CONTAMINATION INVESTIGATION USING GEOELECTRICAL RESISTIVITY AND HYDROGEOLOGICAL DATA: A CASE STUDY OF REGOLITH GROUNDWATER AROUND AGWAN-NEPA DUMPSITE, KEFFI, NORTH-CENTRAL NIGERIA

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ABSTRACT

Groundwater contained in regolith aquifer within Agwan-Nepa dumpsite and environs in Keffi (north-central Nigeria) was investigated to ascertain its contamination condition. Groundwater flow directions were established from static water table elevation measurements. Transverse unit resistance (T) and longitudinal unit conductance derived from geoelectric sections were employed in conjunction with spacing of water table elevation contours to capture variation pattern in hydraulic conductivity and permeability. Water filtrate obtained from a colloidal solution of soil sample taken at the dumpsite, and water samples from twenty different hand-dug wells were analysed for acidity level (pH), electrical conductance (EC) and total dissolved solids (TDS) at the Acme Laboratory in Vancouver BC, Canada. Topsoil and weathered basement are respectively very thin (0.4-0.8m) and slightly thin (4-7m) at the dumpsite and its immediate surrounding area. This creates high potential for groundwater contamination from dissolved solids migrating vertically downwards from dumpsite's surface load. Transverse unit resistance values for topsoil at dumpsite and its vicinity (100-160Ωm^2) indicate vertical hydraulic connectivity between the soil and the regolith below. The values also validate the existence of high potential for groundwater contamination at the dumpsite. The transverse unit resistance value for weathered basement increases outward from the dumpsite in a radial pattern. Its longitudinal unit conductance similarly decreases outwards. This reflects hydraulic connectivity between the dumpsite and its immediate surrounding area, and constitutes a potential for contaminant dissolved solids to migrate outwards from dumpsite to its vicinity. Values of pH, TDS, and EC decrease outward from the dumpsite, along the southerly direction of groundwater flow. This ascertains that a contamination plume exists at the dumpsite, and that the contaminant dissolved solids are dispersed southerly from the dumpsite. Values of pH, EC and TDS are respectively 7.18, 352µs/cm, and 197.6 mg/l at groundwater convergence zone in southwest of the dumpsite. This indicates that water at the convergence zone is uncontaminated and fit for drinking.

INTRODUCTION

Agwan-Nepa dumpsite is massive, located within Keffi in North Central Nigeria, and is defined by Latitudes 8°49'00"N, 8° 53'00"N and Longitudes 7° 51' 00'E, 7° 55'00'E (Fig.1). Many inhabitants of this area obtain drinking water from regolith aquifer.

