and lacustrine deposits and in the study area columnar basalts are common intrusive. Recent alluvium is being deposited along the present coastline and margins of the delta of the Meme, Malange and Ndian rivers.

1.5. Hydrogeology

The aquifer(s) in this area are heterogeneous intercalation of fluvio-deltaic and marines conglomerates, sands, sandy clays, lateritic silts, silty clays, clayey sands, shales, marl lenses and the fractured recent volcanics which constitute good aquifers in most areas around Ekondo-Titi, Mbonge, Bongongo, Illor and Lobe Town.

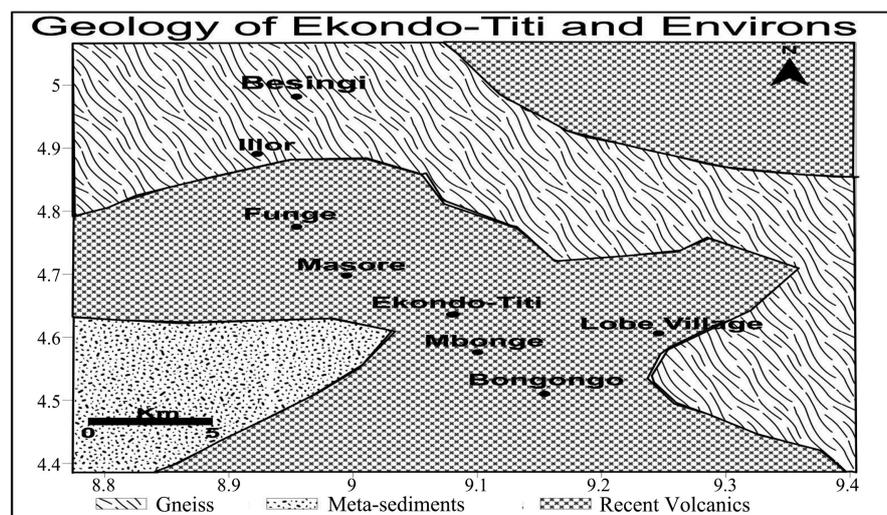


Figure 2. Geologic map of Ekondo-Titi and environs made up of four rock types; gneiss, metasediments, recent volcanism and granites.

2. Materials and Methods

2.1. Sample Collection, Pre-Treatment and Chemical Analysis

Thirty-seven samples were collected from pre-selected wells, boreholes and springs. Site selection was based on spatial distribution of the wells, boreholes, springs and population. At each site, groundwater temperature, electrical conductivity, total dissolve solids and pH value were measured in situ, using portable field pH, EC and TDS meters as shown in **Table 1**.

Prior to sampling, the pre-cleaned sample bottles were rinsed with the sample water. The well water was withdrawn with the use of a 50 ml syringe, and then filtered through the 0.2 μm mixed cellulose ester filter into 50 ml high-density polyethylene HDPE containers. The sample was preserved by acidifying to $\text{pH} < 2$ by adding nitric acid and sealed using a permanent tape. The samples were labelled and put into the sample bottle collection bag. The filtered groundwater samples were later shipped to the Activation laboratory in Canada for trace metal analysis by Inductive Coupled Plasma Mass Spectrometer ICP-MS.

2.2. Hazard Identification

Involves the identification of the chemical of concern and documenting its toxic effects on human beings after field mapping. It also involves the characterization of potential contaminants and their relative mobilities [17] as shown in **Table 2**.

Table 1. Field Equipment, Softwares, their specifications and functions used in the study.

Equipment/Softwares	Specifications	Functions
Bike	Commercial Bikes (Bensikin)	To transport fieldworkers to wells
GPS	GARMIN GPSMAP 60csx	To measure longitude, latitude and elevation of wells
EC Meter	Hanna Hi 98304/Hi98303	To measure Electrical Conductivity of water.
pH Meter	Hanna Hi 98127/Hi98107	To measure pH of water.
Measuring Tape	Weighted Measuring Tape	Measurement of well diameter and depth.
Digital Thermometer	Extech 39240 (-50°C To 200°C)	To measure water temperature
Total Dissolved Solid	Hanna HI 96301	To measure Total dissolved solids
Water sampler	Gallenkampf 500 ml	To collect water sample from well
Syringe	50 ML, 100 ML Polystyrene	Acidification and filtration of sample
Nitric acid	98% Pure Nitric Acid	Sample preservation by acidifying to $\text{pH} < 2$
Filter	Cellulose Ester Filter 0.2 μm	Filtration of sample
Sample bottles	Polyethylene (HDPE) 50 ml	To hold sample for onward transmission to laboratory
Sealing Tape and marker	Permanent Tape and marker	Sealing of sample bottle and labeling for transmission to the laboratory
IBM SPSS Statistics	Version 24.0	Statistical analysis for PCA
Global Mapper	Version 11	GIS Geolocation of wells
Surfer Golden Software	Version 12	GIS plotting contours for spatial distribution

Table 2. Trace metals and their effects [3].

Component	Toxicity effects
Zn	Zinc suppresses copper and iron intake causing peripheral neuropathy.
Co	Active in vitamin B12 and in chemical reactions. Excess causes hearth failures.
Cu	Excess leads to acute gastrointestinal problems
Cr	Excess may result in renal failures. Excess of Cr ⁺⁶ is carcinogenic.
Mn	Manganese toxicity result in neurological disorder; manganism, with symptoms of tremors
Cd	Cadmium compounds are known human carcinogens.
V	Vanadium causes albumin in urine
Ni	Nickel is carcinogenic and causes neurological deficits
As	Arsenic causes cancer of the skin, lungs, liver and bladder.
Sb	Antimony causes gastrointestinal problems, kidney damage or liver damage
Al	Aluminium causes neurotoxicity.
Pb	Lead is a carcinogen affecting every organ and system in the body.

2.3. Exposure Assessment

This is the process of measuring or estimating the intensity, frequency and duration of human exposures to an environmental agent [17]. The main exposure pathway taken into consideration in this study was intake of the metals through water consumption. The daily environmental exposures to metals were assessed for carcinogenic and non-carcinogenic elements.

The intakes of metals through ingestion of groundwater were calculated using Equation (1) [18].

$$ADD = \frac{C \cdot IR \cdot ED \cdot EF}{BW \cdot AT \cdot 360} \quad (1)$$

where;

ADDs are Exposure duration (mg/kg-day)-The Average Daily Dose (ADD) of the contaminant through water pathway indicates the quantity of chemical substance ingested per kilogram of body weight per day.

C is Concentration of contaminant in the environmental media (e.g., µg/L, mg/L).

IR is Ingestion rate per unit time (e.g., mg/day or L/day).

EF is Exposure frequency (day/year).

ED is Exposure duration (years).

BW is Body weight of receptor (kg).

AT is Averaging time = life expectancy (years) 365 is the conversion factor from years to days.

For non-carcinogenic effects, AT = ED in days, carcinogenic effect, AT = 70 years or 25,550 days.

2.4. Dose-Response/Toxicity Assessment

This is the quantitative relationship that indicates the contaminants degree of toxicity to exposed species. It also involves the identification of the toxicity criteria used to evaluate human health risk associated with the chemical of concern in the study area. The amount of chemical that can affect human health is estimated. The Reference Dose RfD is used for non-carcinogen risk.

2.5. Risk Characterization

This is the final phase of the risk assessment process. In this phase, cumulative exposure and dose-response assessments are integrated to yield probabilities of effects occurring in human beings under specific exposure conditions and time scales. Also incorporated is information from hazard identification, exposure assessment, toxicity assessment and risk estimation to evaluate the potential risk to residents.

