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Research Paper

Hydrochemical Characterization of Groundwater and Surface Water Sources in parts of Southern Ijaw Local Government Area, Bayelsa State, Nigeria

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This study aims at evaluating the hydro-geological/hydrological conditions to measure the water levels/surface water conditions in Southern Ijaw Local Government Area of Bayelsa State passing through the following communities: Buluo-Orua, Toru-Orua, Kabiama, Amatolo, Okumbiri, Toru-Egeni and Toru- Ebeni. The investigation was carried out to ascertain the hydro-geological/hydrological characteristics in the area. Water levels recorded in the site BH-1(1.0m), BH-2 (0.5m), BH-3 (2.0m), BH-4 (0.5m), BH-5 (1.0m) and BH-6 (2.0m), respectively. The physico-chemical properties of surface water and groundwater in the area measured are within permissible limits, except pH and iron which needs treatment. All the heavy metals, except Co and Fe show values <0.01mg/l. Coliform counts of groundwater in these areas exceed the WHO (2011) guide value of 0cfu/ml and are generally unsafe for drinking. The low value of TSS in the area in site is due to very high static water level (SWL). Coliform counts of groundwater in the areas exceed the WHO (2011) guide value of 0cfu/ml and are generally unsafe for drinking. The groundwater pH should be treated with sodium bicarbonate to reduce the acidity content. Owing to high iron concentration, filtration process should be carried out to remove Iron. It is recommended that a regular monitoring and assessment of groundwater in the area is necessary to ensure that the quality is within regulatory limits.

Keywords: Hydrochemistry, Groundwater, Surface water, Borehole, Bayelsa state

Introduction

The availability of good quality water is vital for life, wellbeing, food and socio-economic development of mankind and it is generally obtained from two principal natural sources: groundwater such as borehole water and water

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well (McMurry and Fay 2004; Mendie 2005; Boateng *et al*., 2016) and surface water such as fresh water lakes, rivers, streams etc. However, poor contaminated water can be threaten to health, more over to the subsistence of the biotic integrity and therefore hinders the ecosystem services and functions of aquatic ecosystems (Howladar *et al.,* 2017). On the other hand, water is necessary and an unavoidable element for domestic and industrial purposes because of its numerous physical and chemical both quantitative and qualitative characteristics.

Surface waters are more vulnerable to pollution due to their easy accessibility for disposal of wastewaters (Bu *et al.,* 2009; Howladar *et al.,* 2014). Prevention and control of the surface water pollution must rely on the reliable information of water quality and identification of pollutant sources (Howladar *et al*., 2017). Hydrochemical investigations to assess the potability of groundwater in many areas of the Niger Delta, especially in Bayelsa State, Nigeria have been done by several water quality researchers (Nwankwoala *et al*., 2013; Nwankwoala *et al.,* 2014; Okiongbo and Douglas, 2014; Oborie & Nwankwoala, 2014; Oki and Akana, 2016). Groundwater qualitydepends on a number of factors, such as geology of the area, degree of chemical weathering of the local rocks, chemistry of recharge water, rock water interactions and other subsurface geochemical processes.

Groundwater moves through pore spaces within rocks and reacts with minerals that make up the rocks in the course of migration (Amadi *et al.,* 2012; Nwankwoala & Udom, 2013; Boateng *et al*., 2016). Groundwater quality in any locality takes after the chemical composition of the aquifer through which it migrates in accordance with the hydrological cycle and flow direction (Amadi *et al.,* 2010). The aim of this study therefore is to evaluate the hydrochemical characteristics, water quality, contamination as well as sources of contamination of ground and surface water in some part Southern Ijaw Local Government Area of Bayelsa State passing through the following communities: Buluo-Orua, Toru-Orua, Kabiama, Amatolo, Okumbiri, Toru-Egeni and Toru- Ebeni. The investigation was carried out to ascertain the hydro-geological/hydrological characteristics as underlying soil conditions in that area. This study will provides geotechnical data to reviews sustainable scenarios with potential considerable cost minimization as quality hydro-geotechnical aspects, for better understanding of importance sustainability in that area. It is against this backdrop this study tends to analyze the water levels/surface water/ hydrogeological conditions and soil characteristics in some part of Southern Ijaw Local Government Area of Bayelsa State.

Study Location and Geology of the Area

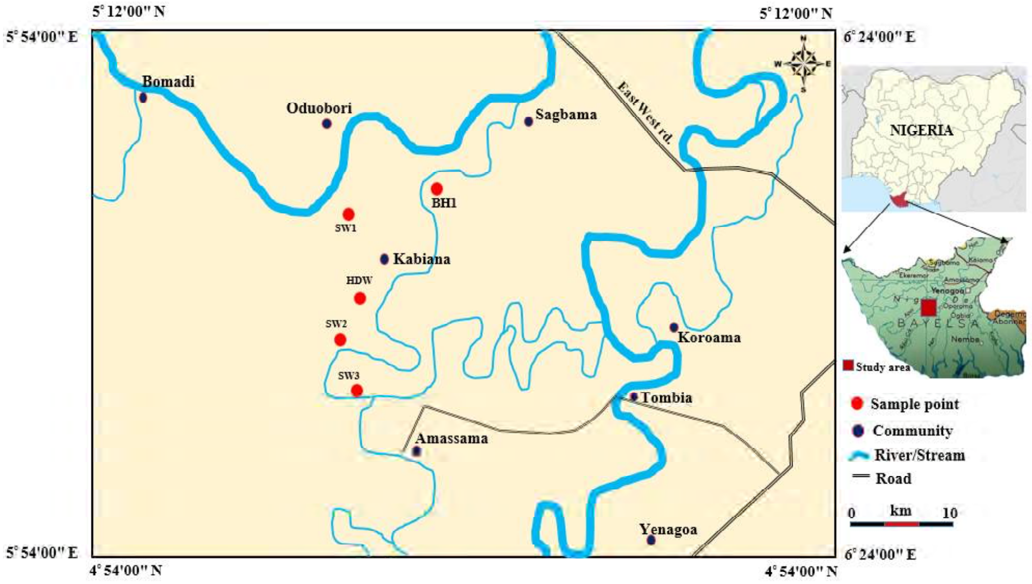
The study area, Southern Ijaw Local Government Area, Bayelsa State, Nigeria lies in the coastal Niger Delta sedimentary basin. The geology of the Niger Delta has been described in details by various authors. The formation of the Delta started during Early Paleocene and resulted mainly from the buildup of fine grained sediments eroded and transported by the River Niger and its tributaries. The Tertiary Niger Delta is a sedimentary structure formed as a complex regressive off-lap sequence of clastic sediments ranging in thickness from 9,000 - I2,000 m (Abam, 1999). Starting as separate depocenters, the Niger Delta has coalesced to form a single united system since Miocene. The Niger Delta is a large and ecologically sensitive region, in which various water species including surface and sub-surface water bodies exist in a state of dynamic equilibrium (Abam, I999). Stratigraphically, the Niger Delta is sub-divided into Benin, Agbada and Akata Formations in order of increasing age.

The Benin Formation is the water bearing zone of the area. It is overlain by Quaternary deposits (40-I50m thick) and generally consists of rapidly alternating sequence of sands and silty clays with the latter becoming increasingly more prominent seawards (Etu-Efeotor and Akpokodje, I990). The clayey intercalations within the Benin formation have given rise to multi-aquifer system in the area (Etu-Efeotor and Akpokodje, I990).

The Benin Formation is the aquiferous layer and all boreholes in the area are drilled into it (Etu-Efeotor and Akpokodje, 1990; Offodile, 2002). Minor intercalations of shale layers give rise to multi-aquifer system, out of which two types have been identified (Etu-Efeotor, 1981). The first aquifer is commonly unconfined while the rest are confined. The first (Holocene age) is more prolific and extends to about 60-90m (unconfined) while the second (Oligocene) is less prolific and underlies the first. Multi-aquifer systems have also been identified from lithologic logs of boreholes from other parts of the Niger Delta by Edet (1993).

The study area has been noted to have poor groundwater quality due to objectionable high concentration of certain groundwater parameters and encroachment of saltwater or brackish water into the freshwater aquifers (Nwankwoala *et al*., 2011) The static water level in the area ranges from 0-2m during the rainy season and I-3m during the dry season (Nwankwoala and Daniel., 2016). The main source of recharge is through direct precipitation where annual rainfall is as high as 3000mm (Amajor and Ofoegbu, I988). The water infiltrates through the highly permeable sands of the Benin Formation to recharge the aquifers (Nwankwoala *et al.,* 2011; Nwankwoala & Udom, 2011). Groundwater in the area occurs principally under water table conditions (Short & Stauble, 1967; Udom and Amah, 2006).

Figure 1: Map Showing Sampling Locations



Methods of Study

Field Investigations and Sample Collection

Field investigation was carried out at the site between July 31st and 1st August, 2018. Boring of 6Nos hole to the depths of 3.5m was carried out using hand auger. Soil sampling as well as groundwater levels in the area was taken and recorded. The location marking/coordinates and position heightening of the boreholes were determined and recorded using a GARMIN Etrex portable global positioning system (GPS) unit. Hydro-geological studies/surface water hydro-chemical study carried out includes:

(i) Measurement of the groundwater levels in the area

(ii) Groundwater/surface water quality and hydro-chemical assessment

Groundwater Sampling

To ensure integrity of samples and that representative samples were collected, the following measures were taken: borehole was sampled from private well. Before a sample is taken, stagnant water is removed by pumping the well for about 30 minutes and water samples were taken directly from the sampling tap at the well head and not along the flow line. The 1.5 litre (minimum) polyethylene plastic bottle used in sample collection was properly rinsed with the water sample before collecting the sample. The samples were properly labeled indicating location, time of sampling, date, sample number, time collected, and borehole depths, where necessary. To minimize sample deterioration, samples were packaged in ice coolers for preservation before transportation to the laboratory for analysis.

Boring

The boreholes were executed with hand auger. The procedure adopted for boring was opening of the ground with the auger by rotating in clockwise direction the T-handle of the auger extension. Additional extension is attached to the auger after advancing 1m down-hole until required depths are achieved.

Representative disturbed samples were taken at regular intervals of 1.0m depth, and also when a change in soil type was observed. More importantly, the depth at which groundwater is encountered is noted and recorded. The samples obtained were used for a detailed and systematic description of the soil in each stratum in terms of its visual and haptic properties and for laboratory analysis. Table 1 is the summary of Field Measurements.

Table1: Summary of Field Measurements

Location/BH No.	Maximum Depth Drilled(m)	Water Table (m)	Coordinates	Elevation (m)
Buluo-Orua BH-1	3	1	N05^{0}06’19.9’’ E006^{0}07’09.3’’	6
Buluo-Orua BH-2	3.5	0.5	N05^{0}05’46.1’’ E006^{0}06’57.0’’	0
Toru-Orua BH-3	3	2	N05^{0}05’80.5’’ E006^{0}04’38.4’’	6
Kabiama BH-4	3	0.5	N05^{0}02’39.86 E006^{0}04’28.26’’	–
Amatolo BH-5	3.5	1	N05^{0}01’43.3’’ E006^{0}03’50.1’’	3
Toru-Ebeni BH-6	3	2	N04^{0}59’35.06’’ E006^{0}04’28.26’’	7

Laboratory Analysis of Water Samples

Analysis of all primary water samples were carried out at an approved laboratory in Port Harcourt (Analytical Concept Limited) complying as much as possible, the recommendations of the World Health Organization (WHO 2008; 2011) standards. Parameters tested for were the physico-chemical properties of the water and occasionally microbiology and the results were compared with the WHO standards for drinking water quality. Certain regularities established for the dissociation of major inorganic constituents in groundwater were also applied to cross-checking the reliability of available data sets. The samples were checked for reliability and accuracy using a combination of methods.

Bacteriological Analysis

The bacteriological analysis was carried out to determine the presence of coliform in the water. The water samples were mixed thoroughly in Petri dish using sterile pipette. 5 x 10 ml Media Culture Agar (MCA) were asceptically inoculated with 10 mls of the water sample. The tubes were incubated at 37^0C for 24 hours and all tubes that showed acid and gas were regarded as presumptive positive. The most probable number (MPN) of coliform organisms present in 100ml of sample was ascertained using Mc Crady's statistical table (Baker and Breach, 1980). The control experiment was distilled water with zero coliform count per 100ml.

