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Urbanization and Major Ion Hydrogeochemistry of the Shallow Aquifer at the Effurun - Warri Metropolis, Nigeria

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Abstract

Results from chemical analyses of forty dug well water samples in the Effurun-Warri metropolis show that mean pH is 7.1 and mean TDS is 193 mg/l. Representative mean levels of cation occurrence include Ca, Mg, Na and K at 6.13mg/l, 4.09 mg/l, 4.89 mg/l and 3.37 mg/l respectively. Mean anion concentration for bicarbonate was 8.20mg/l, 1.27mg/l for sulphate and 23.74mg/l for chloride. Physical and chemical parameters are thus well below WHO and Standard Organization of Nigeria drinking-water quality standards. Piper diagram plots of the data indicate that ground water is predominantly Ca+Mg+Na Chloride facie and that mixing and ion exchange processes control the dominant cation in space and thus at each specific locality. Leachates from the many, widely distributed and unregulated landfills and dumpsites have been identified as possibly the principal sources of major ion loading to groundwater. The ubiquitous onsite sewage treatment soak away pits also contribute major ions to groundwater. These two sources are thus accountable for any observed local spikes in groundwater chloride content rather than sea water intrusion as had been previously suggested.

Keywords: urban water, leachates, major ions, dump sites, ion exchange, Niger Delta, Benin Formation

1. Introduction

The quality of ground water and surface water in the Effurun - Warri metropolis, the densely populated hub of the oil and gas industry in the western Niger Delta, Figure 1, Figure 2 has attracted considerable research interest because in the absence of reliable formal public water supply systems the majority of an estimated population of up to one million residents (Babatola & Uriri, 2013), commerce and industry rely on self-supplies from dug wells and shallow boreholes. Thus, potential contamination of shallow groundwater with heavy metals from four primary sources have been suggested: oil and gas and related industry activities (Aremu, Olawuyi, Metshitsuka, Sridhar, & Oluwande ,2002; Nduka & Orisakwe, 2007, 2009; Emonyan, Akporhonor & Akpoborie, 2008; Etchie, Etchie & Adewuyi, 2011), leachates from unregulated garbage dumps (Akudo, Ozulu & Osogbue , 2010), road wash and storm water runoff (Egboh, Nwajei & Adaikpoh, 2000) and soils (Iwegbue, Nwajei, Ogala, & Overah, 2010). In addition, Olobaniyi and Owoyemi (2004; 2007) have also suggested possible chloride enrichment of the underlying aquifer by recharge from the tidal Warri River and its tributary creeks and argue that heavy ground water abstractions in parts of the city are potentially inducing sea water intrusion from the Atlantic Ocean. The influences of all these factors on the major element geochemistry and the quality of groundwater are not well understood.

Furthermore, published research on the chemistry of water from the area has usually been devoid of geolocated data points and this has hitherto severely limited the identification and closer examination of any inherent spatial and possible temporal trends in the occurrence of chemical constituents in groundwater. Thus the objective of this paper is to provide a description of the major element geochemistry of groundwater using geo-referenced data and against which future evaluations and trends in this highly vulnerable and rapidly expanding urban environment may be compared. The results reported herein constitute part of a groundwater evaluation study, partial results from which have been reported by Akpoborie, Uriri and Efobo (2014).

1.1 Study Area

1.1.1 Climate, Physiography and Drainage

The Effurun-Warri metropolis lies roughly between latitude 5^0 30'N - 5^0 45N and longitude 5^0 15'E - 5^0 50'E, Figure 2 and enjoys a hot (23^0C - 37^0C) and humid (Relative Humidity, 50 - 70 per cent) equatorial climate with a dry season that extends from about November to February, and a wet season that begins in March, peaks in July and October. 30-year mean annual rainfall is 3000mm (Adejuwon, 2011).

The area rests mainly on the Sombreiro –Warri Deltaic Plain (SWP) one of the distinguishable physiographic landforms resulting from Recent and modern delta top deposition in the Niger Delta (Short & Stauble, 1967; Allen,1965) the others being the Brackish Water and Mangrove Swamps (BMS) and the Fresh Water Swamps (FWS). The city is bound on its western edge by the BMS, swamp terrain that has so far limited city expansion in that direction.