2.6. Carcinogenic Risk Assessment

Carcinogenic risks were determined by calculating the potential of an individual to develop cancer as a result of cumulative exposure to each potential carcinogen over a lifetime. For carcinogen, identified by a weight-of-evidence classification of the chemical [19]. The estimated daily dose and the cancer slope factor are multiplied together to find the lifetime cancer risk posed by the chemical. Cancer slope factors are estimates of carcinogenic potency and were used to relate estimated daily dose of the trace metal over a lifetime exposure to the lifetime probability of excess tumors Equation (2) [19] [20] [21].

$$CR = ADD \cdot SF \quad (2)$$

CR is the excess probability of developing cancer over a lifetime as a result of exposure to a contaminant or carcinogenic risk. It is unit less, SF is the slope factor of the contaminant [mg/kg/d]⁻¹.

2.7. Non Carcinogenic Risk Assessment

Non-carcinogenic hazards are characterized by the hazard quotient (*HQ*). *HQ* is a unitless number that is expressed as the probability of an individual suffering an adverse effect. To estimate noncarcinogenic risk, the hazard quotient (*HQ*) was calculated using Equation (3) [22].

$$HQ = \frac{ADD}{RfD} \quad (3)$$

RfD is the reference dose mg/kg/d. It represents a toxicity index of a daily exposure to the population in comparison to a safe level of exposure orally over a lifetime [23].

2.8. Harzard Index (HI)

It is the toxic risks due to all the potentially hazardous substances present in the

same media simultaneously [24]. Since more than one toxicant is evaluated, the interactions of all the toxicants were considered and assumed to be cumulative. Thus, the *HI* was calculated by summing all the *HQ* for all toxicants, Equation (4) [22].

$$HI = \sum_{i=1}^n HQ_i \quad (4)$$

2.9. Pollution Risk Evaluation Indices

Generally, pollution indices are estimated for a specific use of the water under consideration. The trace metal degree of contamination (DC), enrichment factor (EF), ecological risk index (Er), potential ecological risk index (RI), pollution load index (PLI) and geo-accumulation index (*I*_{geo}) were used to evaluate the pollution potential of Ekondo-Titi and environs as in **Table 3**.

3. Results and Discussion

Physicochemical Parameters

The physicochemical parameters of groundwater in Ekondo-Titi and environs: temperature, pH, EC and TDS were measured in-situ for 184 wells and springs and summarized in **Table 4**.

3.1. Water Level Fluctuations

Depth-to static water level (m) of groundwater ranged from: 0.7 - 3 as in **Figure 3**. Areas with shallow depths to static water levels such as Besingi, Masore and Ekondo Titi are susceptible to pollution if the wells are not appropriately constructed and protected whereas areas with deep water levels could be more protected from pollution since run-off does not enter into the well during rainy season if well constructed.

3.2. Groundwater Flow Direction

Groundwater flows towards the Southern and Northwestern part of the study area which could probably be a recharge zone. This recharge zone is at Mbonge and Besingi as in **Figure 4**.

Table 3. Formulae for calculation of pollution indices.

SN	Trace element pollution indices	Formulae	Reference
1	Degree of Contamination	$DC = \sum_{i=1}^n C_f^i$	[25]
2	Enrichment factor	$ER = \frac{(C_i/C_{ie})_{\text{sample}}}{(C_i/C_{ie})_{\text{background}}}$	[26]
3	Ecological risk factor	$E_r^i = T_r^i \times C_f^i$	[27]
4	Ecological risk index	$RI_i = \sum_{i=1}^n E_r^i$	[27]
5	pollution load index	$PLI = \sqrt[n]{C_{f1} \times C_{f2} \cdots C_{fn}}$	[28]
6	Geo-accumulation index	$I_{geo} = \log_2 \left[\frac{C_i}{(1.5C_{ni})} \right]$	[29]

Table 4. Field determined physicochemical parameters; electrical conductivity (EC), pH, total dissolved solids (TDS) and temperature of groundwater in study area.

Parameter	Min	Max	Mean
T (°C)	26.1	30.2	28
PH	4.2	7.6	5.703
EC (mS/cm)	2	32	11.26
TDS (mg/L)	1.34	21.44	7.544

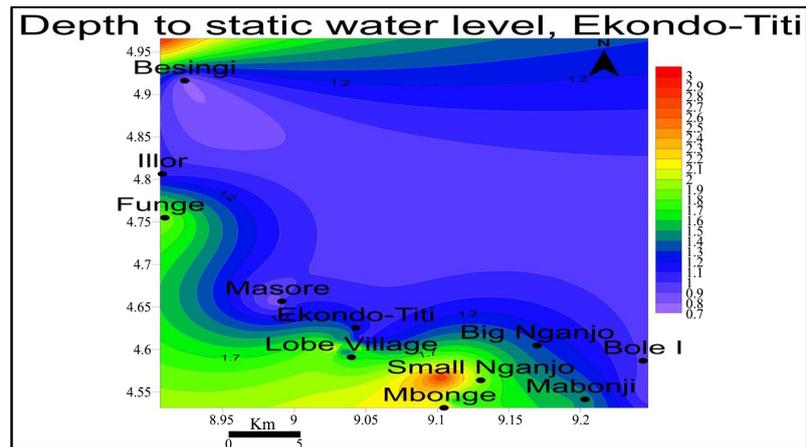


Figure 3. Depth to static water level; high values are at Mundemba and Funge whereas low values are at Besingi, Masore and Ekondo Titi.

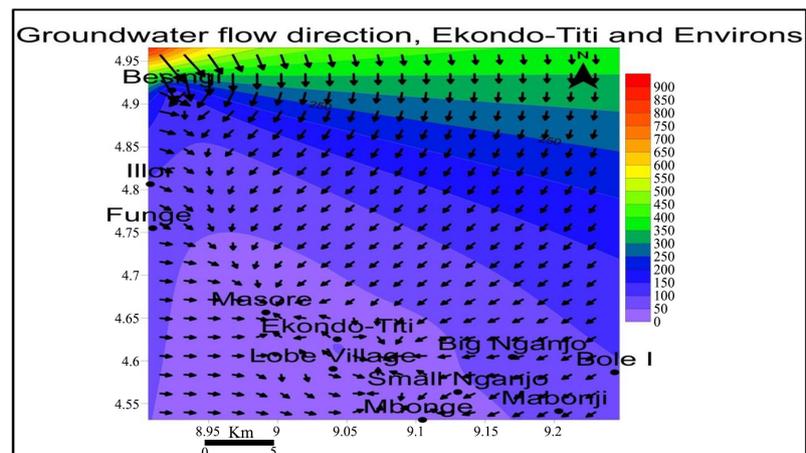


Figure 4. Groundwater flow direction in study area indicating that water flows towards the Southeastern part of Ekondo-Titi and environs.

3.3. Temperature

Temperature values of groundwater ranged from: 26.1°C - 28.9°C as in **Figure 5**. The temperature variation is similar in the different areas, suggesting a single aquifer since groundwater in the same aquifer have similar temperature. This is also indicative of a phreatic aquifer as the temperatures are close to air temperatures.

3.4. pH

The pH value of most of the groundwater samples in the study area ranged from 4.2 - 7.6 as in **Figure 6**. The values of pH of a water sample are recognized as an index of classifying groundwater as acidic < 5.5, slightly acidic 5.5 - 6.5, neutral 6.5 - 7.5, slightly alkaline 7.5 - 8, moderately alkaline 8 - 9 and alkaline > 9. This clearly shows that the groundwater in the study area is acidic to slightly alkaline.

3.5. Electrical Conductivity

The EC ranged from 2 - 30 mS/m as in **Figure 7**. The low electrical conductivity is due to less solute concentration in the groundwater probably due to short contact time with the rocks or occurrence of non-soluble host rocks at the P-T conditions.