Results and Discussion

Groundwater conditions (water table) in the area were encountered in the six (6) boreholes within the depths explored. Table 3 below shows the depths of water table in the area.

Water levels recorded in the site BH-1(1.0m), BH-2 (0.5m), BH-3 (2.0m), BH-4 (0.5m), BH-5 (1.0m) and BH-6 (2.0m), respectively. Generally,

Table 2: Equipment and Analytical Methods used for Physico-chemical Analysis

Parameter	Type of test	Equipment/Analytical Method	Standard
pH	In-situ	Digital pH meter	APHA 4500H*B
Temperature	In-situ	Mercury-in-glass thermometer	
Conductivity	In-situ	Digital conductivity meter	APHA 2510B
Turbidity	Laboratory	HACH2100AN tubidimeter	APHA2130B
Calcium, Magnesium, Potassium, Alkalinity	Laboratory	Direct atomic absorption	ASTMD511-93
Sodium, Hardness	Laboratory	Titration method	ASTM512B
Total Dissolved Solids	Laboratory	Filtration and evaporation	APHA 2510A
Sulphate and Phosphate	Laboratory	Turbidimetric method	ASTMS-516
Chloride	Laboratory	Silver nitrate titration	ASTM512B
Nitrate	Laboratory	Brucine method	APHA 4500*E
Bicarbonate	Laboratory	Colorimetric method	
Heavy metals	Laboratory	Atomic absorption spectrophotometer	APHA 3111B

Table 3: Water Tables in the area

S/No	BH/No	Groundwater Depths (m)
1	BH-1	1.0
2	BH-2	0.5
3	BH-3	2.0
4	BH-4	0.5
5	BH-5	1.0
6	BH-6	2.0

static water level in most parts of the area range from 0 – 1m during the wet season and 1 – 3m during the dry season. Rainfall is the major source of recharge to aquifers in the area.

The water table in the area is affected by climate, rainfall and drainage condition. The study area is characterized by unconfined aquifers which contain a phreatic surface (water table) as an upper boundary that fluctuates in response to recharge and discharge (such as from a pumping well). Unconfined aquifers are generally close to the land surface and, for the most part, constitute shallow groundwater, with continuous layers of materials of high intrinsic permeability extending from the land surface to the base of the aquifer. In the unconfined aquifer, water table increases during the rainy seasons and falls during the dry season. The aquifers in this area obtain steady recharge through direct precipitation and major rivers (e.g. River Nun). Very limited water table fluctuation is expected in the areas where there is heavy rainfall nearly all the year round.

Water Chemistry Results

Water quality in the study area shows considerable variation with local geology, geomorphology, depositional environment and degree of use and abuse. Being situated within the deltaic plain mega-depositional environment, the study area comprises swamps, creeks, tidal channels, rivers and their distributaries and lakes. Brackish water resulting from tidal influx dominates the coast. The activities attendant to oil exploration and exploitation added to wrong practice of human and industrial waste disposal to contaminate surface water sources. Groundwater therefore offers the only source of fresh water supply in the study area. Hence the only means of evaluating the quality of water tapped by a well is an analysis of the pumped water.

Table 3 shows water quality data, mainly surface with only 1No Borehole and 1no hand dug well from the study area. Although one rarely can be certain that a sample from a well represents exactly the composition of all the water in the vertical section at that point, it is usually a useful indication of the average composition of the available water at that point. Also since the screens are usually placed at the bottom of the string of casing pipes, it can be assumed that the water quality represents the water at the total completion depth of the well and hence the aquifer from which water is pumped. A comparison of the results of analysis of groundwater samples from the study area and these guidelines indicates that some quality issues really exist in the groundwater of the study area. The trends amongst relevant physico-chemical chemical parameters are discussed in Table 3.

pH

pH represents the negative base -10 log of the hydrogen-ion activity in water. It is measured in moles per liter. Even when no other solutes are present, a few of the H_2O molecules in liquid water will be broken up into H^+ and OH^- ions. This process of dissociation is a chemical equilibrium that may be written as:

Table 3: Results for Analysis of Water Samples in Southern Ijaw, Bayelsa

S/No.	Parameters	SW1 Toru-Orua N05^{0}05'80.5" E006^{0}04'38.4"	SW2 Amatolo N05^{0}01'43.3" E006^{0}03'50.1"	SW3 Toru-Ebeni N04^{0}59'35.06" E006^{0}04'28.26"	BH1 Boluo-Orua N05^{0}06'19.9" E006^{0}07'09.3"	Hand Dug WellKabiamaN 05^{0}02'39.86 E006^{0}04'28.26"
1.	pH	6.86	5.86	5.82	6.34	6.79
2.	Conductivity (µs/cm)	101	82.00	73.00	92	463
3.	Salinity as Chloride (mg/l)	42.90	36.30	38.60	37.70	99.00
4.	Dissolved Oxygen (mg/l)	4.20	4.30	4.60	5.30	4.70
5.	Temperature (^{o}C)	26.90	26.80	26.40	26.20	26.40
6.	Total Dissolved Solids (mg/l)	56.00	45.00	40.00	51.00	2.55
7.	Total Suspended Solids (mg/l)	17.00	15.00	60.00	1.00	2.00
8.	Turbidity (NTU)	18.90	19.50	54.60	0.390	0.907
9.	Alkalinity as CaCO$_3$ (mg/l)	7.00	6.00	5.00	3.00	21.00
10.	Hardness as CaCo$_3$ (mg/l)	6.00	4.00	4.00	5.00	15.00
11.	Sodium, Na (mg/l)	1.57	2.18	1.15	2.91	8.72
12.	Calcium, Ca (mg/l)	8.27	5.86	3.62	5.99	34.16
13.	Potassium, K (mg/l)	2.50	1.44	4.54	1.95	39.80
14.	Magnesium, Mg (mg/l)	1.05	0.54	0.67	1.15	3.13
15.	Nitrate, NO$_3$ (mg/l)	1.20	1.10	1.00	1.10	2.40
16.	Sulphate, SO$_4^{2-}$ (mg/l)	4.00	2.00	1.00	3.00	9.00
17.	Phosphate, PO$_4^{3-}$ (mg/l)	0.54	0.31	0.27	0.42	2.55
18.	Chemical Oxygen Demand 9mg/l)	0.19	0.56	1.50	0.42	2.06
19.	Biochemical Oxygen Demand (mg/l)	0.13	0.38	1.00	0.28	1.38
20.	Manganese, Mn (mg/l)	0.13	0.15	0.05	0.19	0.11
21.	Copper, Cu (mg/l)	<0.001	<0.001	<0.001	<0.001	<0.001
22.	Lead, Pb (mg/l)	0.038	<0.001	<0.001	<0.001	<0.001
23.	Iron, Fe (mg/l)	2.364	1.777	3.872	<0.001	<0.001
24.	Zinc, Zn (mg/l)	0.003	<0.001	0.008	0.007	0.008
25.	Arsenic, As (mg/l)	<0.001	<0.001	<0.001	<0.001	<0.001
26.	THB (cfu/100ml) x 10^4	3.20	4.20	3.70	3.90	4.90
27.	THF (cfu/100ml) x 10^4	3.20	3.60	3.10	3.00	1.60

$$H_2O\ (l) = H^+ + OH^- \qquad ...(1)$$

For neutral waters, H^+ equals $OH^- = 7$. Water is considered alkaline when OH^- ions > H^+ ions and pH > 7. When the $H^+ > OH^-$ and pH <7, the water is described as acidic. The values range from 5.82 – 6.86, indicating slightly alkaline. Interestingly, all the values are within WHO standards (WHO, 2011). Hem (1989) noted that water with pH values between 4.0 and 6.0 are usually associated with small amounts of mineral acids from sulphide sources and/or organic acids. Those with pH less than 4 contain free acid. Waters with pH values between above 7 are high in bicarbonate ions.

Electrical Conductivity (EC)

The electrical conductance, or conductivity, is the ability of a substance to conduct an electric current. The electrical conductivity (EC) in the study area ranges from 73.00µS/cm – 463.00µS/cm. It gives an idea of the amount of total dissolved salts (TDS) present in the water. Conductivity increases as the TDS increases and in general, the corrosivity of the water increases as TDS and electrical conductivity increase. Electrical conductance depends on temperature and types and concentration of different dissociated ions in the water. Temperature is usually taken as 25°C hence electrical conductivity depends only on type and concentration of dissociated species present in the water.

Salinity as Chloride

Salinity as Chloride ranges between 36.30 mg/l to 99.00mg/l in the studied water samples. From this study, low salinity is observed and this did not correlate well with the alkaline nature of the water. There is no salt on account of the results of the study. However, there may be salt water encroachment in some adjoining areas owing to the presence of creeks traversing the area. In this instance, two major factors may contribute to the saline water intrusions in the area, viz: (i) the excessive pumping of groundwater capable of disturbing the hydrodynamic equilibrium in the aquifer (Lee and Song, 2007); and (ii) the reduction of groundwater gradients which may allow saline water to displace freshwater in the aquifer (Lee and Chang, 1974). When this happens, the groundwater quality deteriorates very rapidly, thereby leading to increase in the salinity of the water.

Total Suspended Solids (TSS)

The concentration of TSS ranges from 1.00 to 60.00mg/l in waters in the study area. TSS is not stated in WHO (2011) guidelines. WHO (1996) stipulates 10mg/l as the desirable level of TSS and a maximum permissible limit of 25mg/l in drinking water. In the study area, the highest TSS value (1.00mg/l) was recorded in Boluo-Orua. A comparison of measured TSS value with WHO (1996) standards shows that the water samples are within the maximum permissible limit implying that the water is suitable for drinking/domestic uses, except for industrial purposes in which there may be need for treatment before use. The low value of TSS in the area in site is due to very high static water level (SWL). Suspended solids in water can be removed by sedimentation or water filtration.

Total Hardness

The hardness of water is the sum of the ions which can precipitate as hard particles from water mainly Ca^{2+} and Mg^{2+}. This is regarded as Ca^{2+} + Mg^{2+} or Total hardness. It is usually expressed in meq/l (Appelo and Postman, 1993). It is assessed by the ability of the water to precipitate soap. This parameter is very important in manufacturing processes. Hardness values in the study area range from 4.00mg/l – 21.70mg/l whereas the World Health Organization, (WHO) sets 100mg/l and 500mg/l as highest desirable and maximum permissible values respectively. The implication is that groundwater in most parts of the study area are within WHO standard for hardness. When the hardness is very low, $\leq$ 10 mg/l, the water becomes corrosive and capable of dissolving heavy metals such as iron causing corrosion and incrustation. Hardness is therefore not a major quality issue in groundwater in the area.

Nitrate (NO_3^-)

The concentration level of nitrate in the sampled groundwater in the area ranges from 0.34mg/l to 2.40mg/l. The WHO (2011) highest desirable level for nitrate in drinking water is 50mg/l. Though water level is high in most of the boreholes sampled, there is no contamination of the water by nitrate from the surface. The low levels of nitrate recorded in the area show that the groundwater is free from pollution, and safe for consumption by human and livestock with respect to this parameter. Nitrate in groundwater owes its origin from activities such as application of fertilizers in farms, plant decomposition, human sewage, soakaways, industrial and domestic effluents, and emissions from combustion engines (Lenntech Water Treatment and Air Purification, 2008).

High concentration of nitrate in water causes a disease known as “Blue Baby Syndrome” or methemoglobinemia in infants (Udom, 1989; Twort *et al.,* 2000). This disease is characterized by blood changes and cyanosis in which the hemoglobin apparently becomes incapable of transporting oxygen (Ofoma *et al.,* 2005).

Sulphate (SO_4^{2-})

The concentration of sulphate in all the groundwater samples in the study area ranged from 1.00 to 9.70mg/l. These values are below the WHO (2011) guideline of 250mg/l. Sulphate in the area has an average value of 4.5mg/l. Sulphate in combination with calcium and magnesium is capable of making water hard.