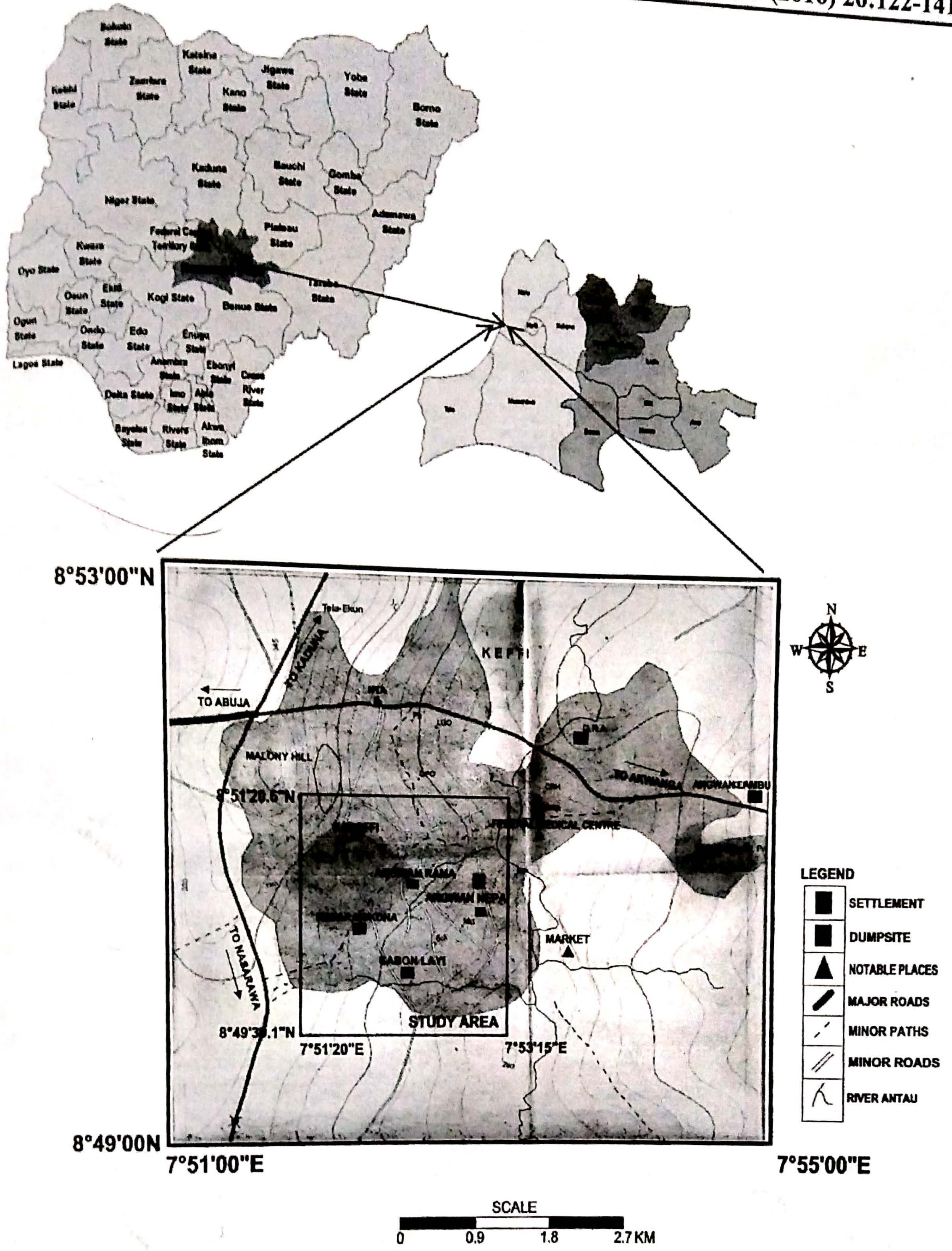

Figure 1. Location map of the Study area

PROBLEM INVESTIGATED

Inhabitants of dumpsite environments commonly suffer diseases such as osteomalacia, skin cancer, kidney failure and neurological malfunction that are linked with drinking of contaminated groundwater (Deming, 2002; Adegoke *et al.*, 2009; Ayolabi *et al.*, 2013; Singh *et al.*, 2015). This linkage creates the necessity to carry out contamination investigation of groundwater contained in the regolith aquifer in the environs of Agwa-Nepa dumpsite. It is conventional to employ low electrical resistivity values from surface geoelectrical survey to qualitatively delineate areas where groundwater is contaminated due to anomalously high amount of dissolved solids from dumped miscellaneous wastes (MacFarlane *et al.*, 1983; Becker, 2002; Rosqvist *et al.*, 2003; Jegede *et al.*, 2011; Carpenter and Reddy, 2011; Omolayo and Tope, 2014). The shortcoming in such approach is that highly clayey interval within the regolith could mimic similar low resistivity values, and thus misdirect interpretation. There is also a paucity of publications on the use of quantitative parameters derived from electrical resistivity measurements to infer migration direction of dumpsite