3.6. Total Dissolved Solids

The total dissolved solids ranged from 0.80 - 6.2 mg/L as in **Figure 8**. These TDS values are <500 mg/L thus indicating that the groundwater in Ekondo-Titi and environs is fresh.

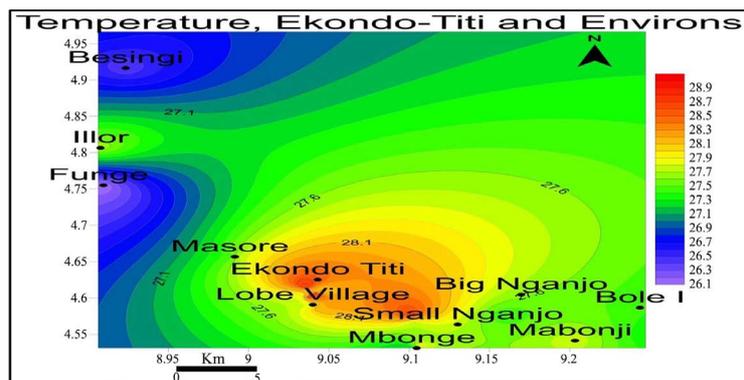


Figure 5. Spatial variation of groundwater temperatures; Temperatures are generally higher at, Illor, Masore, Big Nganjo, Mabonji, Mbonge, Small Nganjo and Ekondo Titi while low values are at Besingi and Funge.

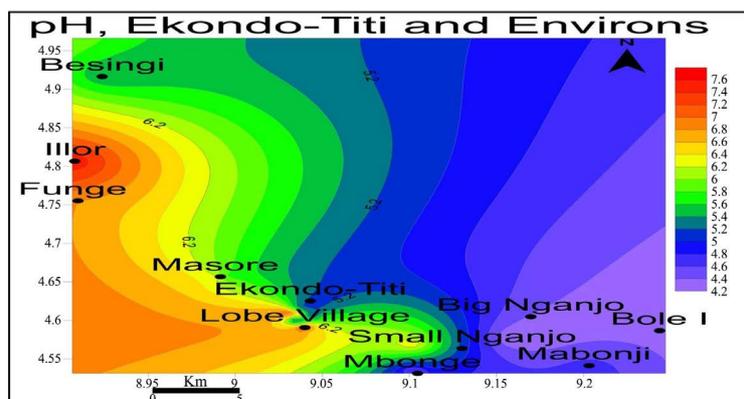


Figure 6. Spatial variation of pH; High pH values are at Ekondo Titi, Illor, Lobe village, Masore and Funge while low values are at Besingi and Big Small Nganjo, Mabongi and Bole I.

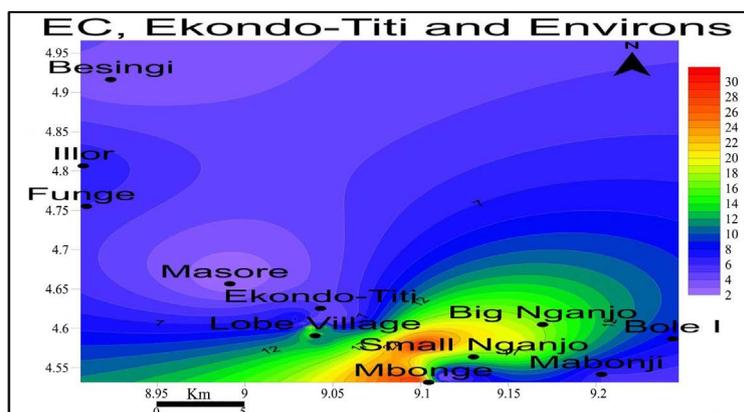


Figure 7. Spatial variation of Electrical Conductivities (mS/m); EC is at maximum at Mbonge, Big Nganjo and Small Nganjo Illor and Ekondo whereas Titi low values are at Funge, Masore and Besingi.

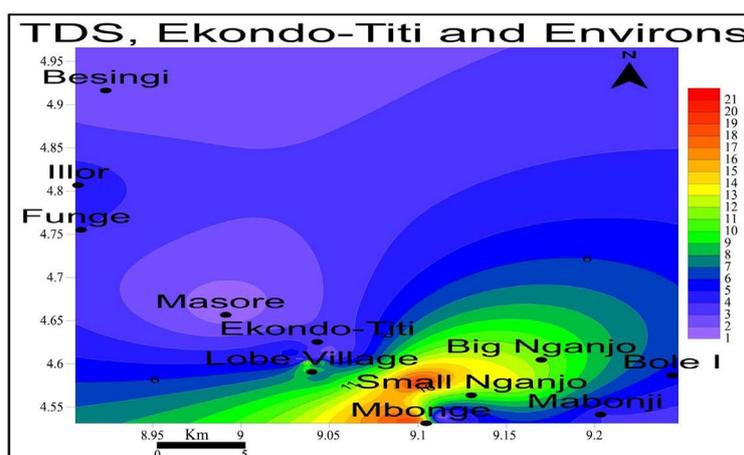


Figure 8. Spatial variation of total dissolved solids mg/L; TDS is at maximum at Mbonge, Big Nganjo and Small Nganjo Illor and Ekondo whereas Titi low values are at Funge, Masore and Besingi.

The results for twelve samples of trace metal analysis ICP-MS are presented in **Table 5**. The concentrations of fourteen trace metals; Zn, Pb, Co, Cu, Cr, Mn, Sr, Cd, V, Fe, Ni, As, Li, Ba, Mn, and Pb were evaluated. The concentrations of these trace metals are below the [30] allowable limit. However, the cumulative effects of long term consumption of these trace metals in the groundwater necessitated a health hazard and pollution evaluation risk assessment since [31] reported the occurrence of Arsenic in groundwater in this area.

3.7. Pearson's Correlation Analysis (PCA) between Trace Metals and Physico-Chemical Parameters

Correlation between trace metals in groundwater within the study area was carried out using Pearson's correlation analysis (PCA) as shown in **Table 6** to establish the relationships that exist between the variables; trace metals and the physico-chemical parameters. r values > 0.5 or < -0.5 are significant, 0.72 strong (moderate) and 0.80 Very strong correlation.

Table 5. Trace metal concentration ($\mu\text{g/L}$) and basic statistics of groundwater in Ekondo-Titi and environs.