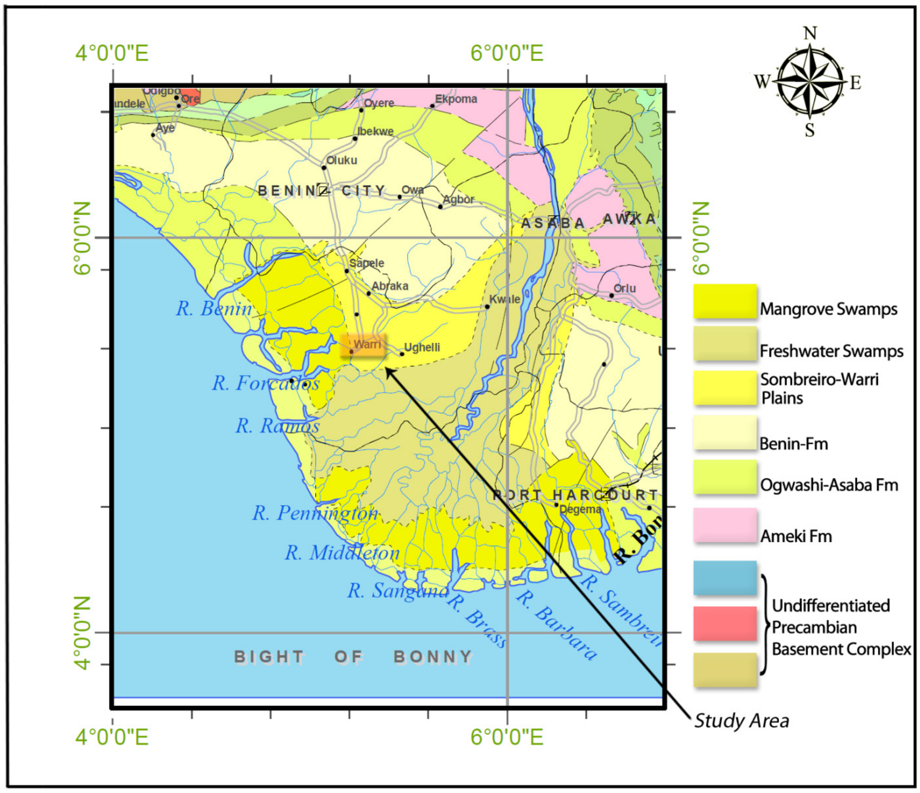


Figure1. Geological map of the western Niger Delta showing location of the Effurun-Warri Metropolis (Adapted from NGSA, 2004)

The Sombreiro –Warri Deltaic Plain is low lying, with an almost imperceptible seaward gradient and its lower parts merge with the water table and turn into swamps as evident in the Effurun-Warri metropolis. The area is circumscribed and drained by the tidal Warri River to the south and its tributary Ogunu/Edjeba Creek to the north, Figure 2. Mangroves line river banks especially in the western sector where they are sustained by weakly brackish water propagated landwards by a tidal regime.

1.1.2 Geology and Groundwater Conditions

The sedimentary fill of the late Quaternary delta top BMS and SWP physiographic terrains, Figure 1 has been described in the western Niger Delta by Akpoborie (2011) and in the eastern sector by Abam (2007) and Amajor (1991) and consists of an admixture of fine, to medium grained and coarse sands; silty clay and discontinuous thin clay layers. In the Effurun-Warri area, sandy layers are dominant up to 30m below ground at Osubi and Ejeba neighborhoods (Olobaniyi & Owoyemi, 2004), while further east Otobo, Aigbogun and Ifedili (2007) report the presence of up to 30m thickness of clay in the shallow aquifer at Aladja. In the western river port part of the city that is located on the boundary zone between the SWP and the BMS, Akpoborie (1996) describes two 100m deep boreholes that reveal a succession of black and gray colored silty clay and gravelly clay layers interbedded with coarse and medium grained sand beds. Because it has not been possible to distinguish between the younger Quaternary deposits and the Benin Formation proper in the subsurface, these delta top deposits are universally considered to be a continuation of the Benin Formation, Figure 1.