leachates into regolith groundwater within dumpsite vicinity. This study employs permissible limits of physical parameter values prescribed by World Health Organisation (WHO, 2011) given in table 1 to assess contamination condition of groundwater in regolith aquifer within the environs of Agwan-Nepa dumpsite. It also attempts to deduce the migration direction of leachates from the dumpsite into groundwater using hydraulic conductivity parameters derived from electrical resistivity measurements, and spacing of groundwater isopotential lines (also known as water table elevation contours).

Table 1: Permissible limits of some physical parameters of potable water (WHO,2011)

PHYSICL PARAMETER	PERMISSIBLE LIMIT
pH	6.5-8.5
TOTAL DISSOLVED SOLIDS	300-600MG/L
ELECTRICAL CONDUCTANCE	400 µs/cm

Geology of the Study Area

The rock outcrops in the area are biotite granite, granite gneiss, banded gneiss and schists. The spatial distribution of the rocks is illustrated in Fig.2.

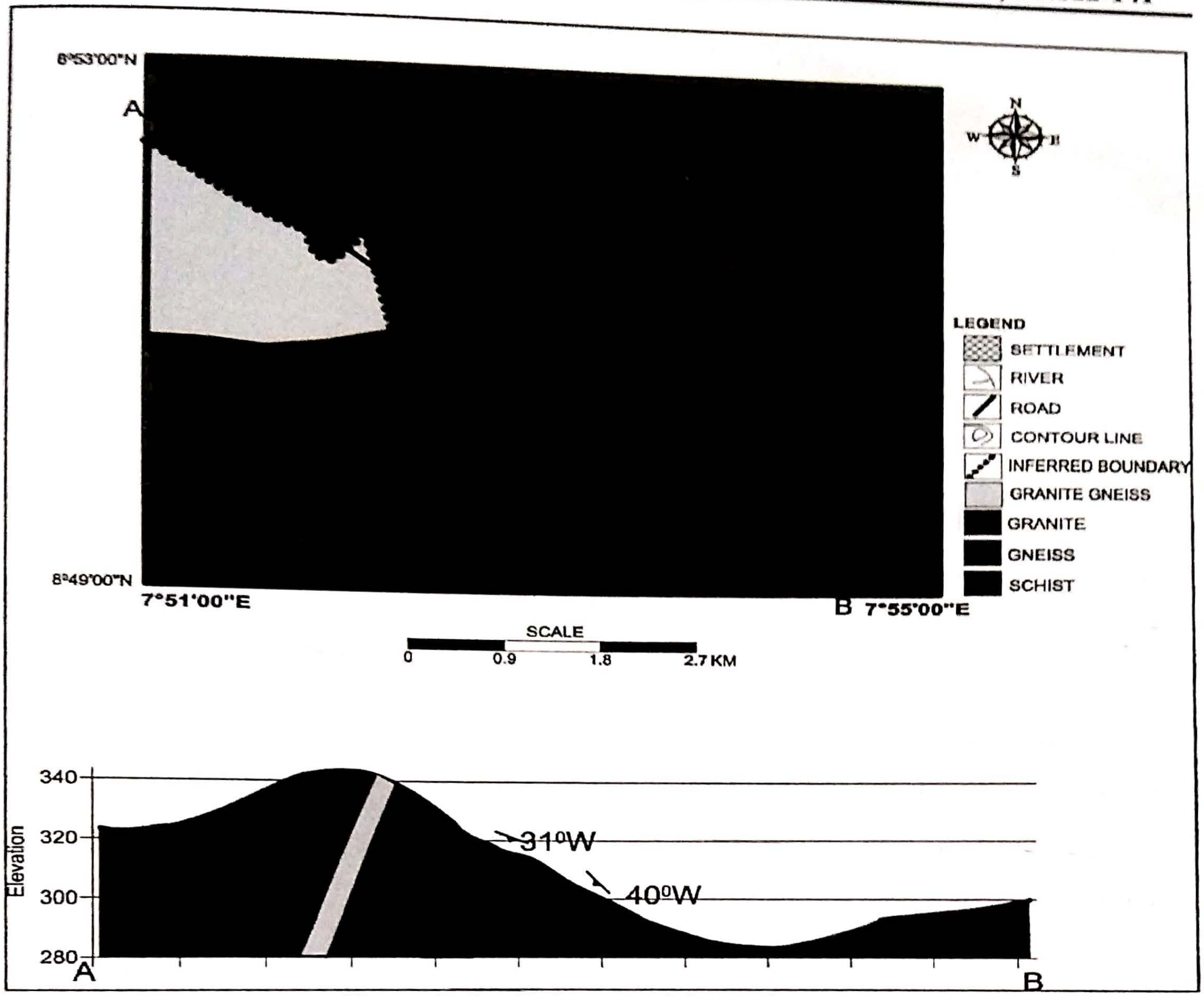

Figure 2. Geologic map of the study area

The biotite granite is an intrusive rock body between the gneiss and the schist, and between the gneiss and the granite gneiss. Figure 3 shows the contact between the biotite granite intrusive body with granite gneiss.