SN	Location	Li	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Sr	Cd	Ba	Pb
1	Mundemba	0.69	0.19	0.63	16.15	59.53	0.94	3.30	4.20	24.73	0.06	11.09	0.13	10.81	1.74
2	Besingi	0.96	0.19	0.40	110.79	792.62	3.91	3.86	15.95	20.32	0.90	19.35	0.10	25.47	1.13
3	Illor	0.11	0.28	0.21	5.32	74.09	1.62	0.97	4.99	5.18	0.40	31.25	0.03	4.39	0.83
4	Funge	0.23	0.27	0.85	15.83	197.47	1.48	2.97	5.21	8.27	0.31	30.91	0.05	17.89	1.03
5	Masore B 1	0.19	0.06	0.20	13.11	28.76	0.64	1.65	2.22	6.54	0.21	12.42	0.06	10.27	0.85
6	Masore B 2	0.21	0.09	0.29	17.15	54.56	1.17	3.08	6.23	37.65	0.15	11.22	0.19	25.00	1.28
7	Ekondo Titi1	0.52	0.09	0.20	44.30	33.74	2.58	3.53	3.07	14.46	0.36	55.90	0.06	47.44	0.56
8	Ekondo Titi2	0.47	0.20	0.41	82.07	2488.43	4.08	6.10	4.71	14.75	0.26	56.83	0.07	54.18	0.76
9	Ekondo Titi3	0.44	0.10	0.15	65.04	122.44	2.08	67.41	18.07	5.99	0.24	57.87	0.04	93.02	0.55
10	Ekondo Titi4	0.31	0.27	0.18	21.40	76.92	1.18	1.64	1.38	2.95	0.25	60.55	0.02	72.08	0.64
11	Ekondo Titi5	0.77	0.08	0.15	21.43	38.84	0.51	1.80	2.82	9.10	0.04	11.36	0.05	25.12	0.76
12	Ekondo Titi6	0.73	0.20	0.32	23.05	128.33	0.82	2.07	5.31	57.32	0.08	13.87	1.61	44.29	1.31
13	Ekondo Titi7	2.27	0.35	0.76	125.79	211.01	4.00	11.22	12.12	84.55	0.23	63.22	0.25	159.60	3.47
14	Ekondo Titi8	1.22	0.58	0.91	24.61	319.55	1.49	12.55	22.95	632.25	0.12	23.34	0.39	46.92	6.03
15	Ekondo Titi9	0.60	0.13	0.20	13.81	69.10	0.84	2.16	2.51	37.94	0.05	9.55	0.11	42.84	0.98
16	Ekondo Titi10	2.18	0.04	0.16	125.33	19.91	2.90	5.28	2.32	15.95	0.25	32.11	0.05	93.26	0.75
17	Ekondo Titi11	2.17	0.57	1.05	89.46	236.31	2.96	7.46	12.18	96.82	0.15	27.14	0.27	84.76	4.15
18	Ekondo Titi12	0.45	0.22	0.24	38.71	57.55	1.42	2.31	3.22	24.37	0.11	22.21	0.06	42.29	0.92
19	Ekondo Titi13	0.40	0.15	0.21	96.57	56.85	1.84	3.13	1.84	7.00	0.18	80.48	0.07	65.87	0.80
20	Ekondo Titi14	0.79	0.12	0.32	50.12	107.89	2.92	6.74	5.19	37.84	0.08	23.49	0.11	52.79	1.51
21	Ekondo Titi15	1.09	0.24	1.03	85.41	157.39	6.61	15.85	14.02	112.87	0.22	48.73	0.20	179.80	3.55
22	Ekondo Titi16	0.39	0.33	1.26	10.14	78.46	0.65	2.77	4.99	5.01	0.03	25.90	0.03	20.61	0.92
23	Ekondo Titi17	0.40	0.49	0.74	8.89	65.82	0.56	2.80	4.75	21.11	0.05	33.27	0.10	17.50	1.14
24	Ekondo Titi18	0.29	0.13	0.23	29.47	27.79	0.93	2.67	3.36	8.44	0.03	28.39	0.06	19.79	0.87
25	Ekondo Titi19	0.85	0.08	0.14	68.34	42.38	5.12	7.81	2.58	9.03	0.15	49.46	0.06	114.65	1.01
26	Lobe Village1	1.46	0.08	0.14	118.79	55.74	0.96	1.93	1.22	4.21	0.03	58.86	0.02	22.72	0.65
27	Lobe Village2	1.20	0.27	0.49	177.43	336.68	2.07	6.11	8.62	81.63	0.14	122.04	0.17	35.76	3.47
28	Lobe Village3	0.26	0.23	0.19	9.51	1823.32	0.21	1.07	1.59	62.45	0.14	2.37	0.03	11.03	0.56
29	Bongongo	3.39	0.08	0.31	538.22	69.97	17.83	28.77	6.29	34.31	0.22	75.16	0.14	340.35	1.07
30	Mbonge 1	3.64	0.42	0.41	62.49	133.17	1.84	4.01	1.90	5.22	0.40	62.18	0.04	126.05	0.55
31	Mbonge 2	2.64	0.13	0.21	142.99	212.79	5.40	7.56	3.61	26.28	0.51	56.72	0.11	261.69	0.79
32	Mbonge3	5.76	0.31	0.75	142.53	456.34	8.07	12.41	5.92	45.26	0.39	62.08	0.13	278.74	2.18
33	Mbonge 4	5.38	0.08	0.30	94.03	186.96	1.95	3.60	1.62	9.97	0.13	49.37	0.03	122.45	0.76
34	Small Nganjo	0.80	0.28	0.48	25.25	416.02	1.17	3.72	5.28	77.83	0.07	8.50	0.12	22.12	2.76
35	Big Nganjo	4.66	0.34	0.73	35.56	466.04	3.00	4.63	3.60	29.29	0.68	200.56	0.08	162.47	1.04
36	Mabonji	1.39	0.12	0.37	52.87	173.96	2.50	15.00	2.42	31.17	0.07	12.60	0.06	51.81	1.37
37	Bole I	1.65	0.12	0.87	34.13	157.72	3.94	13.33	2.32	18.42	0.05	21.46	0.03	107.19	0.70
Min		0.11	0.04	0.14	5.32	19.91	0.21	0.97	1.22	2.95	0.03	2.37	0.02	4.39	0.55
Max		5.76	0.58	1.26	538.22	2488.43	17.83	67.41	22.95	632.25	0.90	200.56	1.61	340.35	6.03
Mean		1.38	0.21	0.45	71.25	271.20	2.76	7.66	5.69	46.66	0.21	42.48	0.14	78.73	1.44

The trace metal with the highest concentration is FE with a maximum value of 2488.43 $\mu\text{g/L}$ measured at Ekondo Titi 2.

Table 6. Correlation matrix of *r* values for trace metals and physico-chemical parameters in Ekondo-Titi and environs.

	Li	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Sr	Cd	Ba	Pb	Temp	pH	EC	TDS
Li	1																	
V	0.12	1																
Cr	0.18	0.68	1															
Mn	0.44	-0.18	-0.08	1														
Fe	-0.03	0.11	0.01	-0.02	1													
Co	0.47	-0.13	0.08	0.89	0.03	1												
Ni	0.09	-0.11	0.002	0.35	-0.06	0.39	1											
Cu	-0.04	0.45	0.42	0.12	0.05	0.15	0.52	1										
Zn	0.01	0.53	0.36	-0.04	0.05	-0.01	0.08	0.66	1									
As	0.33	0.09	-0.02	0.16	0.21	0.26	0.03	0.21	-0.1	1								
Sr	0.49	0.13	0.08	0.34	0.03	0.28	0.14	-0.003	-0.08	0.44	1							
Cd	-0.04	0.15	0.08	-0.03	-0.06	-0.04	-0.05	0.21	0.25	-0.12	-0.12	1						
Ba	0.73	-0.03	0.12	0.72	-0.06	0.85	0.38	0.08	-0.01	0.32	0.45	-0.01	1					
Pb	0.09	0.63	0.58	0.06	-0.02	0.08	0.07	0.71	0.79	-0.12	0.01	0.26	0.08	1				
Temp	-0.04	-0.11	-0.19	0.15	-0.05	0.07	0.19	0.03	0.06	-0.43	-0.06	0.09	0.09	0.08	1			
pH	-0.47	0.06	-0.18	-0.001	-0.04	-0.21	-0.08	-0.06	-0.16	-0.09	-0.04	-0.08	-0.44	-0.17	-0.05	1		
EC	0.55	-0.03	-0.08	0.65	-0.03	0.64	0.39	0.01	-0.11	0.34	0.63	-0.19	0.82	-0.05	0.16	-0.14	1	
TDS	0.55	-0.03	-0.08	0.65	-0.03	0.64	0.39	0.01	-0.11	0.34	0.63	-0.19	0.82	-0.05	0.16	-0.14	1	1

In **Table 6**, PCA matrix shows a very strong positive correlation between Cr/V, Ba/Li, Ba/Mn, Pb/Ni, Pb/Zn Cu/Zn and a moderately strong positive correlation between Co/Mn, Ba/Co, Ba/EC and Ba/TDS. A high correlation coefficient (nearly 1 or -1) means a good relationship between two variables, and a correlation coefficient around zero means no relationship. Positive values indicate a positive relationship while negative values of *r* indicate an inverse relationship [23].