These shallow deposits are exploited everywhere in the Niger Delta with dug wells and shallow boreholes for domestic water supplies. Specifically in the Effurun-Warri area where public water supplies are inadequate, homeowners rely on groundwater from shallow dug wells and relatively inexpensive boreholes that are predominantly less than 40m deep. The dug wells and boreholes tap the medium to coarse – grained shallow aquifer sands. The permeability of the sands ranges from a reported $2.3x10^{-5}$cm/sec to $3.8x10^{-5}$cm/sec (Akpoborie, Ekakite & Adaikpo, 2000; Olobaniyi & Owoyemi, 2004; Niger Delta Development Commission, 2006). Deep regional groundwater flow in the Niger Delta region is reportedly in the west and south west direction (Ophori, 2007). In the Effurun –Warri area local flow in the shallow aquifer is controlled by a south westerly trending groundwater mound that extends from the Effurun GRA towards the neighborhood of Ekurede - Itsekiri and from which mound groundwater flows northwards, westwards, southwestwards and even eastwards (Akpoborie et al., 2014).

2. Methodology

Replicate water samples were collected from randomly located but evenly spread forty dug wells in the Effurun-Warri metropolis during a sampling program that was undertaken in mid - October, 2011. New, one litre size polyethylene bottles were used for collection of water samples. Prior to collection, the bottles were each washed with clean water and cleaning reagents then thoroughly rinsed with distilled, deionised water. After the pH, Total Dissolved Solids (TDS) and Electrical Conductivity (EC) were measured at point of collection, samples were sealed stored in ice chests and eventually transported to the laboratory within the hour of collection. The coordinates for selected sampling locations and associated codes are shown in Table 1 and Figure 2.

Electrical Conductivity and Total Dissolved Solids were measured *in situ* using the HACH Conductivity/TDS meters respectively. The pH was determined by means of a Schott Gerate model pH meter and the HACH Spectrophotometer was employed in determining the NO_3 ion using the cadmium reduction method. Na and K ion concentrations were obtained with a Jenway Clinical flame photometer. Sulphate content was determined by turbidimetry and Ca, Mg, HCO_3 and Cl with appropriate titrimetric methods as described by APHA (1992).

Table 1. Dug well water sampling locations at Effurun – Warri and sample codes used in the Piper and Stiff diagrams

Coordinates	Street Address	Sample Code
$N05^0 30.9$; $E005^0 49.13$	Boro Street, Oruhuwhorun	Orw
$N05^0 30.11$;E00549.16	Ero street, Oruhuwhorun	ORUWero
$N05^0 29.0$;$E005^0 49.7$	Apostolic Church, Aladja	Aladja
$N05^0 29.5$;$E005^0 45.5$	Umoji Compound, Aladja	AladjaUmoji
$N05^0 34.4$;$E005^0 47.6$	Arubayi Str Eff. GRA	Ef GRA
$N05^0 31.14$;$E005^0 46.10$	Inikoro Str Enerhen	enerhen
$N05^0 31.8$;$E005^0 44.6$	Ekpen Ajamimogha	Ajm
$N05^0 34.8$;$E005^0 46.5$	Army Barrack	ARM
$N05^0 34.6$;$E005^0 41.9$	Tenumah Str, Ubeji	UBTem
$N05^0 35.6$;$E005^0 33.9$	Ubeji health Centre	UBH
$N05^0 34.5$;$E005^0 41.13$	Deeperlife Camp Rd	UBdpl
$N05^0 34.6$;$E005^0 43.5$	St Gregory Hospital, Ubeji	UBStG
$N05^0 31.14$;$E005^0 43.12$	Ekurede-Itsekiri	UB K-Itse
$N05^0 30.8$;$E005^0 49.16$	Abuja street, DSC Township	DSCAbj
$N05^0 34.2$;$E005^0 44.11$	Ekpan	Ekp
$N05^0 32.6$;$E005^0 45.14$	Ugborikoko	Ogborik
$N05^0 31.9$;$E005^0 44.12$	Agbassa	Agbassa
$N05^0 32.6$;$E005^0 45.14$	Ugboroke close to dump site	Ugboroke
$N05^0 34.8$;$E005^0 46.5$	Mammy Market	MammyMkt
$N05^0 30.8$;$E005^0 42.6$	Ajamimogha	AJM2