Sulphate is a major constituent of groundwater. It is relatively mobile in groundwater because it is hardly affected by sorption. The limiting phase can again be gypsum if the dissolution equilibrium is exceeded. A possible source for sulphate could be gypsum ($CaSO_4.2H_2O$) or anhydrite ($CaSO_4$) from the aquifer matrix (Udom *et al*., 1999; Egbunike, 2005). Sulphate can also originate in part from non-mineral sources such as sewage.

According to Twort *et al*., (2000), other sources of sulphate in groundwater include oxidation of sulphides, sulphites, thiosulphates in well aerated surface waters, and from industrial effluents where sulphates have been used. Sulphorous flue gases discharged to the atmosphere in industrial areas often result in acid rain water containing appreciable levels of sulphate (Twort *et al*., 2000). Sulphate in the rainwater as originating from traffic fumes, industrial activities and oil exploration and production activities (as in gas flaring) going on within the Niger Delta, the study area inclusive.

Heavy Metals

Generally, the results of the heavy metals in the study reveals that, in some locations, values are slightly higher than the permissible levels, f or example, Mn (0.05mg/l – 0.19mg/l) and iron (Fe) <0.001mg/l – 3.87mg/l. The presence of iron in concentrations higher than the (WHO, 2011) recommended limit of 0.3mg/l impacts rusted iron taste, causes stains and may increase the hazards of pathogenic organisms, since most of them need iron to grow. Excessive iron may increase the uptake of copper and lead, which are known to be toxic (Ibe and Sowa, 2002). According to Ngah & Nwankwoala (2013), exposure of water samples to air could cause ferrous (Fe^{2+}) ion in them to oxidize to ferric (Fe^{3+}) ion which would precipitate a rust-coloured ferric-hydroxide which stains plumbing fixtures, laundry and cooking utensils. It may also give undesirable taste. High concentration in groundwater poses potential hazard for many industrial processes such as high pressure boiler feed water, process water, fabric dying, paper making, brewery, distillery, photographic film manufacture, ice making and food processing which require water that is almost entirely iron free (ASTM, 1969).

According to Twort *et al*., (2000) and Punmia *et al*., (2002), deposit of ferruginous materials in a water distribution system can contribute to the growth of iron bacteria which in turn could cause further water quality deterioration by producing slimes or objectionable odours and colour as well as increase in turbidity. Aeration and filtration will usually remove iron from the water. Alternatively, iron can be prevented from coming out of solution by adding a small amount of sodium hexa-metaphosphate to the water. This polyphosphate stabilizes the iron and delays its precipitation. The presence of iron in some location calls for the development of a comprehensive blue print for environmental protection in the area.

Microbial Analysis

Water quality studies must take into account the fact that the presence of a few pathogenic microorganisms (disease causing organisms) in water is more significant than that of many saprophytic bacteria (microbes that obtain food by absorbing dissolved organic matter). This is because of the human health implications. In fact, the World Health Organization (WHO, 2011) guidelines stipulated that all water intended for drinking must have zero coliform count in any 100ml sample of water. Generally, however, water of good quality is expected to give a low coliform count – less than 100 per ml (Pelczar *et al.,* 1993).

Total coliform refers to a group of bacteria used to indicate the potential presence of harmful bacteria in water resulting from human and animal wastes. Bacteria standards (Coliform results) are reported as Colony Forming Units (CFU) of Total Coliform bacteria counted in 100 millilitres of water submitted. Tests for Faecal Coliforms provide a direct means of measuring human and animal waste inputs. THB ranges from 0.40 – 4.90cfu/100ml while THF ranges from 0.58 – 3.60cfu/100ml, in the study area.

Coliform counts of groundwater in these areas exceed the WHO (2011) guide value of 0cfu/ml and are generally unsafe for drinking. The source of this high coliform concentration is generally due to faecal contamination and this poses high risk of cholera and stomach disorder upon consumption. This is enhanced by poor borehole construction in the study area.

Table 4: Results of Statistical Analysis for Water Samples From the Study Area

Parameters	Unit	Range		Mean	Variance	Median	SD
		Min	Max				
pH	Unitless	5.82	6.86	6.33	0.24	6.34	0.49
EC	µScm	73.00	463.00	162.20	28385.70	92.00	168.48
Cl	mg/L	36.30	99.00	50.90	729.08	38.60	27.00
DO	mg/L	4.20	5.30	4.62	0.19	4.60	0.43
Temperature	mg/L	26.20	26.90	26.54	0.09	26.40	0.30
TDS	mg/L	2.55	56.00	38.91	449.64	45.00	21.20
TSS	mg/L	1.00	60.00	19.00	578.50	15.00	24.05
Turbidity	mg/L	0.39	54.60	18.86	485.30	18.90	22.03
Alkalinity	mg/L	3.00	21.00	8.40	51.80	6.00	7.20
TH	mg/L	4.00	15.00	6.80	21.70	5.00	4.66
Na	mg/L	1.15	8.72	3.31	9.60	2.18	3.10
Ca	mg/L	3.62	34.16	11.58	162.04	5.99	12.73
K	mg/L	1.44	39.80	10.05	278.05	2.50	16.67
Mg	mg/L	0.54	3.13	1.31	1.10	1.05	1.05
NO_3	mg/L	1.00	2.40	1.36	0.34	1.10	0.59
SO_4	mg/L	1.00	9.00	3.80	9.70	3.00	3.11
PO_4	mg/L	0.27	2.55	0.82	0.95	0.42	0.97
COD	mg/L	0.19	2.06	0.95	0.64	0.56	0.80
BOD	mg/L	0.13	1.38	0.63	0.28	0.38	0.53
Mn	mg/L	0.05	0.19	0.13	0.00	0.13	0.05
Cu	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Pb	mg/L	<0.001	0.04	-	-	-	-
Fe	mg/L	<0.001	3.87	2.67	1.17	2.36	1.08
Zn	mg/L	<0.001	0.01	0.01	0.00	0.01	0.00
As	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
THB	(cfu/100ml) x 10^4	3.20	4.90	3.98	0.40	3.90	0.63
THF	(cfu/100ml) x 10^4	1.60	3.60	2.90	0.58	3.10	0.76

Table 5: Water Classification for Irrigation Purposes

Sample ID	Water Type	Salinity Hazard	SAR	Exchangeable Sodium Ratio	Magnesium Hazard	Water Density (g/cm^3)
SW1	Ca-Cl	Low	0.137	0.137	17.3	0.997
SW2	Ca-Cl	Low	0.231	0.282	13.2	0.997
SW3	Ca-Cl	Low	0.146	0.212	23.4	0.997
BH1	Ca-Cl	Low	0.285	0.231	24.1	0.997
HDW	Ca-Cl	Medium	0.383	0.193	13.1	0.997

Table 6: Calculation of Carbonates from Alkalinity at Given pH Concentration for Each Sample

Sample Code	HCO$_3$	CO$_3$	CO$_2$	HCO$_3$	CO$_3$	CO$_2$
	mg/L			Mmolal		
SW1	8.529	2.689	0.02189	0.1402	0.04495	0.0004989
SW2	7.312	23.18	0.01851	0.1202	0.3874	0.0004219
SW3	6.096	21.21	0.01401	0.1002	0.3545	0.0003193
BH1	3.657	3.832	0.02807	0.06011	0.06404	0.0006397
HDW	25.59	9.196	0.00613	0.4206	0.1537	0.0001397

Table 7: Correlation Matrix

	pH	EC	Cl	DO	Temp	TDS	TSS	Turb	Alk	TH	Na	Ca	K	Mg	NO3	SO4	PO4	COD	BOD	Mn	Fe	Zn	THB	THF
pH	1																							
EC	.567	1																						
Cl	.580	.998**	1																					
DO	-.022	.101	.067	1																				
Temp	.123	-.243	-.225	-.924*	1																			
TDS	-.262	-.939*	-.938*	-.105	.340	1																		
TSS	-.592	-.436	-.389	-.296	.035	.190	1																	
Turb	-.620	-.495	-.449	-.392	.152	.253	.991**	1																
Alk	.554	.979**	.985**	-.100	-.068	-.927*	-.352	-.394	1															
TH	.661	.993**	.994**	.089	-.210	-.895*	-.466	-.526	.972**	1														
Na	.523	.980**	.964**	.241	-.336	-.915*	-.555	-.614	.929*	.965**	1													
Ca	.610	.997**	.995**	.063	-.187	-.916*	-.474	-.526	.983**	.996**	.975**	1												
K	.500	.993**	.995**	.101	-.283	-.967**	-.334	-.400	.976**	.979**	.963**	.984**	1											
Mg	.669	.980**	.977**	.225	-.326	-.875	-.504	-.576	.932*	.990**	.970**	.979**	.965**	1										
NO3	.603	.998**	.995**	.063	-.190	-.919*	-.469	-.521	.983**	.995**	.976**	1.000**	.985**	.978**	1									
SO4	.775	.954*	.951*	.078	-.124	-.792	-.607	-.655	.930*	.979**	.938*	.970**	.918*	.972**	.968**	1								
PO4	.605	.999**	.998**	.094	-.227	-.923*	-.450	-.509	.979**	.997**	.975**	.999**	.989**	.985**	.999**	.966**	1							
COD	.003	.744	.759	.116	-.450	-.910*	.212	.131	.740	.687	.687	.699	.816	.671	.705	.524	.722	1						
BOD	.003	.744	.759	.116	-.451	-.910*	.212	.131	.740	.687	.687	.699	.816	.671	.705	.524	.721	1.000**	1					
Mn	.264	-.113	-.167	.389	-.024	.327	-.837	-.805	-.216	-.082	.047	-.077	-.215	-.018	-.083	.085	-.099	-.634	-.634	1				
Fe	-.279	-.539	.102	.869	-.894	-.530	.972	.958	-.698	-.246	-.939	-.683	.998*	-.005	-.698	-.550	-.377	.849	.849	-.991	1			
Zn	.108	.434	.448	.659	-.861	-.515	.181	.049	.316	.425	.426	.380	.496	.506	.383	.310	.427	.683	.683	-.361	1.000**	1		
THB	.039	.795	.761	.259	-.383	-.874	-.412	-.449	.746	.722	.861	.772	.798	.718	.776	.647	.767	.706	.706	.024	-.272	.302	1	
THF	-.578	-.955*	-.960**	-.296	.454	.899*	.343	.434	-.899*	-.958*	-.934*	-.941*	-.962**	-.978**	-.942*	-.906*	-.957*	-.776	-.776	.163	-.835	-.665	-.698	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Figure 2: Histogram Showing Cations and Anions