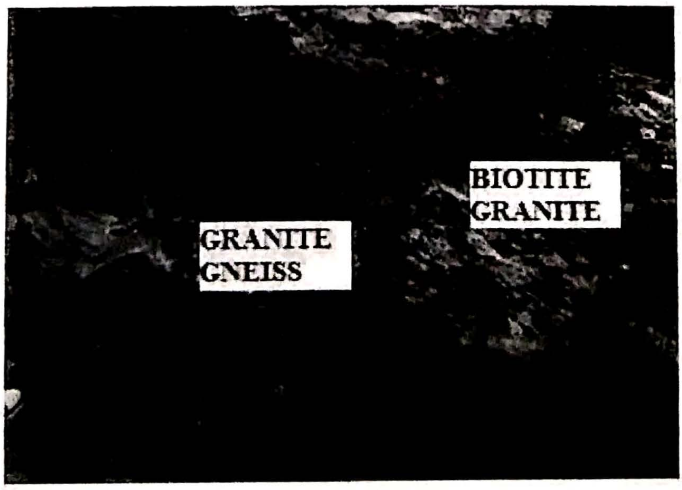

Figure 3. Contact between biotite granite and granite gneiss (0.7km SW of dumpsite site; N 8°51'07" E7°54'22.7"

Pegmatitic veins bearing yellowish minerals with metallic lustre (probably sphalerite, pyrite, chalcopyrite, - pathfinder minerals for gold) are hosted in the schist (Fig. 4).

The rocks are commonly jointed (Fig.5). The principal joints trend NNE-SSW, and NNW-SSE. They constitute a conjugate joint set. Some of the schist outcrops bear micro-faults (Fig.6).

Figure 4. Mineral bearing pegmatitic vein N8°50′ 05″ ; E7° 51′38.5″ (within Kofar Kokona)

Figure 5. Conjugate set of joints observed on granite outcrops (N 8° 51′ 01″; E 7° 52′ 10.8″)

Figure 6. Dextral faults at N8° 54' 05"; E 7° 52' 01"

METHODOLOGY

Detailed lithological mapping of the area was carried out. Static water table elevation was determined by subtracting depth to static water table (obtained using a water level indicator) from the elevation of the top of each well's concrete protection (obtained with a GPS). Water table elevation map was generated with Suffer 11 contouring software. Groundwater divide and groundwater flow directions were established for the regolith aquifer from the water table elevation map. Soil sample was taken from depth of 0.8m at the dumpsite. The sample was soaked in a clean plastic bottle containing one litre of distilled water and shaken vigorously. The resulting colloidal solution was left to settle for one week. This was then filtered and the filtrate labelled L0. Samples of groundwater were taken from the hand-dug wells, and labelled L1-L20. The L0 filtrate and other twenty samples were sent to the Acme Laboratory in Vancouver BC, Canada for determination of physical parameters (Ph, electrical conductivity, and concentration of total dissolved solids). Maps illustrating the spatial variations of the physical parameters were produced using Suffer 11. The values of these physical parameters were compared with WHO (2011) prescribed permissible limits, and thereby assessing their contamination condition.

Vertical Electrical Sounding (VES) was carried out at twenty locations, employing Schlumberger array with AB/2 (half electrode spacing) of 50 m. This ensures that the artificially generated electrical current reached the base of the regolith. Apparent resistivity (ρ_a) was determined as follows:

$$\rho a = \left(\frac{L^2-a^2}{a}\right)\frac{\pi}{4}R \qquad \text{.............................. 1}$$

Where 'L' and 'a' are respectively the distance between the two current electrodes and the distance between the two potential electrodes. R is the resistance (the quotient of the potential difference at the potential electrodes and the measured current between the current electrodes). Geoelectric sections were derived from interpreted resistivity data using Win Resist interpretation software.

Transverse unit resistance (T) and longitudinal unit conductance (S) were estimated for topsoil and weathered basement intervals, following Mailet (1974):

$$T = \sum_{i-n}^{n} hipi \qquad \text{.............................. 2}$$

$$S = \sum_{i-n}^{n} \frac{hi}{pi} \qquad \text{.............................. 3}$$

Where h_i and ρ_i respectively represent thickness and resistivity of interval concerned. Spatial variations in S, T, and true resistivity ρ were plotted and displayed as maps using Surfer11. The integration of groundwater elevation data, established groundwater divide and groundwater flow directions with the physical parameters data and data on S, T, and ρ was employed to establish the existence of a contamination plume at the dumpsite, and establish the migration direction of dissolved solids from contamination plume at the dumpsite to groundwater in the regolith aquifer.

DISCUSSION

The geoelectric curves obtained were mostly H-type, indicating top soil, weathered basement and fresh basement. Figure 7 is representative of these curves.

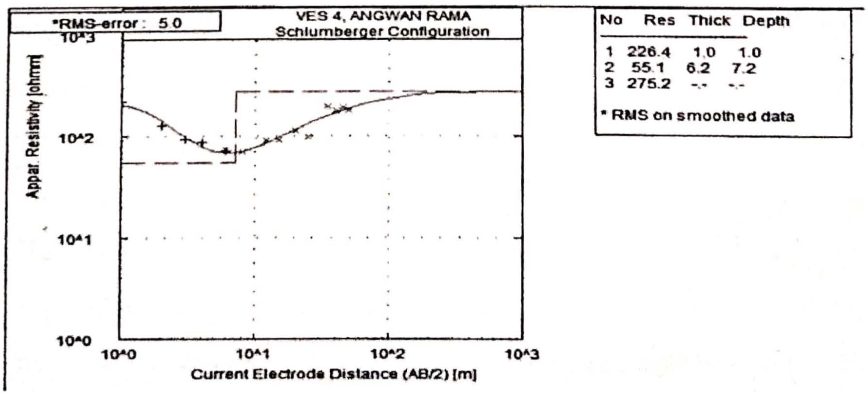

Figure 7. Representative H-type curve for Agwan-Nepa

Figures 8 and 9 illustrate the spatial thickness of the topsoil and weathered basement layers. The soil is thickest in the SW portion (ENE of L18, about 500m from A on profile). It is very thin (0.8-1m) within the dumpsite vicinity at Agwan-Nepa (about 300m from B end of profile) and in Karoffi area. The weathered basement interval is slightly thin (4.5-6.5m) within Agwan-Nepa dumpsite environs (about 650m from B end of profile). Regolith groundwater is more susceptible to contamination in such areas, where thin topsoil overlays thin weathered basement. This is because dissolved solids only have to travel a short distance from the topsoil to reach groundwater in the weathered basement.