N05^{0}34.5;E005^{0}43.5	Town Hall Ubeji	UBTH
N05^{0}34.12; E005^{0}49.10	70 Okuokoko	okuok
N05^{0}18.33; E005^{0}27.51	Iyara3	Iyara3
N05^{0}34.6;E005^{0}47.8	Dudu Crescent Eff. GRA	GRA
N05^{0}31.9; E005^{0}44.12	Okere	OK

3. Results and Discussion

3.1 Water Chemistry

3.1.1 Physical and Chemical Characteristics

Descriptive statistics of physical characteristics and major ion occurrence in ground water sampled at the different locations in the metropolis are shown in Table 2. Water ranges from mildly acidic, pH 5.2 at Iyara to alkaline, pH, 8.9 from a dug well near Ubeji Town Hall. Total Dissolved Solids (TDS) also varies widely from 545mg/l at Ubeji to 19mg/l at Abuja St., Steel Town, Aladja. Fifty seven per cent of all the samples showed a TDS of 200 mg/l or below while twenty five per cent have TDS of less than 100mg/l. The magnitude of range in spatial variation observed in all parameters suggests that mean values of parameters are of limited utility in describing shallow groundwater quality. However, on the basis of the data shown in Table 2, groundwater in the area is fresh and the major chemical constituents each occur at well below the limits specified in the WHO (2011) and SON (2007) drinking-water quality standards.