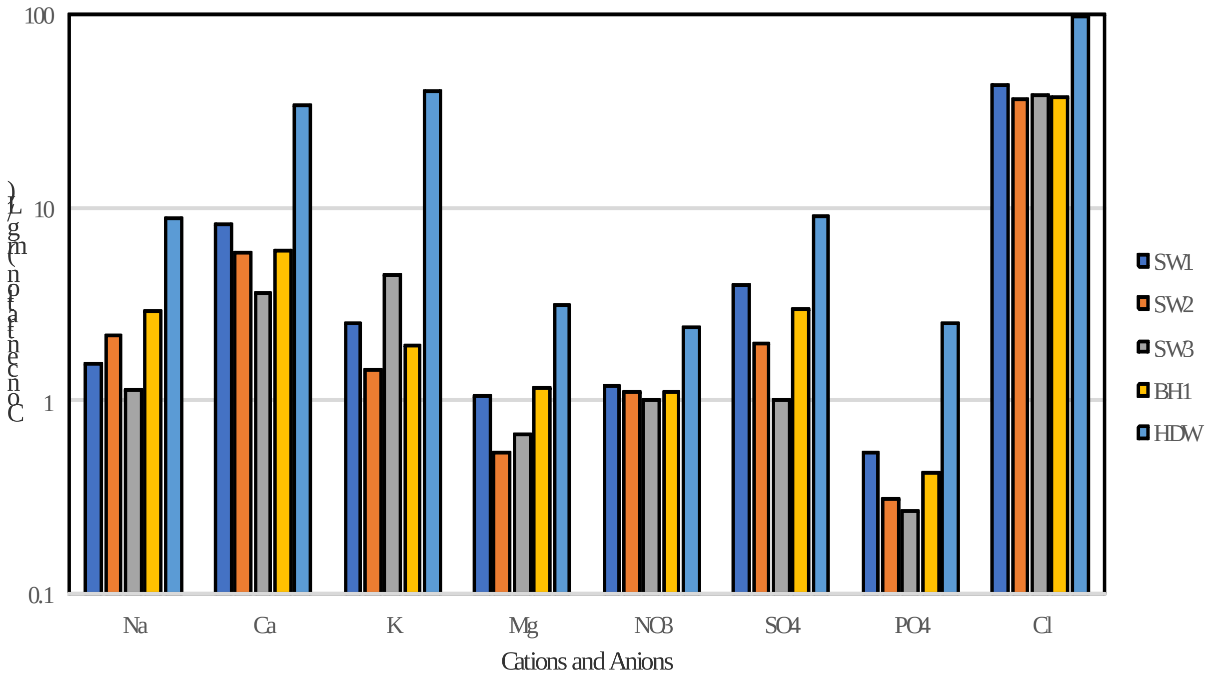


Figure 3: pH Concentrations in the Water Sources

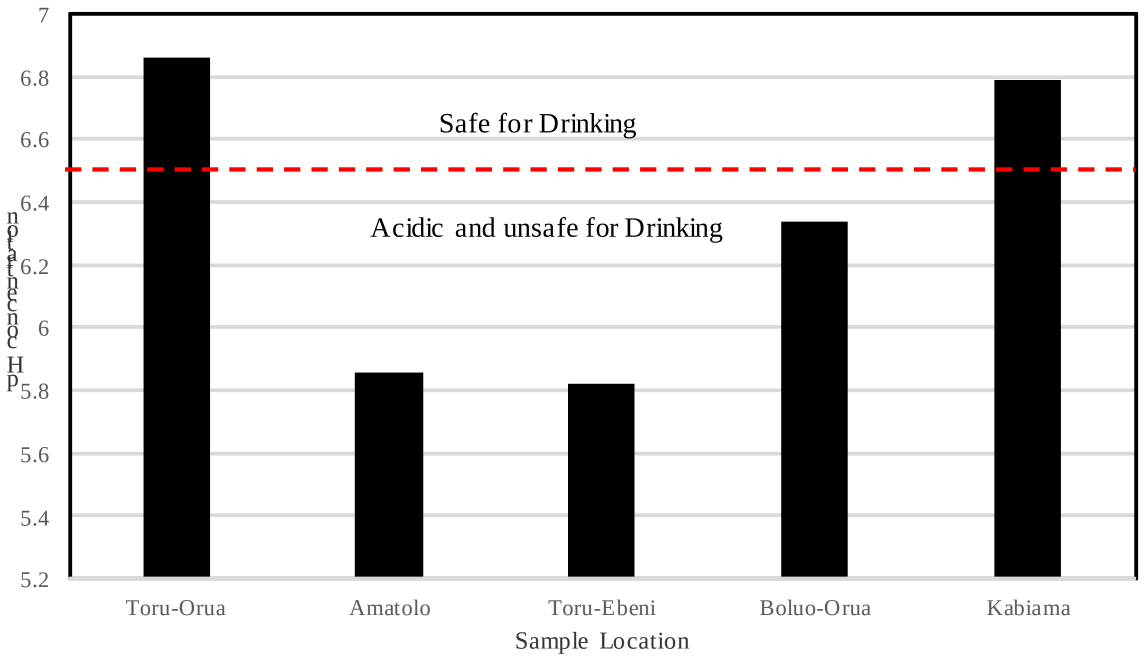


Figure 4: Piper Trilinear Plot of the Water Sources

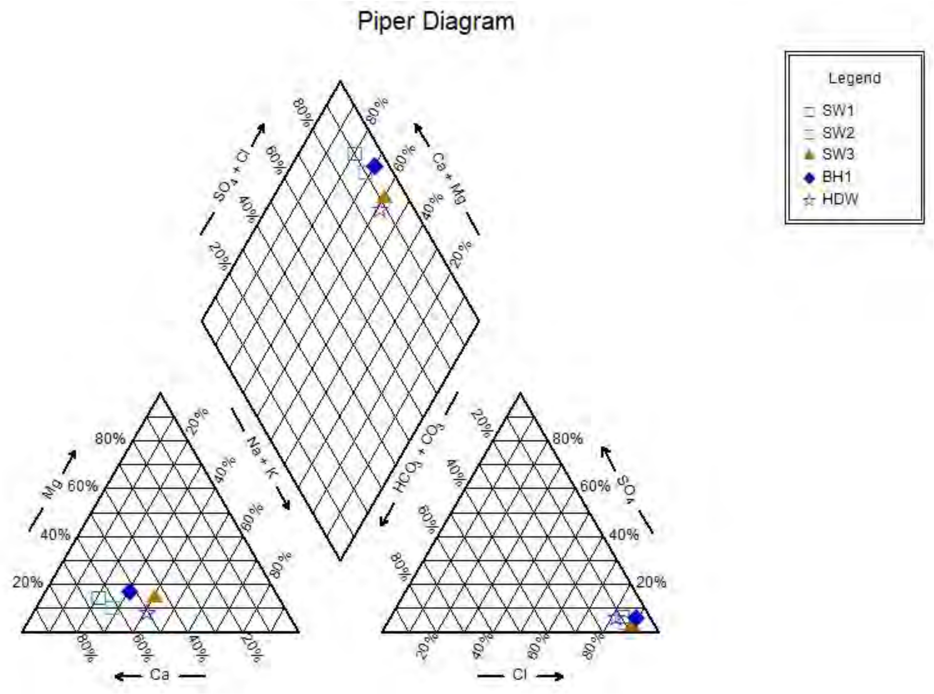


Figure 5: Durov Diagram of the Water Samples

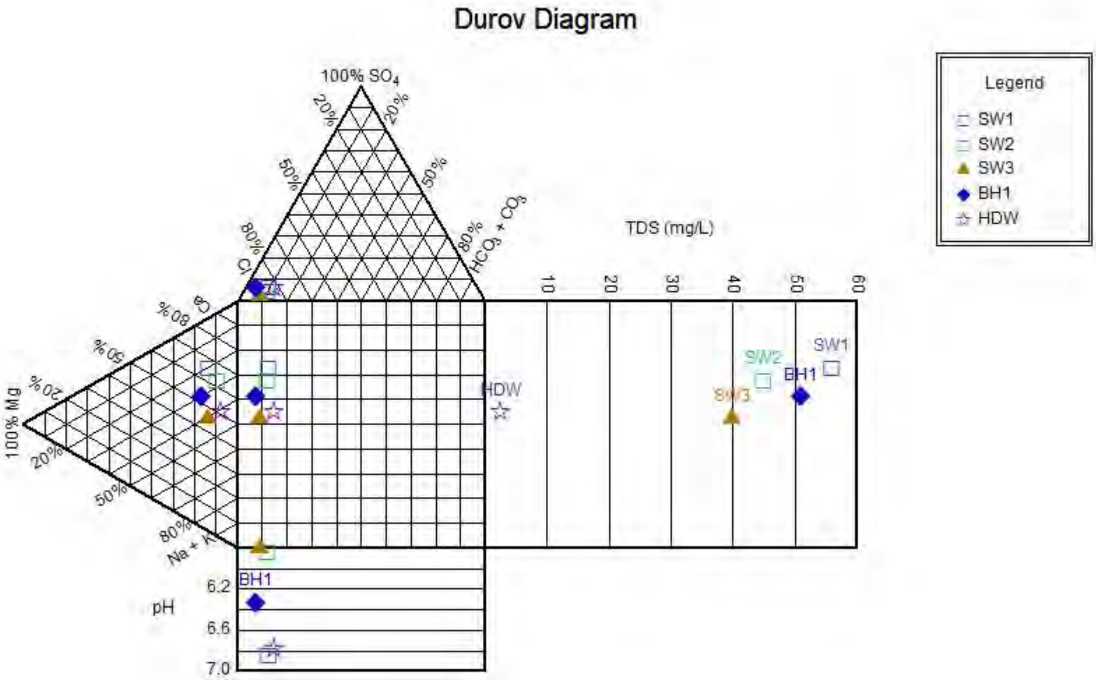


Figure 6: Schoeller Diagram of Water Samples

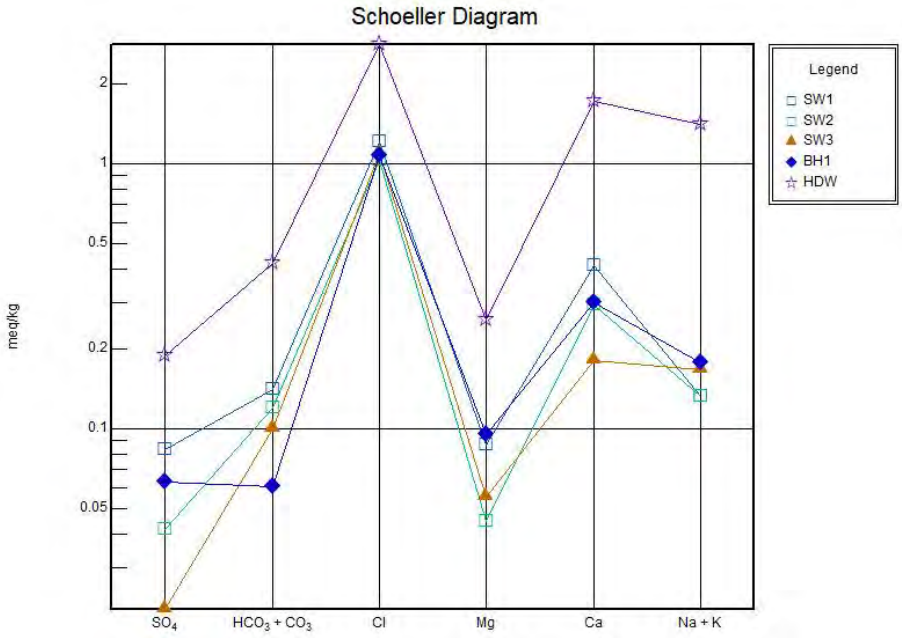


Figure 7: Stiff Diagram for Toru-orua

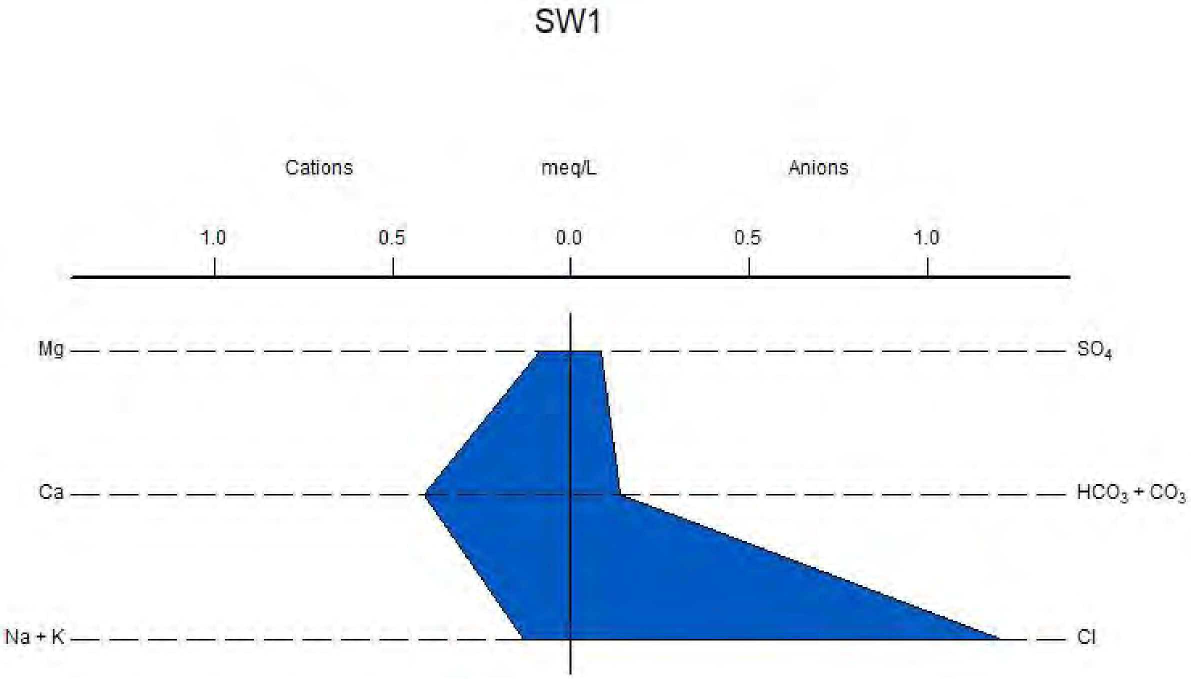


Figure 8: Stiff Diagram for Amatolo

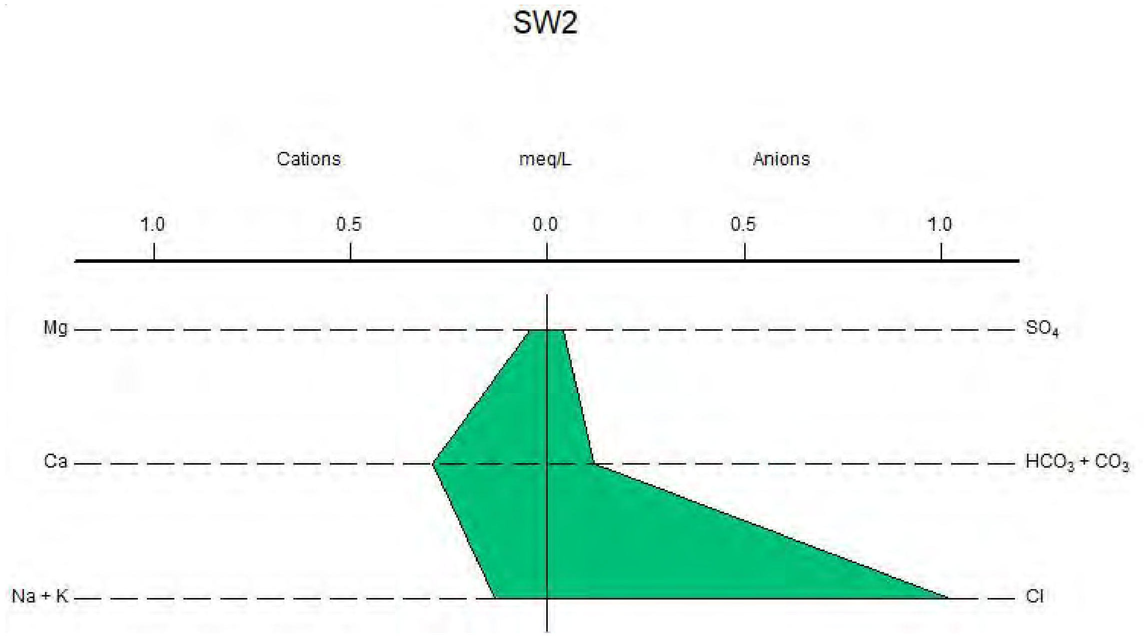


Figure 9: Stiff Diagram for Toru-ebeni