3.8. Hierarchical Cluster Analysis (HCA)

The R-mode Hierarchical Cluster Analysis HCA performed on the groundwater samples produced two clusters based on spatial similarities and dissimilarities: Cluster one; (01) element Fe; soluble. Cluster two (13) non soluble elements divided into two classes; class one (09) V, As, Cd, Cr, Li, Pb, Co, Ni, Cu; less enriched. Class two (04) Mn, Ba, Sr and Zn; enriched **Figure 9**.

3.9. Health Hazard Assessment

Human health hazard assessment was done to estimate the intensity, frequency, and duration of human exposures to the trace metals. Exposure assessment was carried out by measuring the average daily dose ADD of the trace metals selected as in **Table 7**. Carcinogenic and non carcinogenic risk were calculated from the ADD.

Table 7. Parameters used for estimating exposure assessment [19].

Factor/parameter	Symbol	Units	Residential
Exposure duration	ED	Years	30
Exposure frequency	EF	Days in year	350
Average time	AT	Years	76.5
Body weight	BW	Kg	70
Ingestion rate	IR	L/day	2.2
Contaminant concentration	C	ug/L	Table 5

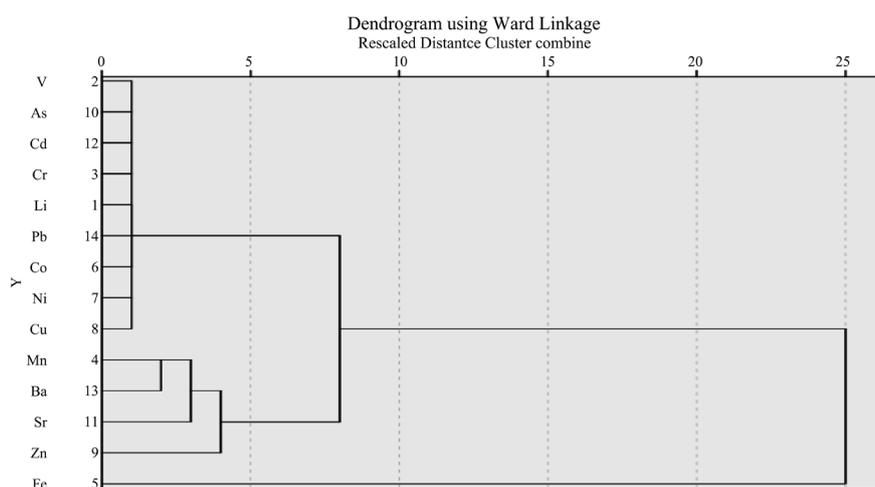


Figure 9. Dendrogram of trace metals in groundwater of Ekondo-Titi and environs made up of two clusters: Cluster one; (01) element Fe; soluble. Cluster two (13) non soluble elements divided into two classes; class one (09) V, As, Cd, Cr, Li, Pb, Co, Ni, C; less enriched. Class two (04) Mn, Ba, Sr and Zn; enriched.

3.9.1. Average Daily Dose

ADD values ranged as follows; (Li) 3×10^{-6} to 2×10^{-4} , (V) 1.1×10^{-6} to 1.8×10^{-5} , (Cr) 4.3×10^{-6} to 4×10^{-5} , (Mn) 2×10^{-4} to 1.7×10^{-2} , (Fe) 6×10^{-4} to 7.8×10^{-2} , (Co) 7×10^{-6} to 6×10^{-4} , (Ni) 3×10^{-5} to 2.1×10^{-3} , (Cu) 4×10^{-5} to 7×10^{-4} , (Zn) 9×10^{-5} to 0.02, (As) 1×10^{-6} to 3×10^{-5} , (Sr) 7×10^{-5} to 6×10^{-3} , (Cd) 5×10^{-7} to 5×10^{-5} , (Ba) 1×10^{-4} to 0.01, (Pb) 2×10^{-5} to 2×10^{-4} all values are below toxic levels as in **Figure 10**.

3.9.2. Hazard Quotient

HQ values ranged as follow; (V) 5.7×10^{-4} to 9.1×10^{-3} , (Cu) 9.5×10^{-4} to 1.8×10^{-2} , (Pb) 4.8×10^{-3} to 5.4×10^{-2} , (Zn) 3×10^{-4} to 6.6×10^{-2} , (Fe) 8.9×10^{-4} to 0.11, (Mn) 1.1×10^{-2} to 1.2 as in **Figure 11**. Mn is the only trace metal with HQ value above permissible limit.

3.9.3. Carcinogenic Risk

The carcinogenic elements; As, Cr, Cd and Ni are; (As) 2.1×10^{-5} to 5.8×10^{-4} , (Cd) 4.3×10^{-6} to 4.2×10^{-4} , (Cr) 2.3×10^{-4} to 2.2×10^{-3} , (Ni) 3.6×10^{-4} to 2.5×10^{-3} as in **Figure 12**. All trace metals and below permissible limits thus con-

sumption of the groundwater over time will not pose any health issues to the inhabitants of the study area.

3.9.4. Hazard Index

HI is the cumulative sum of HQ. The values ranged between 0.03 and 1.2 for each of contaminant indicating toxicity associated with Sample 29 with HI values > 1 as in **Figure 13**.

All the groundwater hazard risk indices; ADD, CR, HQ and HI were less than 1 but for sample 29 which had HI value greater 1 thus the water is of significant health risk as shown in **Table 8**.

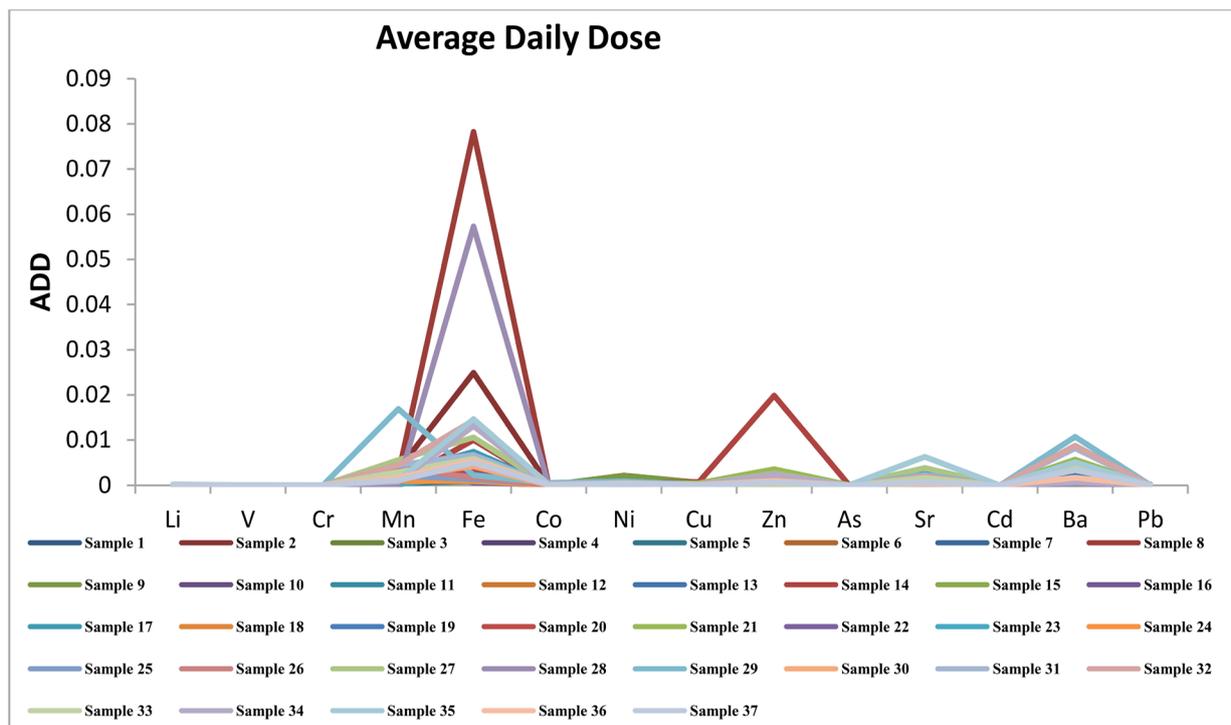


Figure 10. Average Daily Dose (ADD) of trace metals through water intake. All values are below toxic level in Ekondo-Titi and environs.