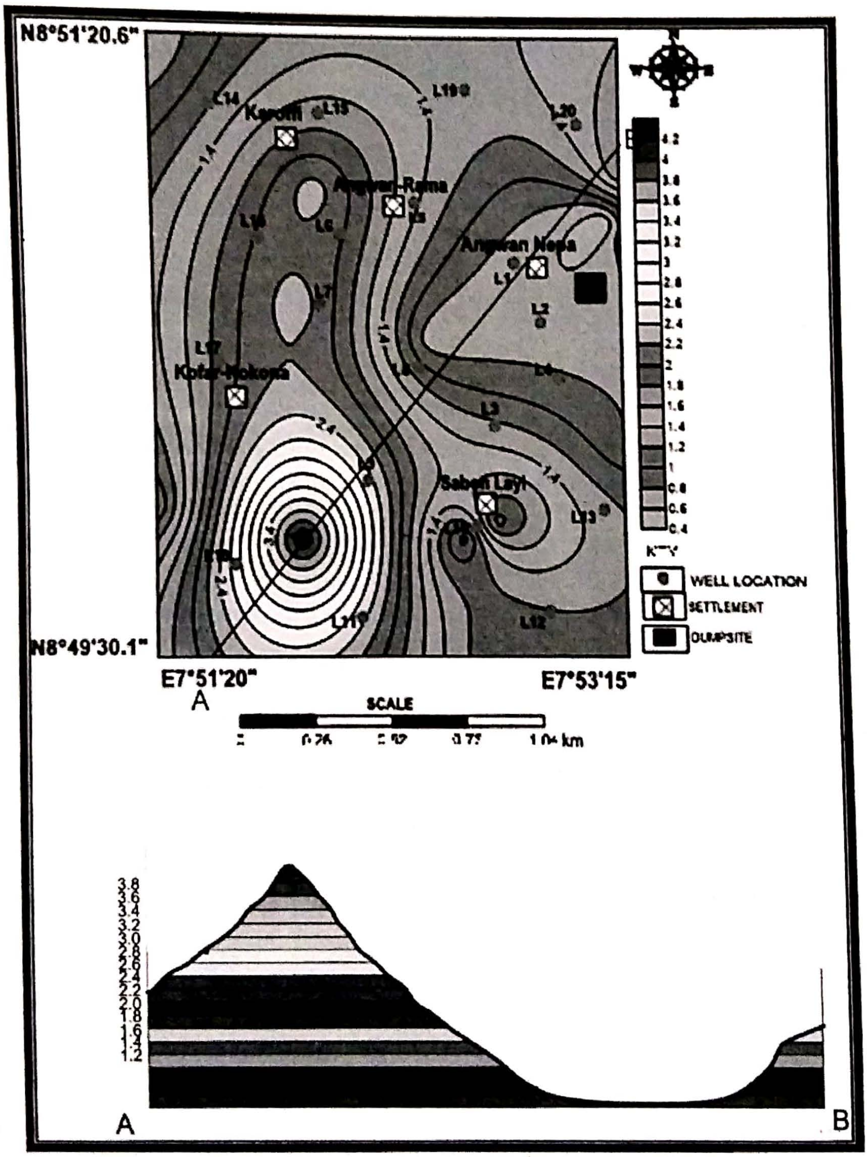

Figure 8. Topsoil thickness map

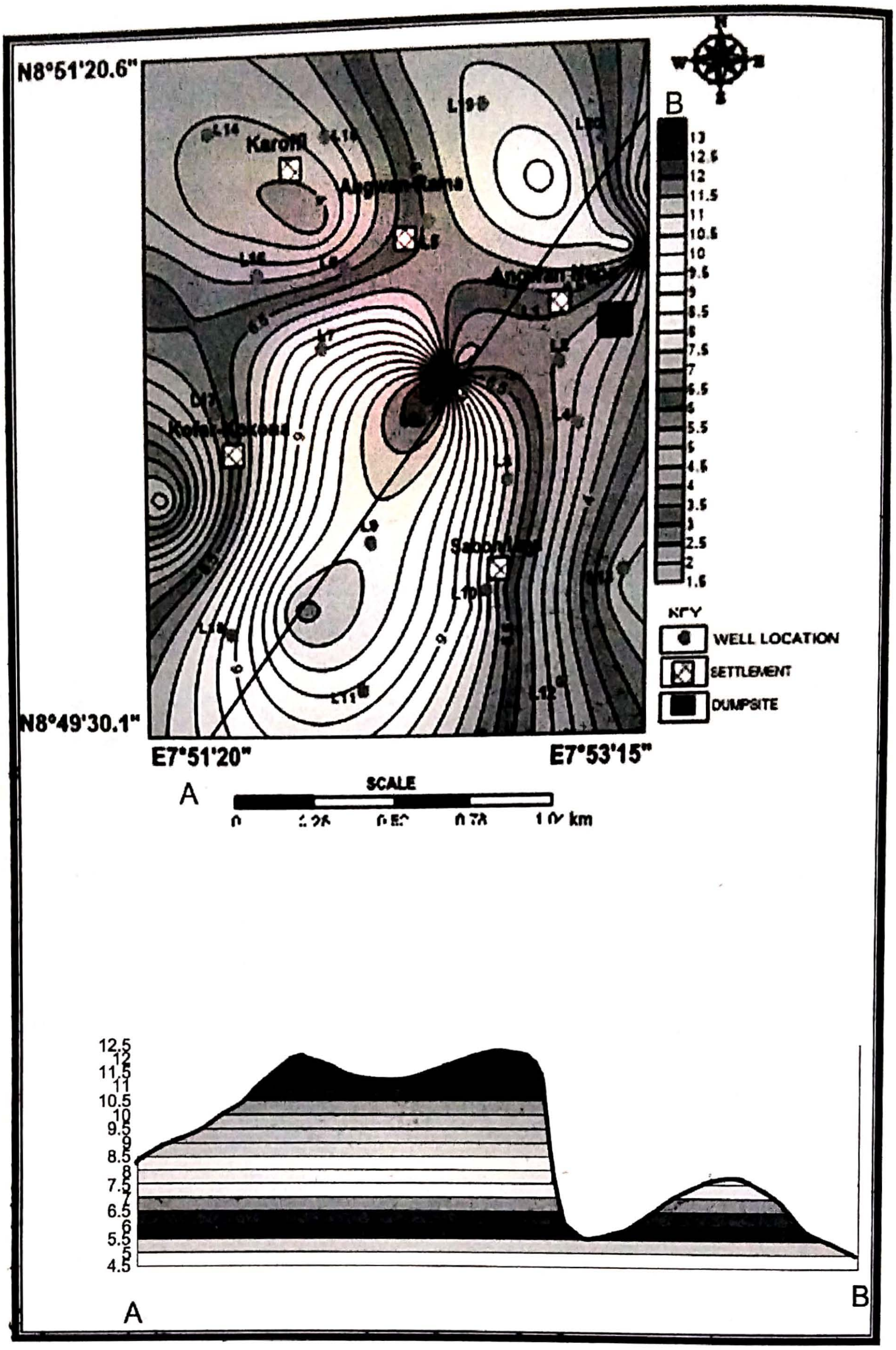

Figure 9. Weathered basement thickness map

Topsoil's isoresistivity map (Fig.10) shows very low resistivity values (40-80Ωm) around Karoffi and Sabon Layi, and moderate values (140-240 Ωm) around Agwan-Nepa (about 600m from B end of profile).

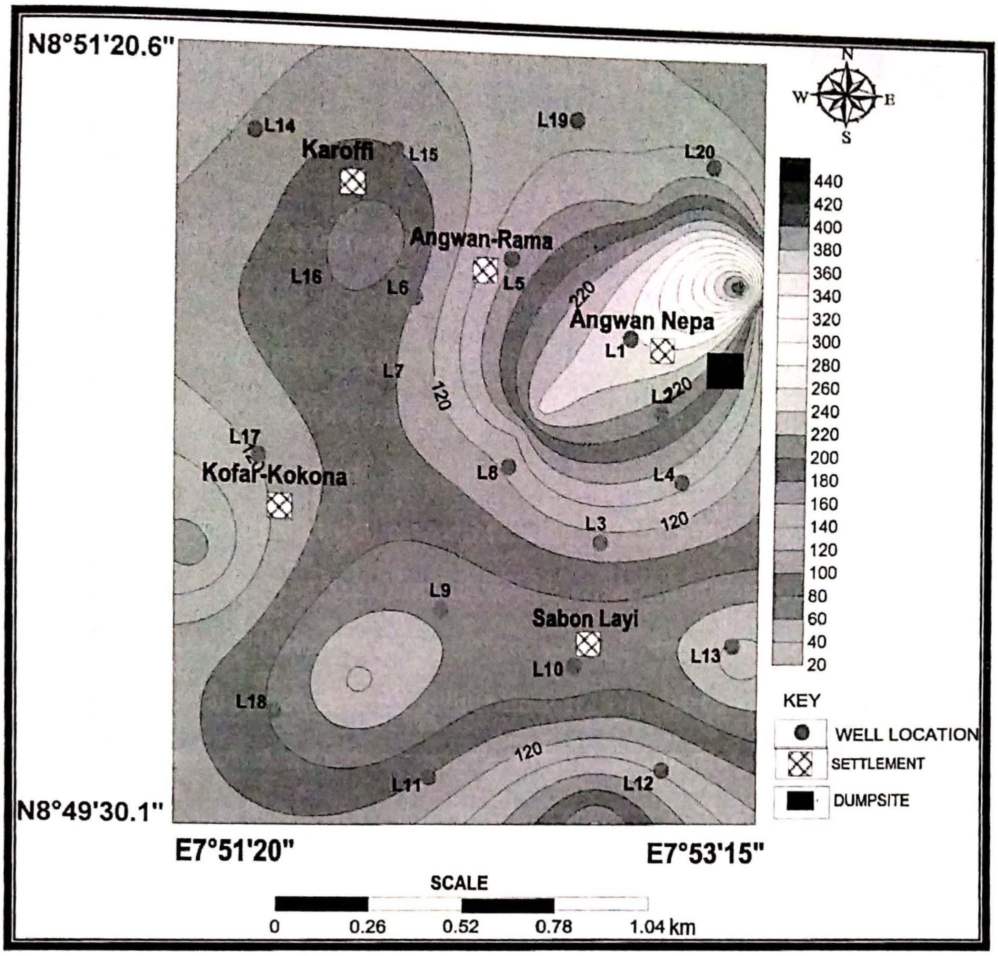

Figure 10. Topsoil's isoresistivity map

Weathered basement's isoresistivity map (Fig.11) indicates very low resistivity values (36-70 Ωm) within Agwa-Nepa dumpsite region (about 550m from B end of profile) and Agwan-Rama areas, and moderate values (85-95 Ωm) in the southern parts.

The spatial values of T for topsoil and weathered basement are shown in figures 12 and 13. Their spatial S values are given in figures 14 and 15 respectively. Topsoil's T is highest (190-200 Ωm^2) in the NE and eastern part of the study area, thus indicating that highest hydraulic conductivity in these areas (Mailet, 1974).