Figure 10: Stiff Diagram for Buluo-orua

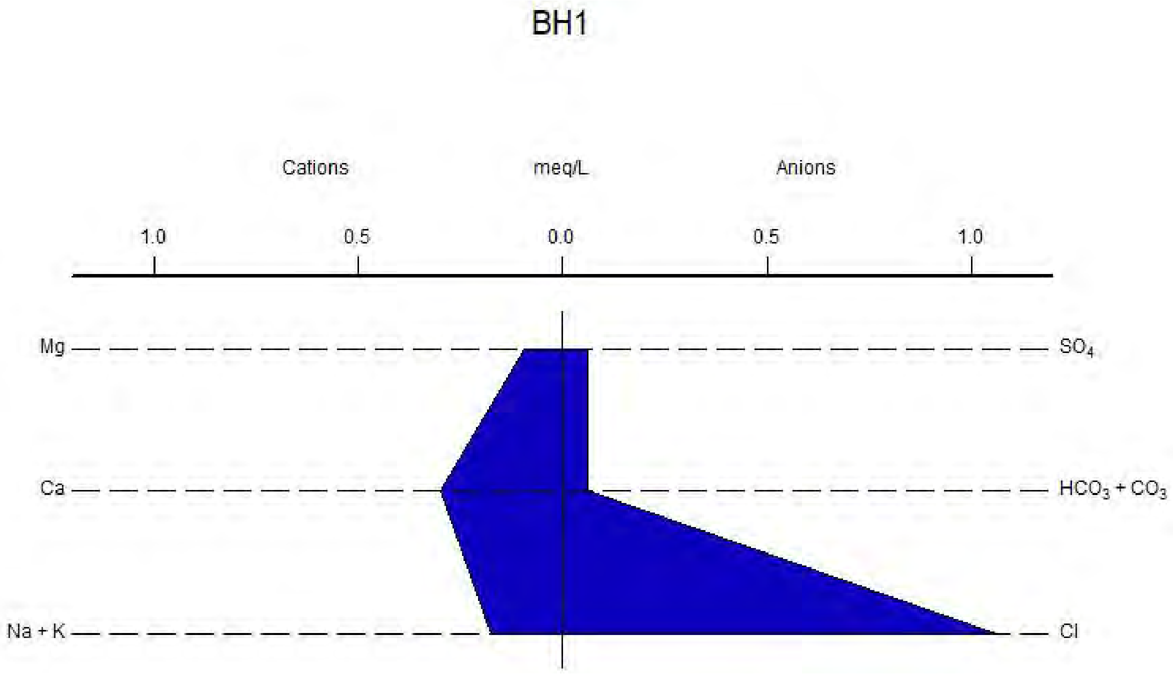


Figure 11: Stiff Diagram for Kabiama

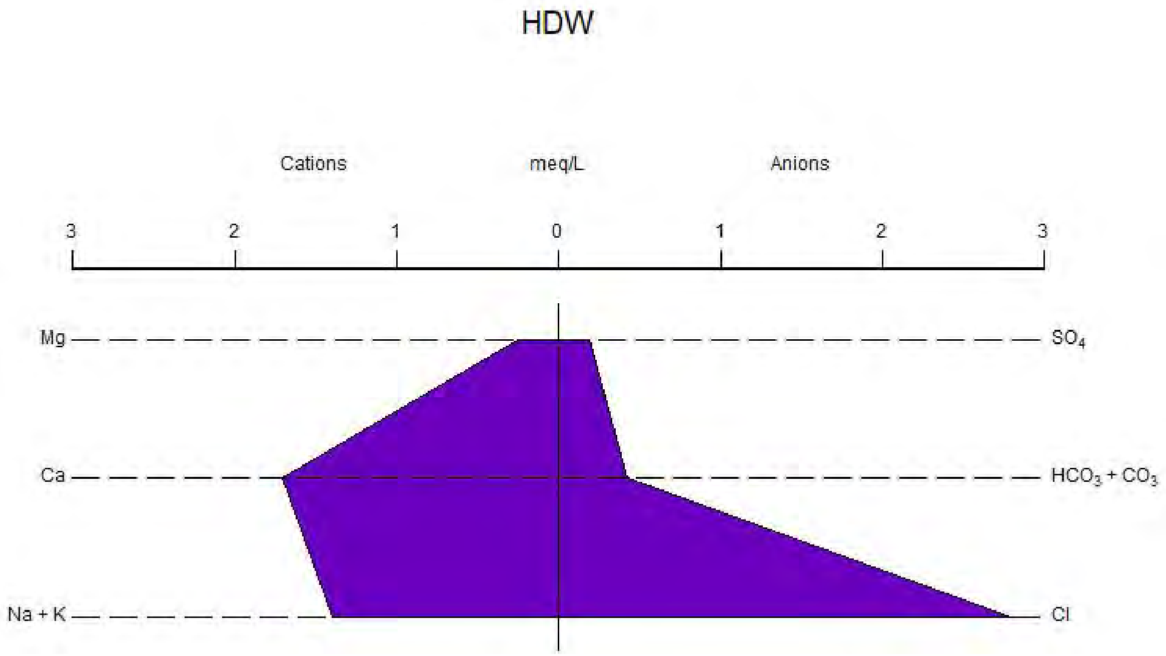


Figure 12: Cross Plots of pH Versus Temperature

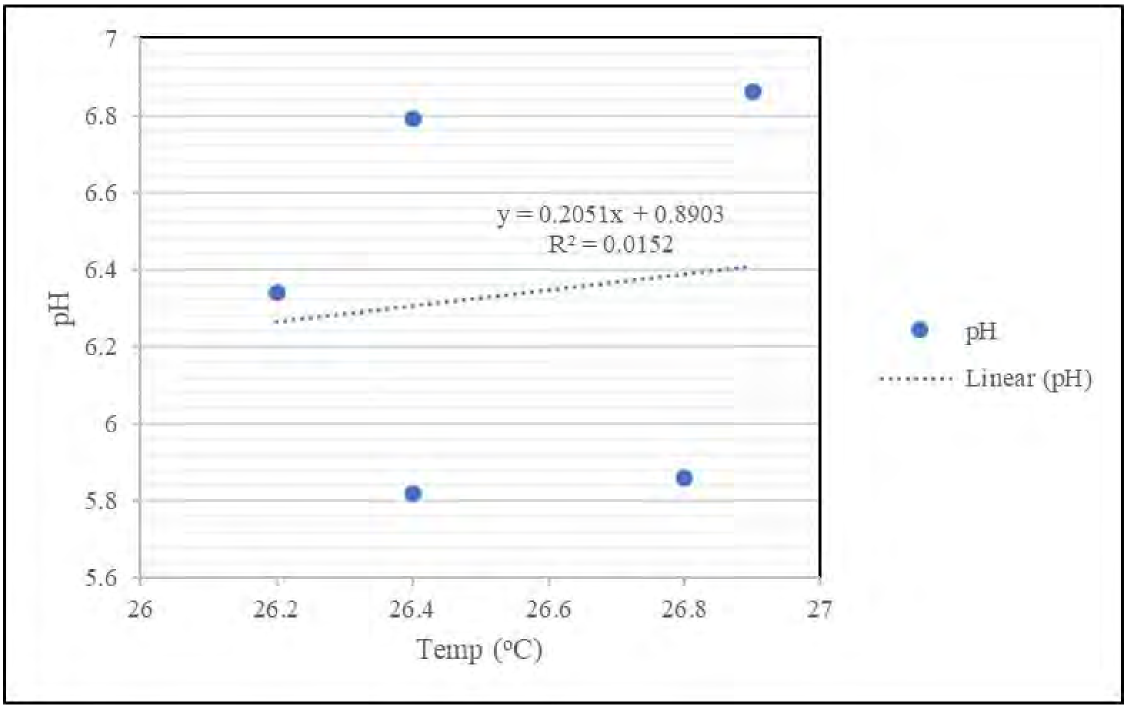


Figure 13: Cross Plots of Bod Versus Cod

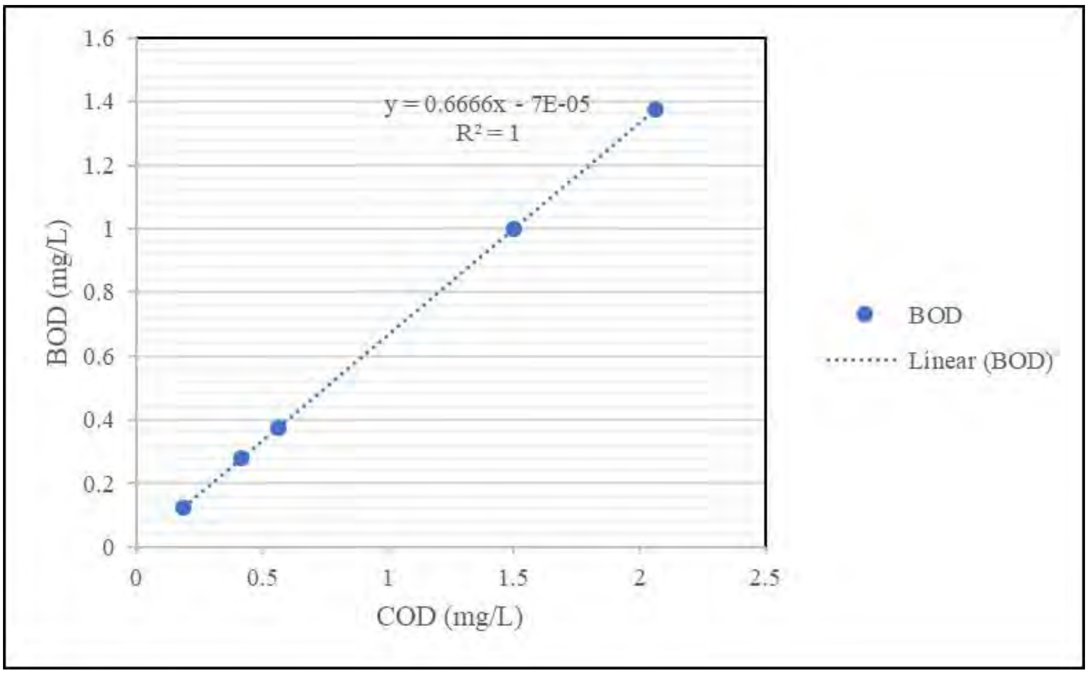


Figure 14: Cross Plots of the Versus Thb

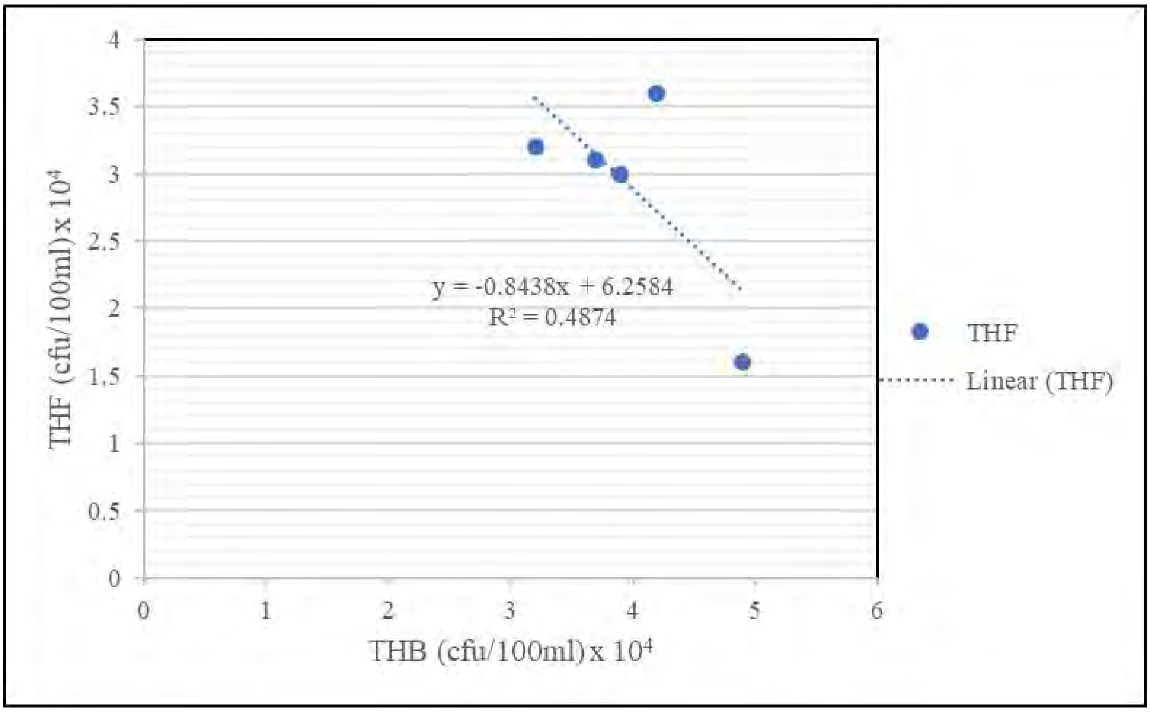


Figure 15: Cross Plots Of Cl Versus Mn

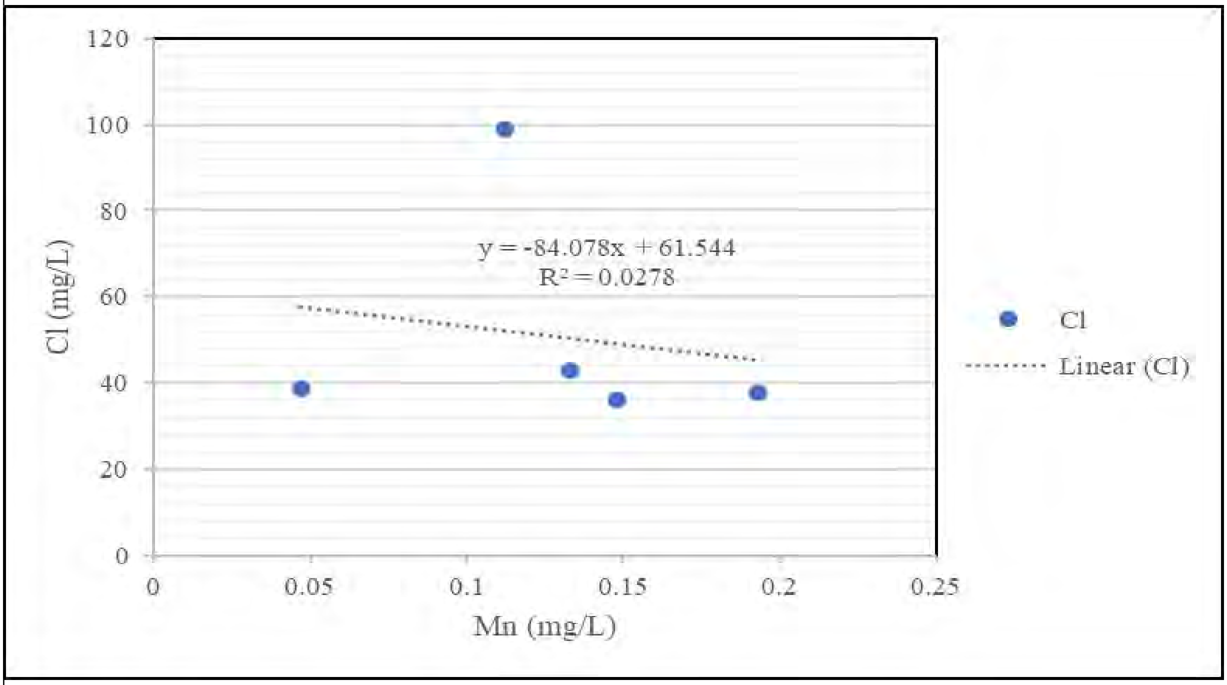


Figure 16: Cross Plots Of Cl Versus Tds

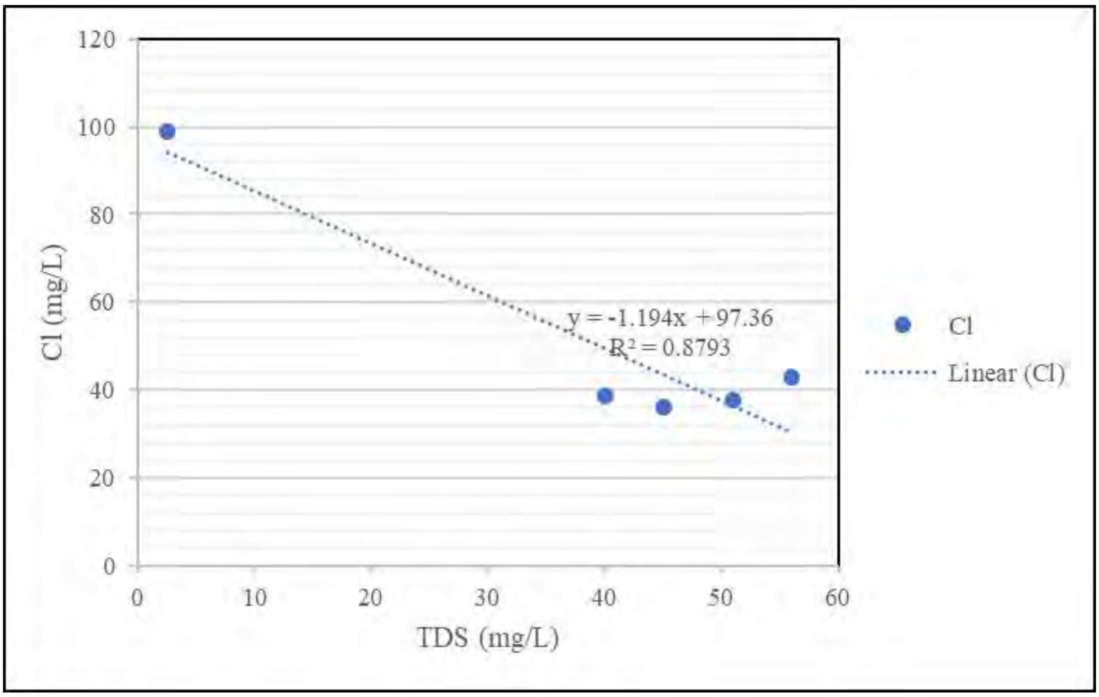