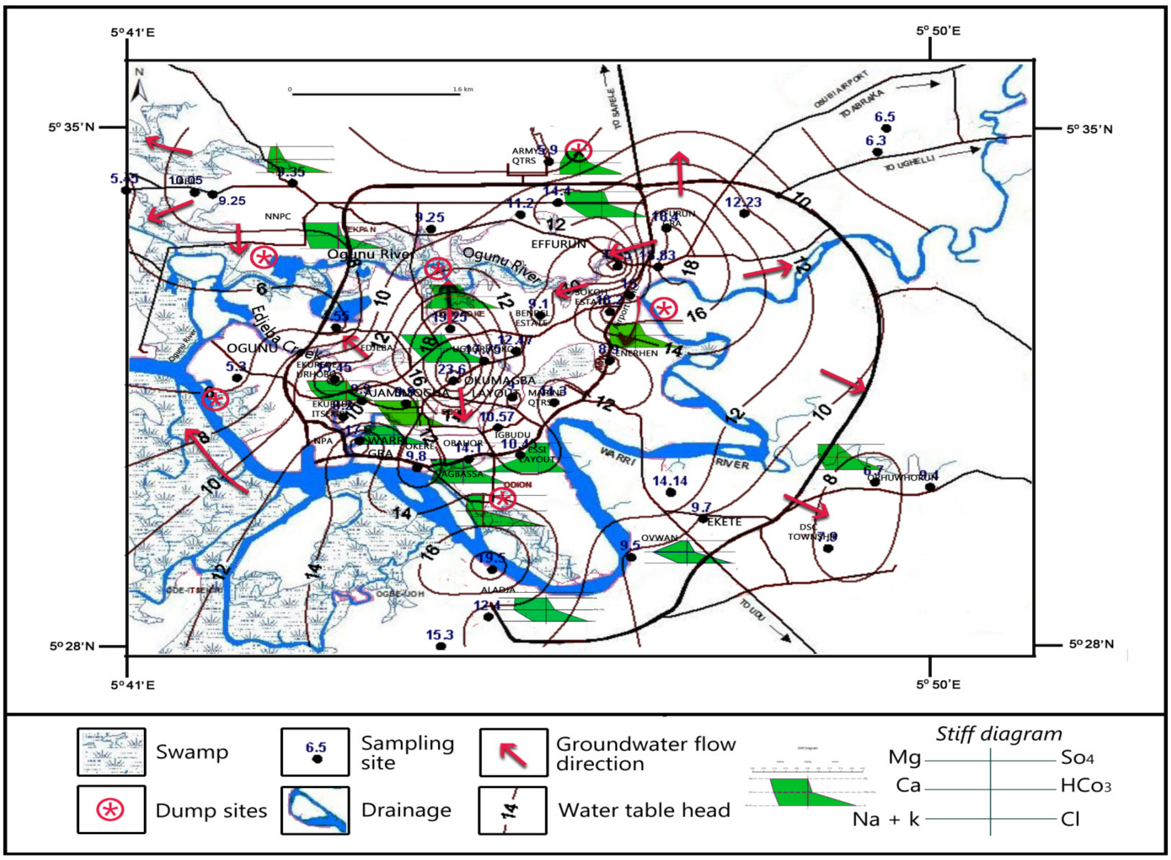


Figure 2. Map of Warri - Effurun area showing water table head distribution and Stiff pattern diagrams (Modified from Akpoborie, Uriri & Efobo, 2014)

These results appear to be in general agreement with previous studies undertaken in the metropolis, a selection of which include those by Akudo et al. (2010), Olobaniyi and Efe (2007) and Olobaniyi and Owoyemi (2004; 2007).

Table 2. Summary statistics of groundwater physical and chemical characteristics

N =40	**Min**	**Max**	**Range**	**Mean**	**Std. Deviation**	**SON (2007)**
pH	5.2	8.9	3.7	7.1	1.04	6.5-9.2
TDS (*mg/l*)	19	545	526	193.20	138.22	500
EC	22	1091	1069	381.14	272.50	500
Na (*mg/l*)	0.04	23.67	23.63	4.89	5.39	200
K(*mg/l*)	0.05	16.43	16.38	3.37	3.91	-
Ca(*mg/l*)	0.25	29.03	28.78	6.13	5.97	75
Mg(*mg/l*)	0.07	18.70	18.63	4.09	4.21	50
HCO_3(*mg/l*)	0.43	24.71	24.28	8.20	6.50	500
SO_4(*mg/l*)	0.0	4.30	4.3	1.27	1.20	200
Cl (*mg/l*)	1.59	104.21	102.62	23.74	22.0	200
NO_3 (*mg/l*)	0.0	5.5	5.5	1.01	1.28	50

3.1.2 Major Ion Geochemistry

The Piper (1944) diagram plot of analyses Figure 3 contains only selected samples because many samples plotted in the same position in both ternary diagrams and the central diamond. In order to reduce clutter many of such samples were removed from the diagram in order to reduce clutter. The ions plot linearly on the upper right quadrant of the Piper diamond reflecting variability and a well developed mixing trend that is also clearly reflected in the cation ternary plot. As a result of this, there appear to be no dominant cation and ground water is predominantly Ca + Mg + Na Chloride facie.

Data from Akudo et al. (2010) who suggested a relationship between dumpsite leachate chemistry and nearby borehole water quality have also been plotted in the Piper diagram, Figure 3. The leachate sample from this data, red circle plots in the lower quadrant of the diamond while borehole water (blue circle) is in near linear alignment with other dug well data. In the cation ternary diagram both borehole water and leachate plot together at the end point of a mixing line that is indicative and may be interpreted as a source of sodium enrichment (Smith & Wahl, 2003).