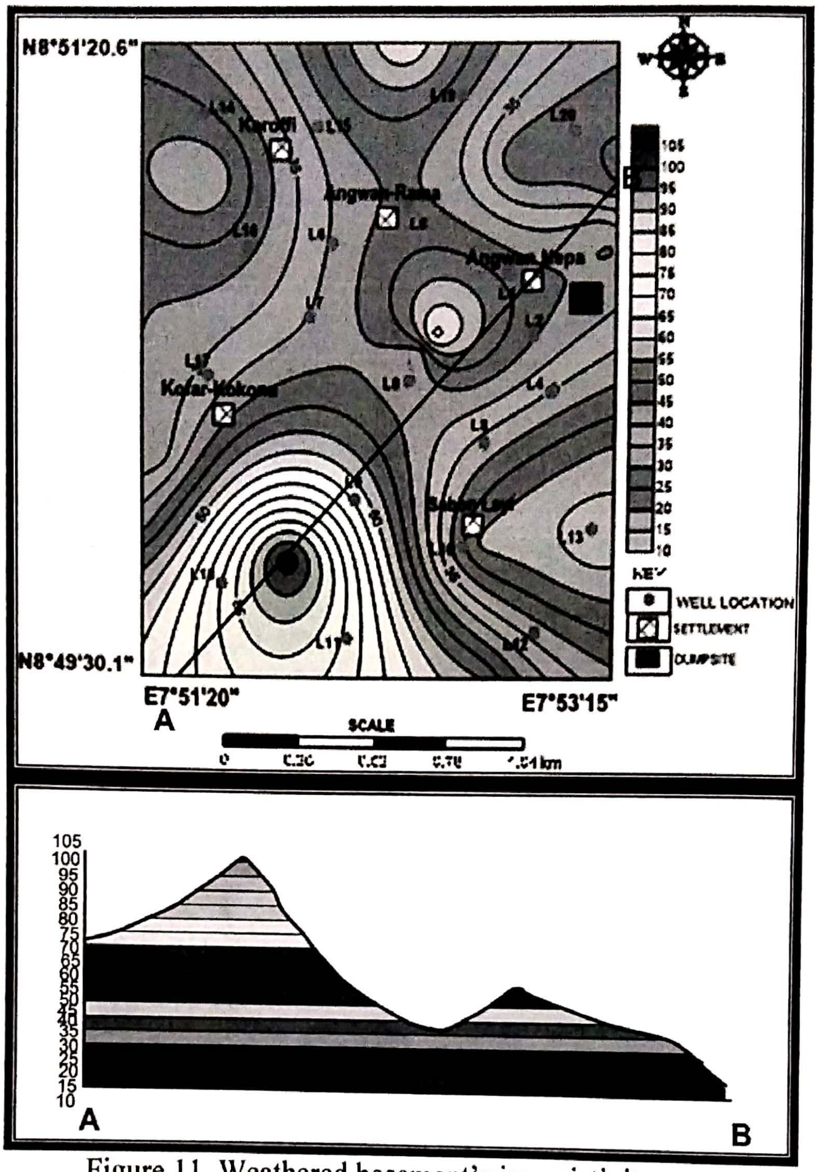

Figure 11. Weathered basement's isoresistivity map

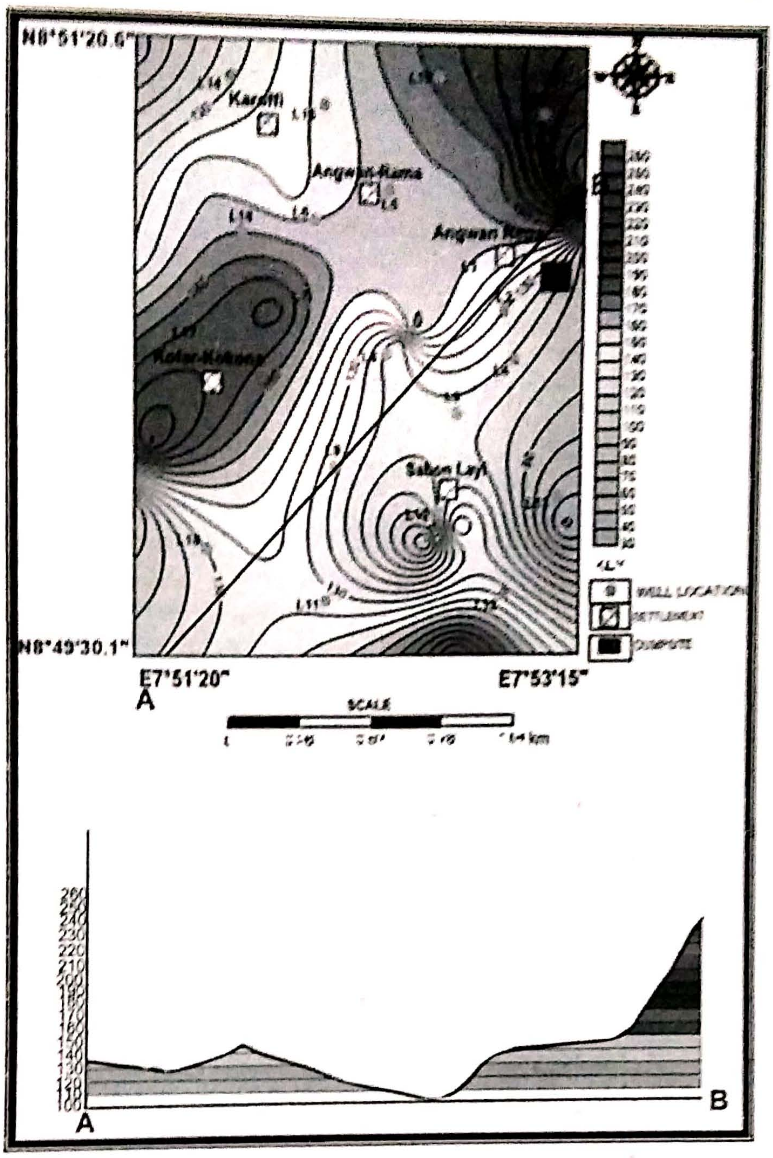

Figure 12. Topsoil's T map

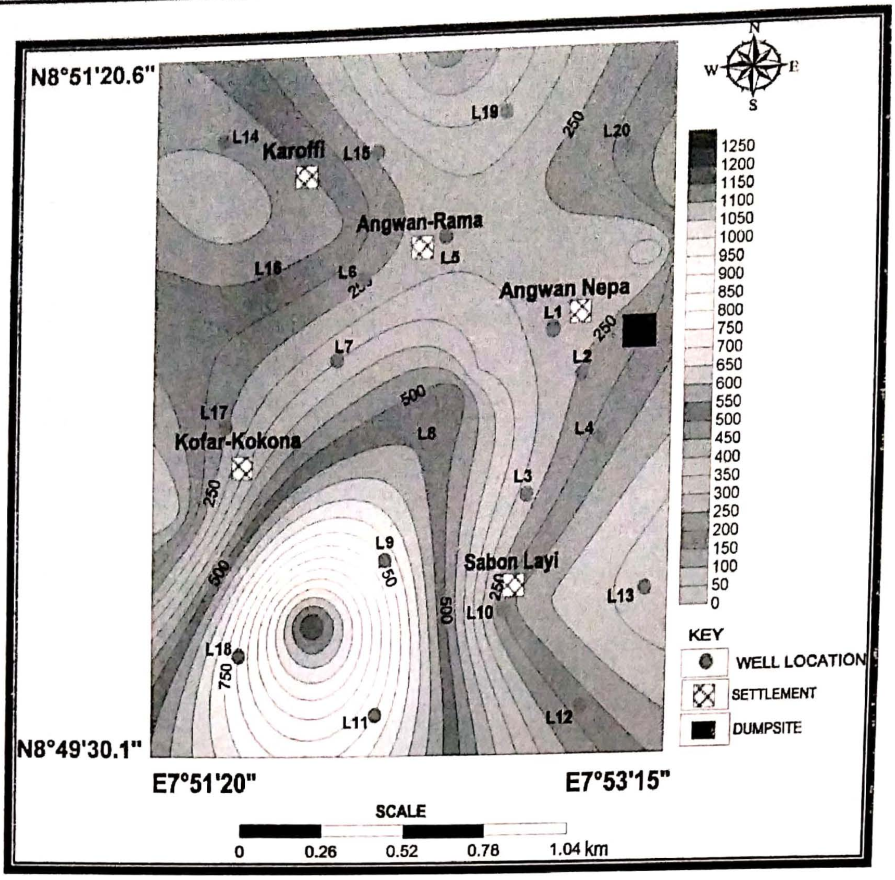

Figure 13. Weathered basement's T map

Moderately high values of topsoil's T (100-160 Ωm^2) dominate Agwan-Nepa, much of the central and southwestern parts, as well as the northwestern parts. These indicate moderate hydraulic conductivity of the intervals in these portions. Weathered basement's T value is moderate to high (150-350Ωm^2) at the dumpsite, and around Agwan-Nepa and Sabon Layi areas. It is very high (750-1250 Ωm^2) in the southern areas, and high in the central portions (350-550 Ωm^2). Figure 14 is topsoil's S map.

Low S values (0.005-0.01Ω) mark topsoil around the dumpsite. The S values are highest (0.075-0.115 Ω) in the southern portions, moderately high around Sabo Layi (0.015-0.035 Ω). Spatial distribution of weathered basement's S values is illustrated in Fig.14.