Figure 17: Cross Plots Of Mg Versus Ca

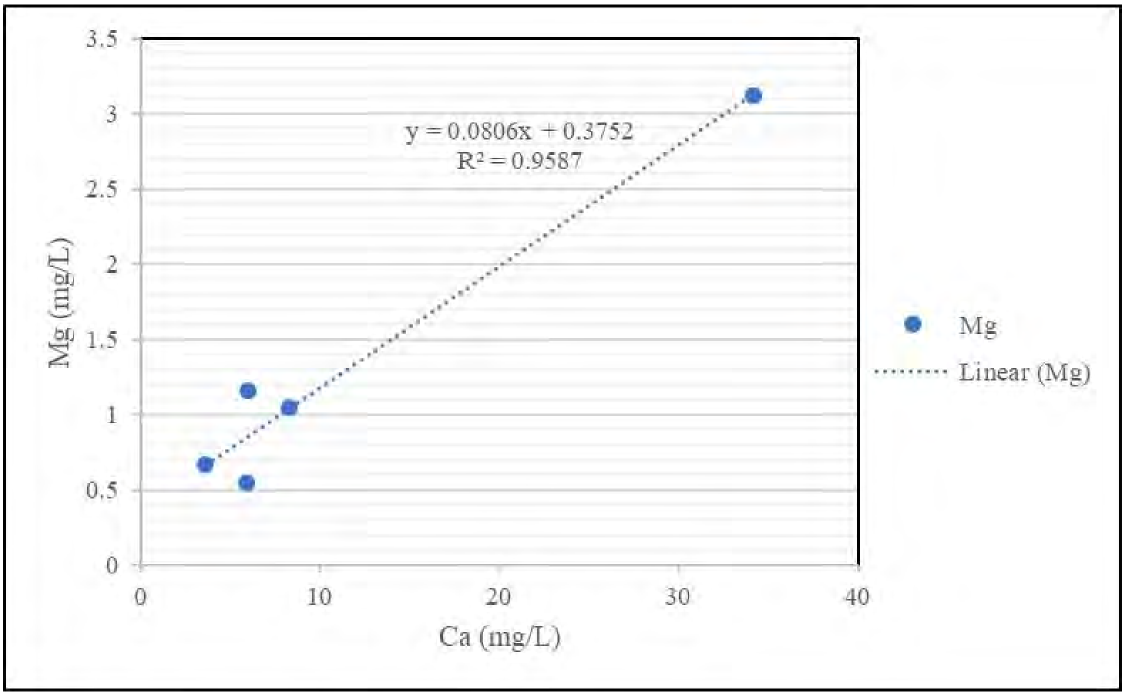


Figure 18: Cross Plots Of So$_4$ Versus Ca

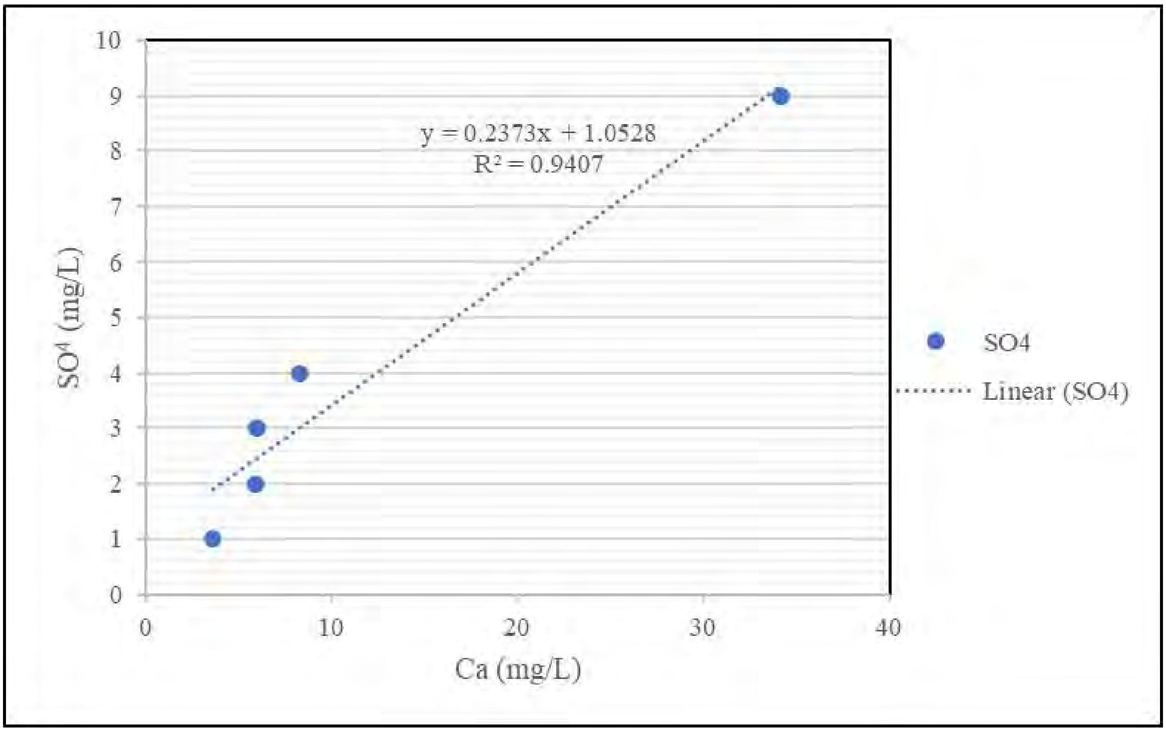


Figure 19: Cross Plots Of Na Versus Ca

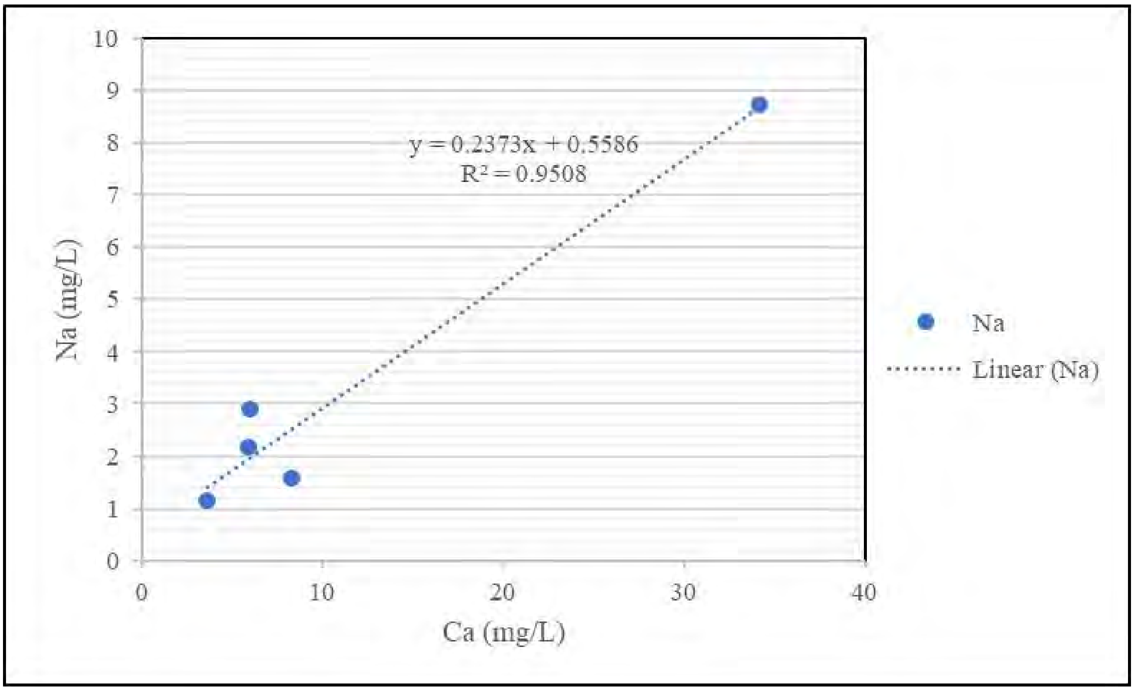


Figure 20: Cross Plots Of Na Versus Cl

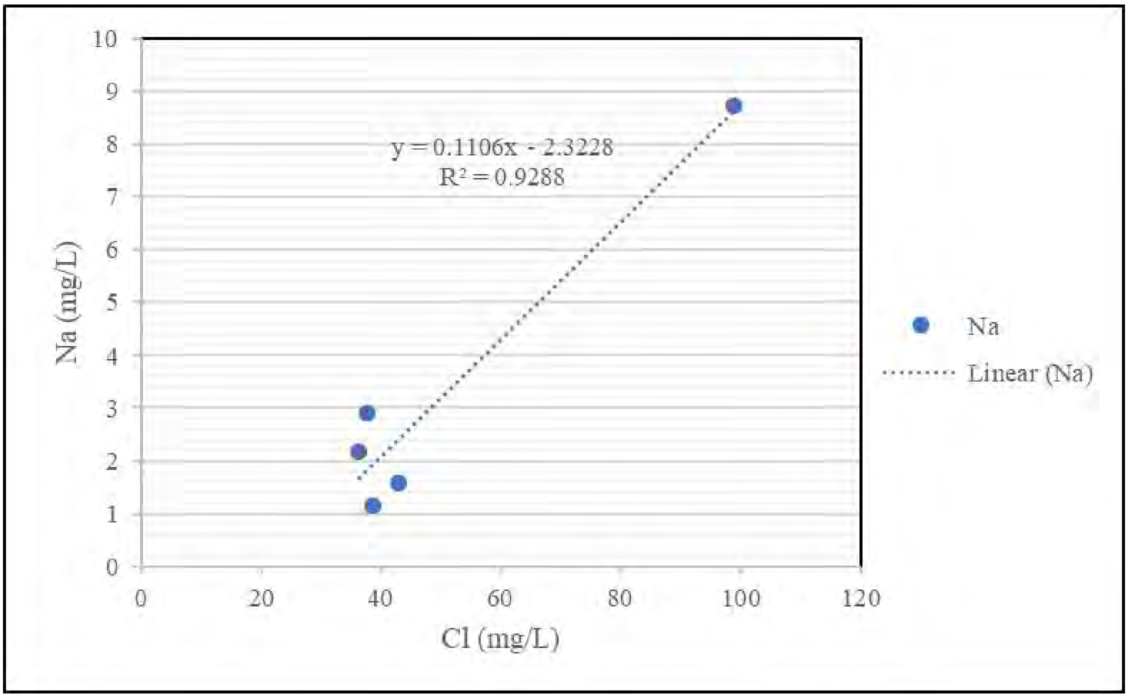


Figure 21: Cross Plots Of Na Versus Mg

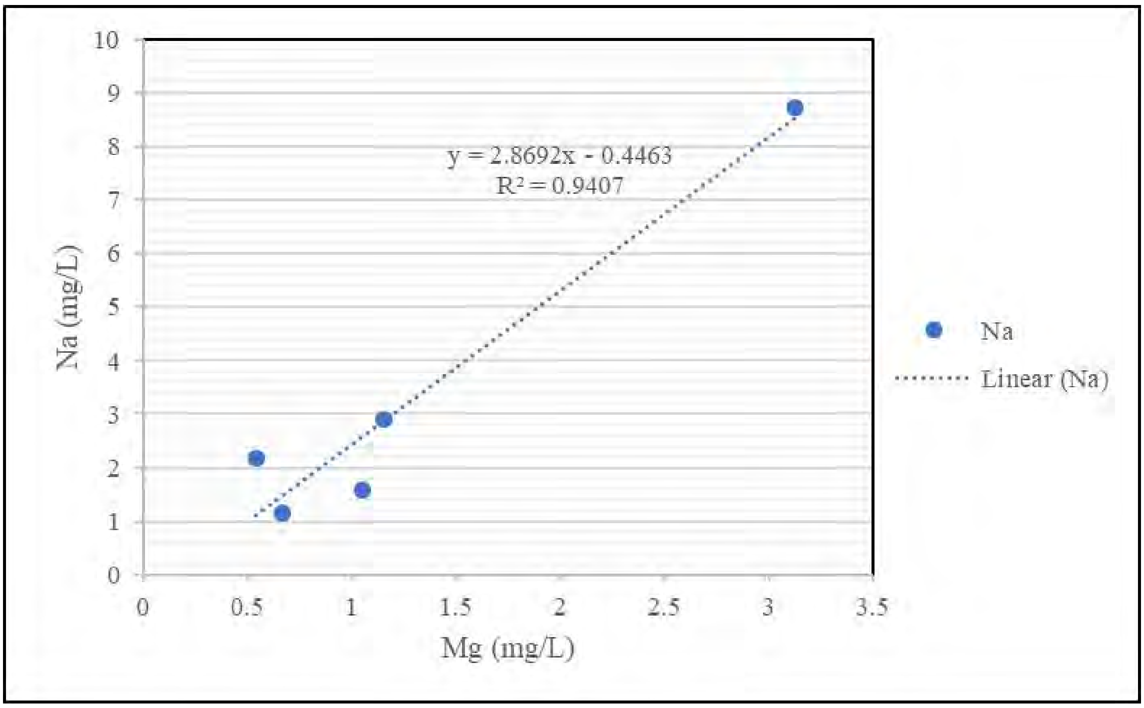


Figure 22: Cross Plots Of So$_4$ Versus Mg

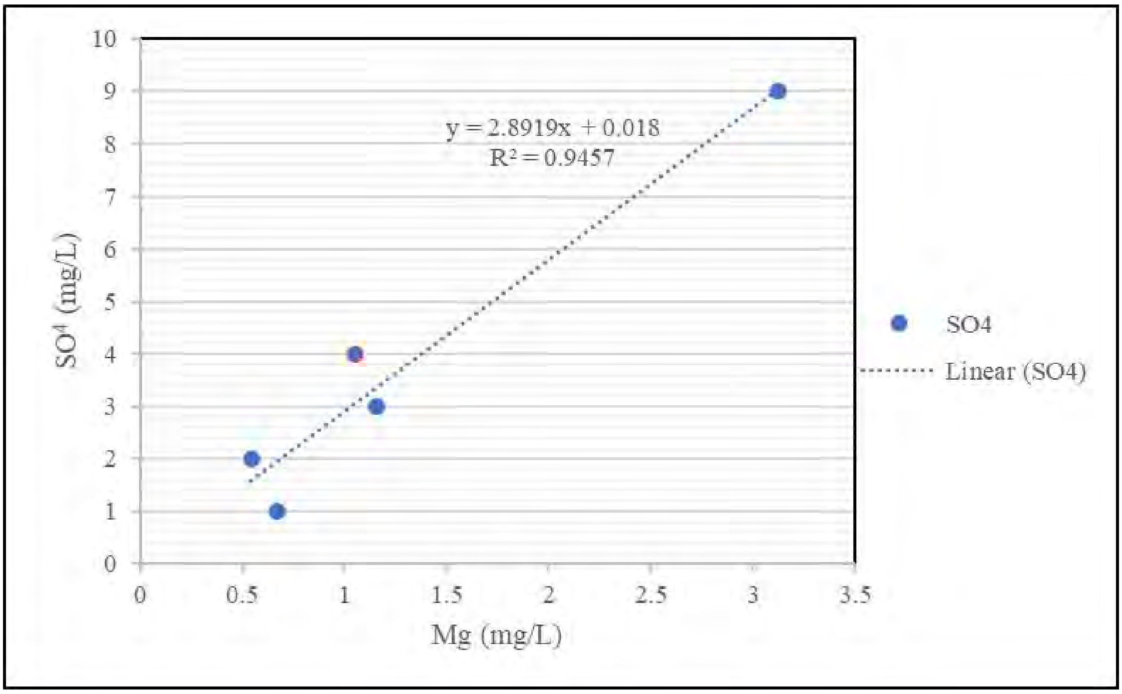


Figure 23: Cross Plots Of Po$_4$ Versus Ca

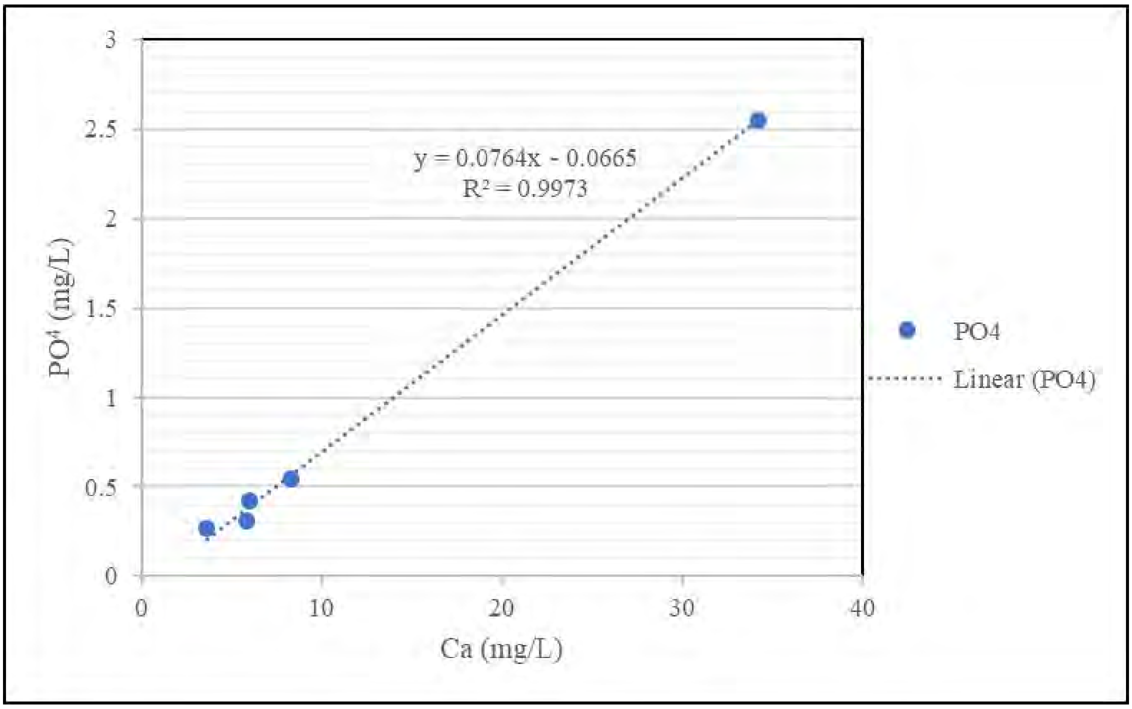