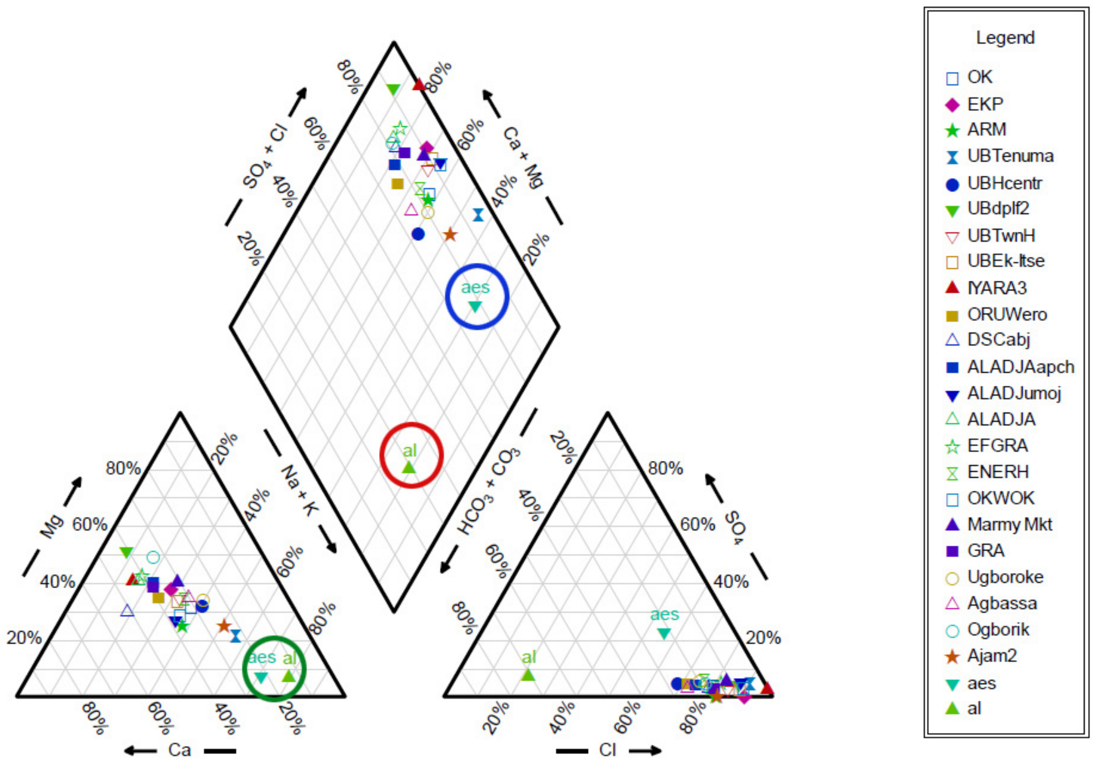


Figure 3. Piper diagram for dug well data and leachate data

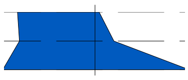
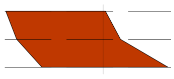
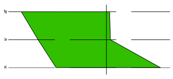
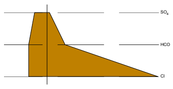
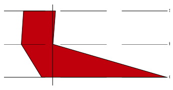
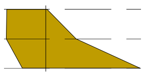
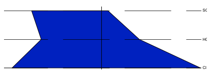
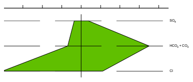
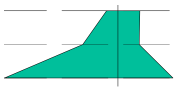
Notes: al = leachate from waste dump at Esisi area; aes = groundwater from domestic borehole near the waste dump; all other sample codes explained in Table 1. Data for the leachate and borehole water obtained from Akudo et al. (2010)

Dumpsite and landfill leachate and sewage are indeed known sources of chloride, bicarbonate, calcium and magnesium loading to native groundwater (Panno et al., 2006; Uma, 2004; Hanchar 1991; Bradley et al, 1987, Baedecker & Back, 1979). Thus Akudo et al. (2010) report dumpsite leachate concentrations of up to 932mg/l, 2,208mg/l, 170mg/l and 396 mg/l for Na, HCO_3, SO_4 and Cl respectively from dumpsites in Warri, while Efe, Cheke and Ojoh (2013) show that up to twenty five huge and open garbage dumpsites and landfills are randomly located in the metropolis, Figure 2. This is in addition to the potentially tremendous amount of sewage generated by close to a million persons from numerous home and industrial onsite septic tank sewage treatment systems.

The shapes, and spatial distribution of Stiff (1951) diagrams derived from chemical analyses of water from selected locations, Table 3 and Figure 2, also suggest groundwater mixing and the resultant transitory nature of ground water chemistry within short distances in this urban setting. Ion exchange involving Na, Mg and Ca is also suggested by the interchange in dominance of these ions in space as groundwater moves in the area. Mixing is enhanced by existing groundwater gradients that control complex and multiple directions of groundwater movement.