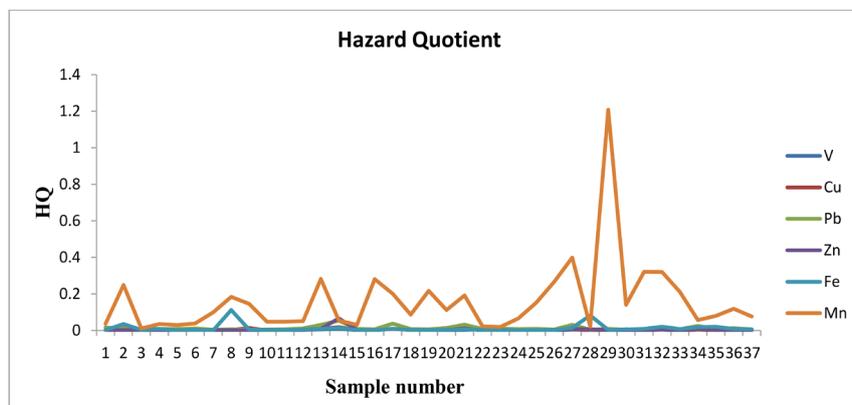


Figure 11. Hazard quotient (HQ) of trace metals through water intake. All values are below toxic levels in Ekondo-Titi and environs.

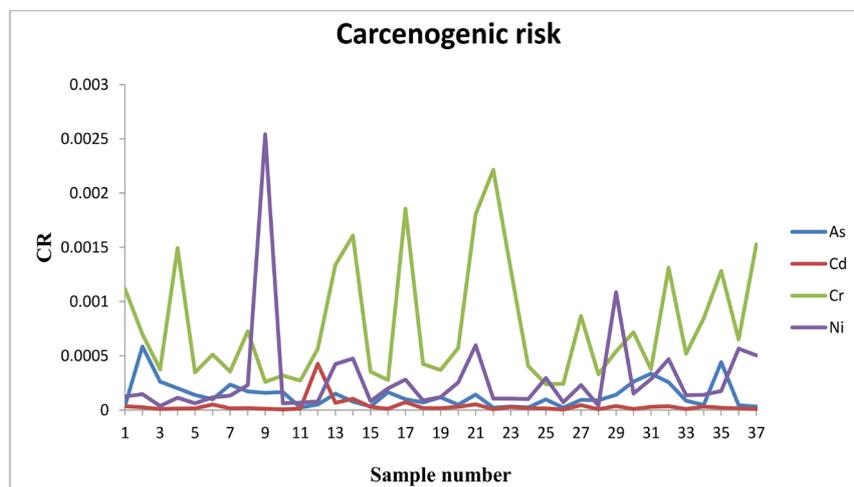


Figure 12. Carcinogenic risk (CR) of each contaminant. All values are below toxic levels in Ekondo-Titi and environs.

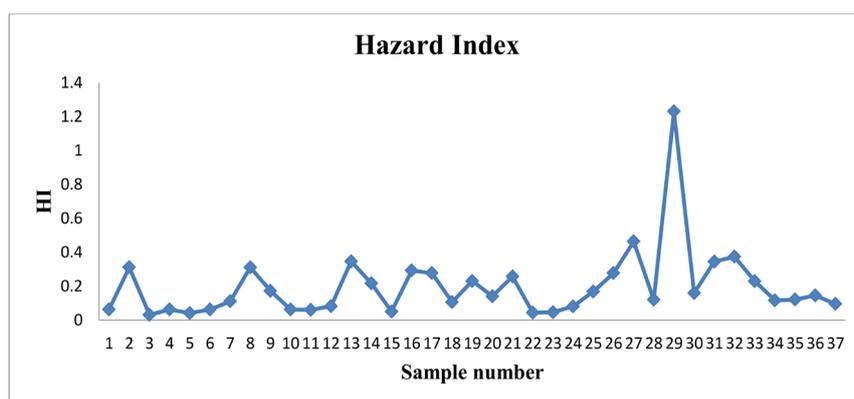


Figure 13. Non carcinogenic toxic risk index or hazard index (HI) of trace metals through water intake in Ekondo-Titi and environs

Table 8. Classification of health hazard assessment carcinogenic and non-carcinogenic risk.

INDEX	Range	Classification	Samples	(%)	Reference
CR	$<10^{-6}$	cause no significant health effects	37	100	[25]
HQ	<1	Acceptable level (no concern)	36	97.3	[32]
	>1	No carcinogenic adverse effects	1	2.7	
HI	<1	Safe	36	97.3	[32]
	>1	Unsafe	1	2.7	

4. Pollution Risk Indices

4.1. Degree of Contamination (DC)

The degree of contamination (DC) was used as reference of estimating the extent of metal pollution (Rubio *et al.*, 2000). The DC values in the groundwater ranged from -13.59 to -5.62 . According to classification [25], all of the samples have low

degree of contamination factor indicating that there is no pollution.

4.2. Enrichment Factor

Enrichment factor is used to infer the most enriched trace metals in the study. EF values < 2 indicate that the metal is entirely from crustal materials or natural processes; whereas EF values > 2 reveal that the sources are more likely to be anthropogenic [33]. The enrichment factors of heavy metals in Mundemba were as shown in **Figure 14**, **Figure 15** and **Table 9**. The sequence of EF in the groundwater was $Ba > Co > Pb > Mn > Ni > Cd > As > Sr > Cr > Zn > Cu > Li > V$. EF values in the study area is between 6.79 to 843.94 which is indicative of significant enrichment and that the source of these metals is from natural and anthropogenic processes. Barium is the most enriched element in the study area; this could be attributed to agricultural wastes.

Table 9. Summary Classification of Ekondo-Titi and environs groundwater based on pollution evaluation indices.