Figure 24: Cross Plots Of So$_4$ Versus Zn

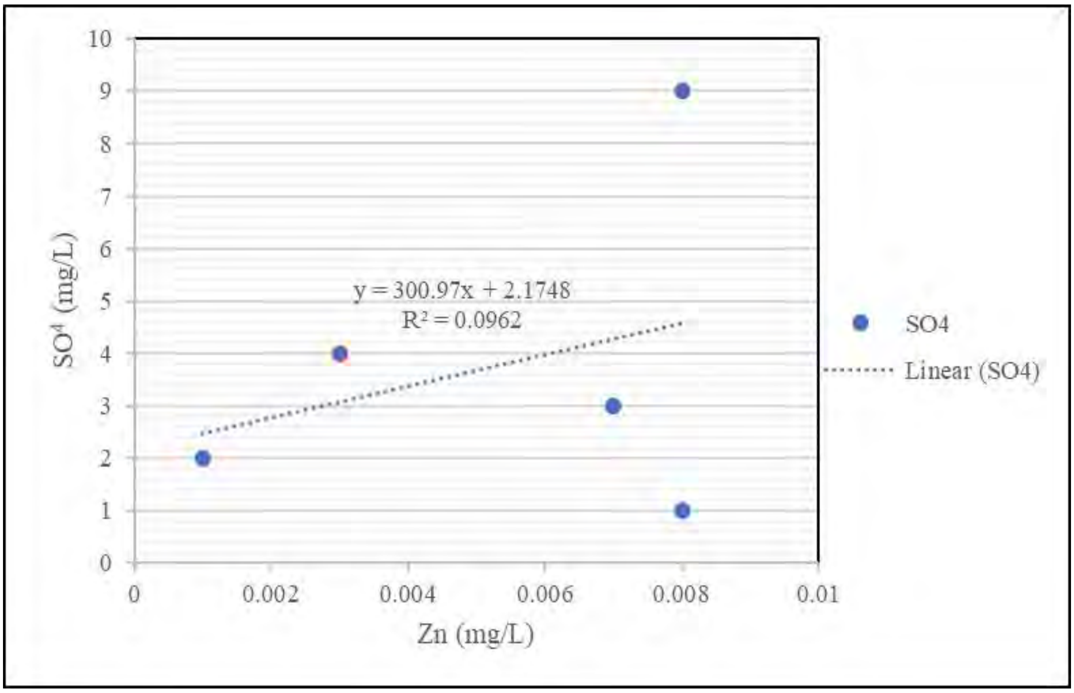


Figure 25: Cross Plots Of Ca Versus Zn

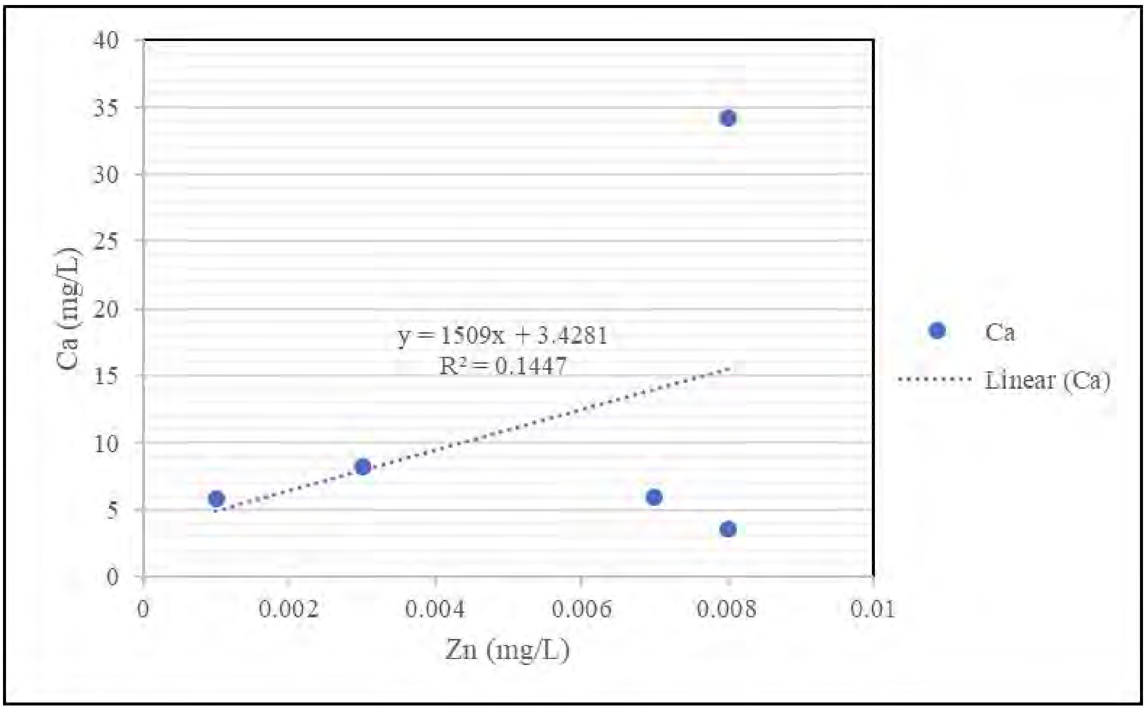
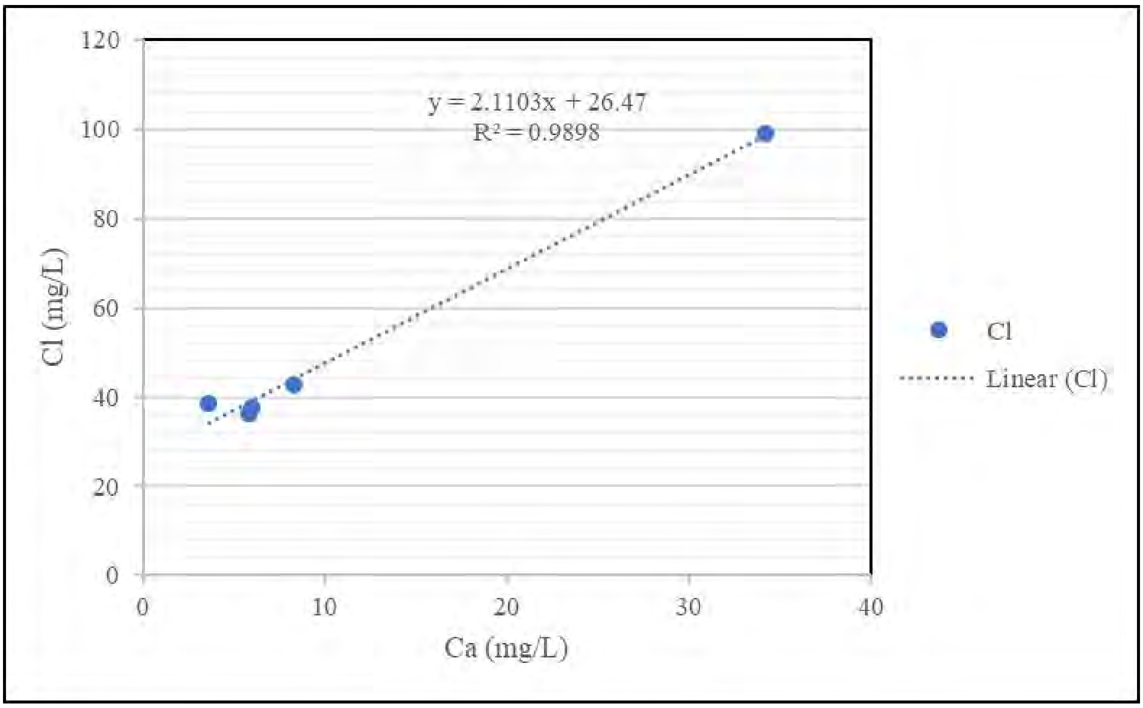


Figure 26: Cross Plots Of Cl Versus Ca



Conclusion

Water levels recorded in the site BH-1(2.5m), BH-2 (0.7m), BH-3 (1.0m) and BH-4 (2.0m), respectively. Groundwater quality in the study area shows considerable variation with local geology, geomorphology, depositional environment and degree of use and abuse. The physico-chemical properties of groundwater in the area measured are within permissible limits, except pH and iron which needs treatment. All the heavy metals, except Co and Fe show values <0.01mg/l. Coliform counts of groundwater in the areas exceed the WHO (2011) guide value of 0cfu/ml and are generally unsafe for drinking. In the study area groundwater pH should be treated with sodium bicarbonate with the demand to lessen the acidity content of the soil. Filtration process should be carried out to remove Iron. Regular monitoring and assessment of groundwater is necessary to ensure that the quality is within regulatory limits.

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