Thus while Aweto and Akpoborie (2011) identify the importance of water – rock interactions in determining the chemistry of shallow groundwater in the SWP deposits that occur in a more rural setting at Orerokpe, anthropogenic factors associated with urbanization in the Effurun-Warri area contribute significantly to ultimate groundwater chemistry.

Table 3. Stiff Diagrams and cation sequences at selected locations at Effurun-Warri

Stiff Diagram	Sample location/ code*	Cation sequence
	Okere /ok	Na+k>Ca>Mg
	Ekurede Itsekiri /	Mg>Ca>Na+k
	Ajamimogha/Ajam	Mg>Ca>Na+K
	Ubeji St Gregory's Hospital/ UbStG	Na+k>Ca>Mg
	Iyara3 /Iyara3	Ca>Mg>Na+k
	Boro St, Oruworun/ Orw	Ca>Mg>Na+k
	Ubeji health cmtr /Ubhcentr	Na+k>Mg>Ca
	Leachate **from Esisi dumpsite/al	Na+k>Ca>Mg
	Esisi area borehohe **/aes	Na+k>Ca>Mg

*Sample location code used in Table 1 and Piper Diagram, Figure 3

**Data obtained from Akudo et al. (2011)

However, potential direct recharge from an average annual 3000mm rainfall is high as indicated by reported groundwater level fluctuation in the wet/dry seasons of up to 5m (Akpoborie, Ekakite & Adaikpoh, 2000) in the SWP. This would enhance dilution of contaminating leachate and sewage as it mixes with native groundwater moving through the shallow aquifer and also possibly explain the low occurrence of the nitrate ion in groundwater, Table 2.

Therefore, evolution of groundwater chemistry in the shallow aquifer underlying the city appears to be driven by such factors as the infusion of dumpsite leachate that is an important source of bicarbonate, chloride and sodium ions into the system; direct recharge from mildly acidic and low pH rainwater (Efe, 2005, Olobaniyi & Efe, 2007), flood water and storm water from drains and gutters (Gobo, Amangabara & Agobie, 2014; Egboh, Nwajei, & Adaikpoh, 2000), untreated sewage and finally, the complex ground water flow patterns (Akpoborie et al., 2014) that exist in the area. Omo-Irabor, Olobaniyi, Oduyemi and Akunna (2008) have also stressed the influence of anthropogenic factors in the determination of water chemistry in the Niger Delta region.

Sea water intrusion into the aquifer underlying Warri-Effurun has also been suggested as an important process in perceived elevated chloride levels in shallow groundwater by Olobaniyi and Owoyemi (2004, 2007) and Olobaniyi and Efe (2007) who argue that sea water intrusion results from excessive ground water abstraction and also from recharging water from the tide influenced Warri River. However, Warri River and tributary creeks are perennial gaining rivers (Akpoborie, et al., 2014)) and there is no evidence of heavy groundwater withdrawals in any part of the city that has caused a reversal of existing gradients. Indeed, the Warri River and its tributary creeks carry predominantly fresh water (Aghoghovwia, 2011; Ogbeibu, Chukwurah & Oboh, 2011). Thus the presence of copious quantities of dump site-generated leachate and untreated sewage from ubiquitous septic tank soak- away pits in the metropolis suggests alternative and more credible sources of any and as has been shown, transitory chloride enrichment to shallow groundwater.

4. Conclusion

This study has shown that groundwater in the SWP deposits at the Effurun Warri metropolis has comparatively low mean TDS and major ions occur generally at levels that are well below SON and WHO drinking-water quality standards. However, because of rapid spatial and horizontal changes in major ion content, statistical mean values of major ion content should be used with caution.

Further, the evolution of groundwater chemistry in the shallow aquifer appears to be driven by urban induced factors that include infusion of dumpsite leachate that is an important source of bicarbonate, chloride and sodium ions into the system; direct recharge from acidic and low pH rainwater, flood water and storm water from drains and gutters, untreated sewage and finally, the complex ground water flow patterns that result from existing gradients and which enhance groundwater mixing.

Acknowledgements

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