INDEX	Range	Classification	Samples	%
DC	< 10	low degree of contamination factor	37	100
	2 - 5	Moderate enrichment	8	21.6
EF	5 - 20	Significant enrichment	14	37.8
	20 - 40	Very high enrichment	15	40.6
Er	< 40	Low potential risk	37	100
RI	< 150	Low ecological risk	37	100
PLI	< 1	No pollution risk	37	100
	0 - 1	Unpolluted to moderated pollution risk from	Li, V, Cr, Co, As, Cd, Pb	
Igeo	3 - 4	Strong pollution risk from	Ba	
	> 6	Extreme pollution risk from	Mn, Fe, Ni, Cu, Zn, Sr	

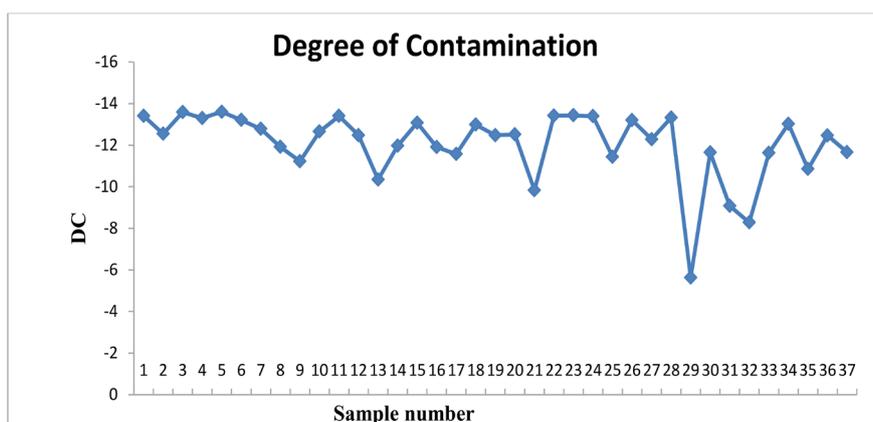


Figure 14. The degree of contamination for trace metals of groundwater in Ekondo-Titi and environs with all samples having low degree of contamination values.

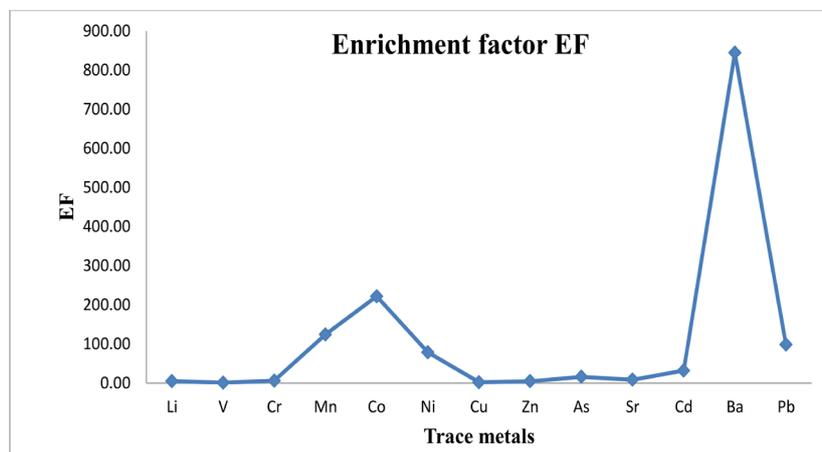


Figure 15. The enrichment factor for trace metal of groundwater in Ekondo-Titi and environs, Barium is the most enriched trace metal.

4.3. Ecological Risk Assessment

Ecological Risk Factor (Er) and Ecological Risk Index (RI)

Er and RI of the trace metals in Ekondo-Titi and environs are given in **Table 9** and **Figure 16** and **Figure 17**. All analyzed trace metals showed low potential ecological risk varying from -29.84 to -0.19 ($Er < 40$). RI of the studied trace metals ranged from -62.07 to -45.53 . It is clear that all the samples show low ecological risk, this indicates low potential pollution.

4.4. Pollution Load Index (PLI)

Pollution load index is a quick tool in order to compare the pollution status of different places [34]. The values of Pollution Load Index are < 1 which is indicative that there is no risk of pollution in Ekondo-Titi and environs **Figure 18**.

4.5. Geo-Accumulation Index

The geo-accumulation index is a quantitative measure of the degree of pollution in groundwater [35]. **Table 10** presents the geo index for the quantification of trace metal accumulation in Ekondo-Titi and environs. Groundwater has no-pollution to moderate pollution risk from Li, V, Cr, Co, Cu, As, Cd and Pb, strong pollution risk from Ba while it is extreme pollution risk from Mn, Ni, Sr, Fe and Zn as shown in **Table 9**.

5. Conclusions

There is no trace metal pollution hazard or pollution risk in Ekondo-Titi and environs since trace metal concentrations are below WHO permissible limits.

The pollution health risk indices are all below the acceptable guideline values.

The enrichment factor showed that the sources of metals are geogenic and anthropogenic processes.

Barium is the most enriched element in the study area; this could be attributed to agricultural fertilizers.

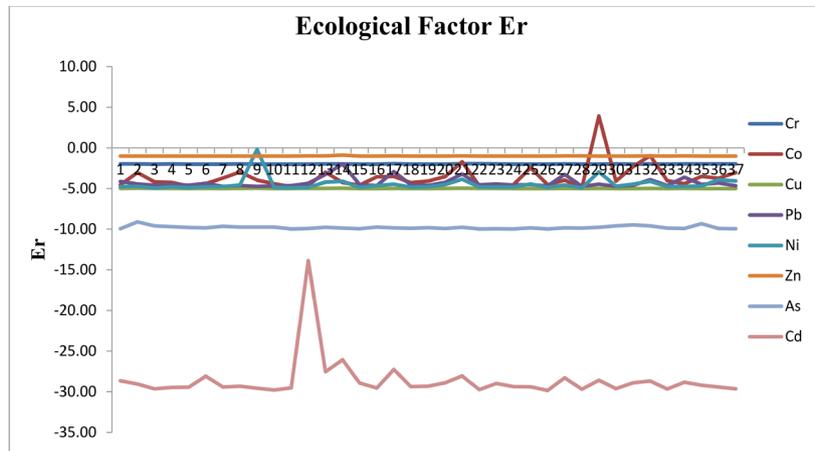


Figure 16. The Ecological risk factor for trace metals of groundwater in Ekondo-Titi and environs.

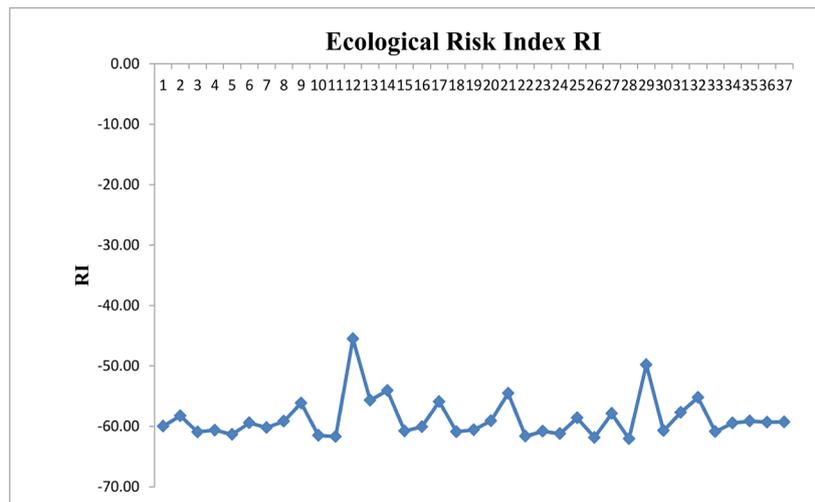


Figure 17. Ecological risk index for trace metal of groundwater in Ekondo-Titi and environs.

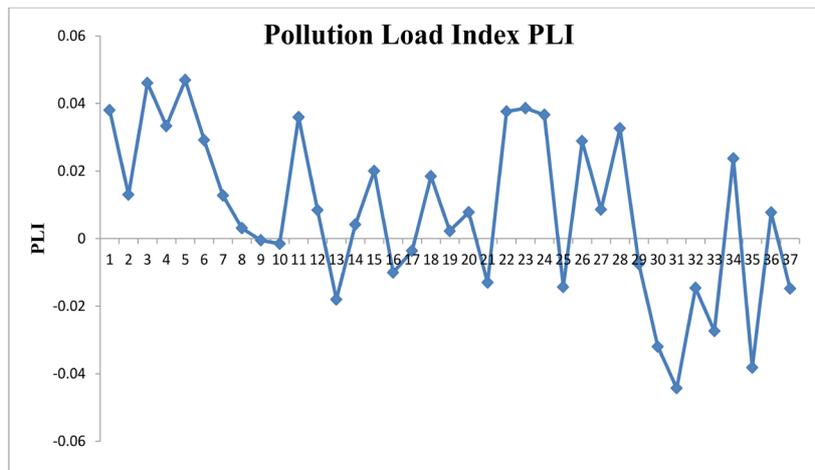


Figure 18. The Pollution load index for trace metal of groundwater in Ekondo-Titi and environs.

Table 10. The Geo-accumulation index (Igeo) of groundwater in Ekondo-Titi and environs.

SN	Li	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Sr	Cd	Ba	Pb
1	0.03	0.008	0.006	1.615	23.81	0.002	0.462	1.68	24.73	1E-04	8.87	8E-05	0.151	0.024
2	0.04	0.008	0.004	11.08	317	0.008	0.54	6.378	20.32	0.002	15.5	6E-05	0.357	0.016
3	0	0.011	0.002	0.532	29.64	0.003	0.135	1.997	5.177	8E-04	25	2E-05	0.061	0.012
4	0.01	0.011	0.008	1.583	78.99	0.003	0.416	2.084	8.268	6E-04	24.7	3E-05	0.251	0.014
5	0.01	0.002	0.002	1.311	11.5	0.001	0.231	0.886	6.541	4E-04	9.93	3E-05	0.144	0.012
6	0.01	0.004	0.003	1.715	21.82	0.002	0.432	2.49	37.65	3E-04	8.97	1E-04	0.35	0.018
7	0.02	0.004	0.002	4.43	13.5	0.005	0.495	1.229	14.46	7E-04	44.7	4E-05	0.664	0.008
8	0.02	0.008	0.004	8.207	995.4	0.008	0.854	1.884	14.75	5E-04	45.5	4E-05	0.758	0.011
9	0.02	0.004	0.001	6.504	48.98	0.004	9.437	7.23	5.986	5E-04	46.3	3E-05	1.302	0.008
10	0.01	0.011	0.002	2.14	30.77	0.002	0.23	0.551	2.95	5E-04	48.4	1E-05	1.009	0.009
11	0.03	0.003	0.002	2.143	15.54	0.001	0.251	1.129	9.103	7E-05	9.09	3E-05	0.352	0.011
12	0.03	0.008	0.003	2.305	51.33	0.002	0.289	2.123	57.32	2E-04	11.1	1E-03	0.62	0.018
13	0.09	0.014	0.008	12.58	84.4	0.008	1.571	4.85	84.55	5E-04	50.6	1E-04	2.234	0.049
14	0.05	0.023	0.009	2.461	127.8	0.003	1.757	9.178	632.2	2E-04	18.7	2E-04	0.657	0.084
15	0.02	0.005	0.002	1.381	27.64	0.002	0.303	1.003	37.94	1E-04	7.64	6E-05	0.6	0.014
16	0.09	0.001	0.002	12.53	7.964	0.006	0.739	0.929	15.95	5E-04	25.7	3E-05	1.306	0.01
17	0.09	0.023	0.011	8.946	94.52	0.006	1.045	4.871	96.82	3E-04	21.7	2E-04	1.187	0.058
18	0.02	0.009	0.002	3.871	23.02	0.003	0.324	1.286	24.37	2E-04	17.8	4E-05	0.592	0.013
19	0.02	0.006	0.002	9.657	22.74	0.004	0.438	0.738	6.998	4E-04	64.4	4E-05	0.922	0.011
20	0.03	0.005	0.003	5.012	43.15	0.006	0.944	2.076	37.84	2E-04	18.8	7E-05	0.739	0.021
21	0.04	0.01	0.01	8.541	62.96	0.013	2.218	5.608	112.9	4E-04	39	1E-04	2.517	0.05
22	0.02	0.013	0.013	1.014	31.38	0.001	0.388	1.994	5.012	6E-05	20.7	2E-05	0.288	0.013
23	0.02	0.019	0.007	0.889	26.33	0.001	0.393	1.898	21.11	9E-05	26.6	6E-05	0.245	0.016
24	0.01	0.005	0.002	2.947	11.12	0.002	0.374	1.345	8.439	7E-05	22.7	4E-05	0.277	0.012
25	0.03	0.003	0.001	6.834	16.95	0.01	1.093	1.034	9.029	3E-04	39.6	4E-05	1.605	0.014
26	0.06	0.003	0.001	11.88	22.3	0.002	0.27	0.488	4.213	6E-05	47.1	1E-05	0.318	0.009
27	0.05	0.011	0.005	17.74	134.7	0.004	0.856	3.447	81.63	3E-04	97.6	1E-04	0.501	0.049
28	0.01	0.009	0.002	0.951	729.3	4E-04	0.15	0.635	62.45	3E-04	1.89	2E-05	0.154	0.008
29	0.14	0.003	0.003	53.82	27.99	0.036	4.028	2.515	34.31	4E-04	60.1	9E-05	4.765	0.015
30	0.15	0.017	0.004	6.249	53.27	0.004	0.562	0.759	5.22	8E-04	49.7	2E-05	1.765	0.008
31	0.11	0.005	0.002	14.3	85.12	0.011	1.059	1.444	26.28	0.001	45.4	7E-05	3.664	0.011
32	0.23	0.013	0.007	14.25	182.5	0.016	1.737	2.368	45.26	8E-04	49.7	8E-05	3.902	0.03
33	0.22	0.003	0.003	9.403	74.79	0.004	0.504	0.648	9.973	3E-04	39.5	2E-05	1.714	0.011
34	0.03	0.011	0.005	2.525	166.4	0.002	0.521	2.113	77.83	1E-04	6.8	7E-05	0.31	0.039
35	0.19	0.013	0.007	3.556	186.4	0.006	0.648	1.439	29.29	0.001	160	5E-05	2.275	0.015
36	0.06	0.005	0.004	5.287	69.58	0.005	2.1	0.967	31.17	1E-04	10.1	3E-05	0.725	0.019
37	0.07	0.005	0.009	3.413	63.09	0.008	1.866	0.929	18.42	9E-05	17.2	2E-05	1.501	0.01
Min	0	0.001	0.001	0.532	7.964	4E-04	0.135	0.488	2.95	6E-05	1.89	1E-05	0.061	0.008
Max	0.23	0.023	0.013	53.82	995.4	0.036	9.437	9.178	632.2	0.002	160	1E-03	4.765	0.084
Mean	0.06	0.009	0.004	7.125	108.5	0.006	1.072	2.276	46.66	4E-04	34	8E-05	1.102	0.02

Groundwater has no-pollution to moderately pollution risk from Li, V, Cr, Co, As, Cd, Pb while groundwater has a strong pollution risk from Ba and extreme pollution risk from Mn, Sr, Fe and Zn, though the concentrations of these trace metals are below WHO guidelines.

From the health hazard indices and pollution risk indices on trace metals, the groundwater in Ekondo-Titi and environs is safe for drinking.

The severity of metal toxicity is governed by several factors, such as dose, nutrition, age, and even life style. Therefore, these low trends that indicate the absence of human health hazards and health risks, the groundwater, might not guarantee the complete and permanent absence of human health hazards and risks due to an increasing level of environmental pollution that might be imposed by the increasing plantation agriculture in this area.

Groundwater sources might become a potential sink of contaminants; this is the reason for recommending a constant monitoring and implementation program in Ekondo-Titi and environs.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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