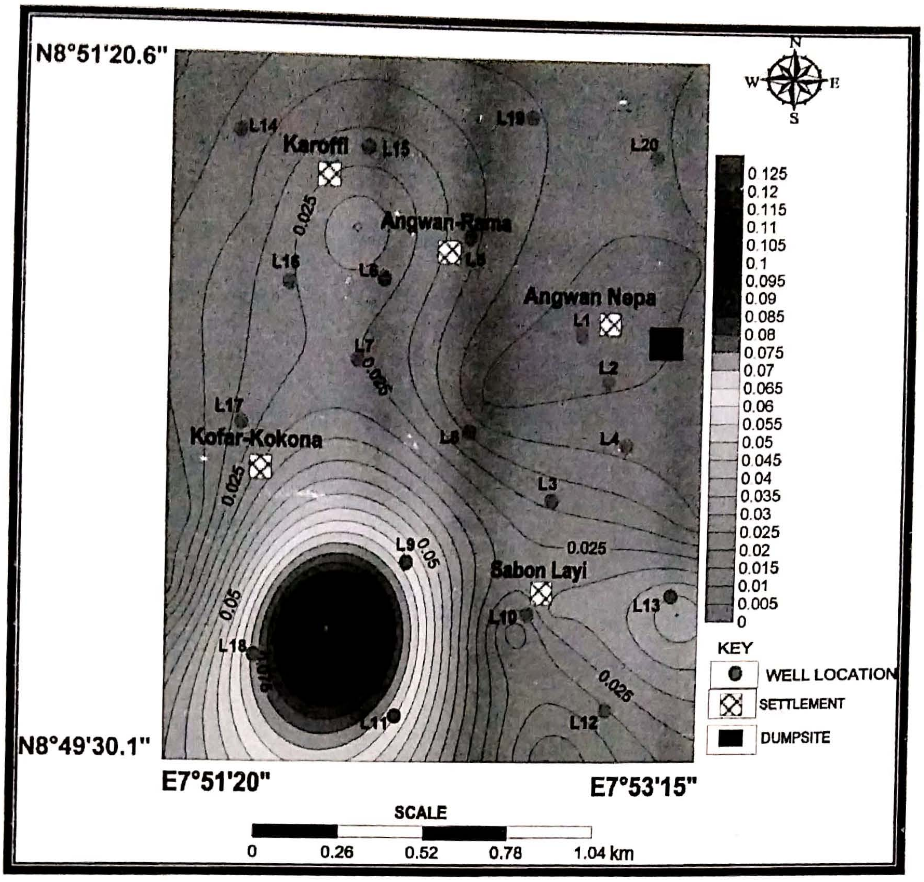

Figure 14. Topsoil's S map

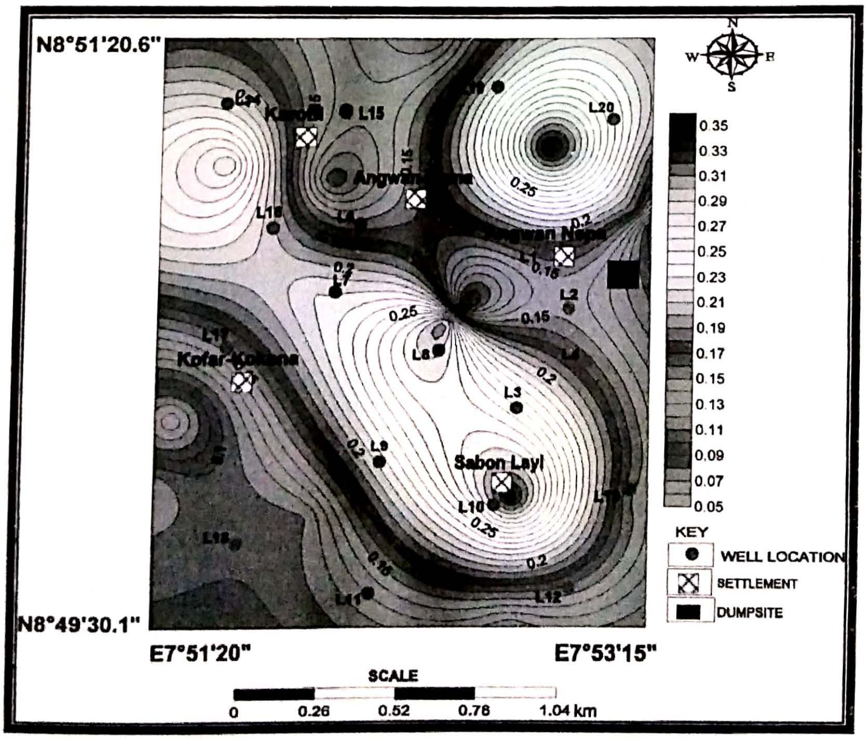

Figure 14. Weathered basement's S map

S is low (0.07-0.115 Ω) within weathered basement at the dumpsite, and quite high at Sabon Layi(0.29-0.33 Ω). Figure 15 is the static water table elevation map.

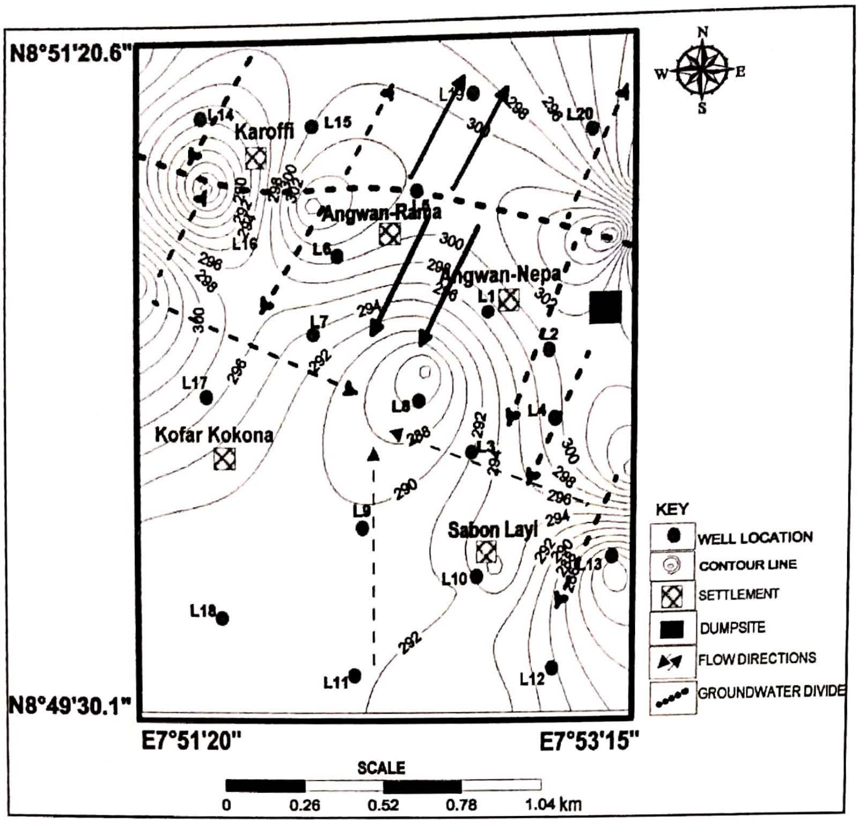

Figure 15. Static water elevation Contour map of Angwan-Nepa dumpsite and its environs

The groundwater divide trends NNW-ESE while the groundwater flows NNE on the north of the divide and SSW on its south. The divide terminates about 0.7Km SE of Karoffi. A groundwater convergence zone exists at about 1Km SW of Karoffi, which is about 4Km NW of the dumpsite. This indicates that groundwater flow system from the dumpsite does not extend up to 4Km NW of the dumpsite. Another groundwater flow convergence zone exists at 2.5Km SW of the dumpsite. This implies that the influence of groundwater from the dumpsite does not extend beyond 2.5Km on its SW portion. The rapid change in groundwater elevation, east of Sabon Layi (around L13) and around south of Karoffi (around L16) implies poor hydraulic conductivity, low permeability and transmissivity of regolith (combined topsoil and weathered layers) in these places. This is validated by low T and high S values that characterise these areas. Moderate values of T and low values of S reflect considerably high hydraulic conductivity, permeability and transmissivity within the regolith at the dumpsite. This is supported by slow change in groundwater table elevation values within the dumpsite vicinity. Acidity decreases generally away from the dumpsite (Fig.16). High acidity level (4.8-4.9 pH) at the dumpsite is attributed to the effect of incessant burning on the heap of junks of miscellaneous metals. The World Health Organisation (WHO, 2011) and the Nigerian Standard for Drinking Water Quality (NSDWQ, NIS554:2007) uphold pH range of 6.5 to 8.5 as limits for water fit and safe for drinking. The pH values (5.2-6.5pH) at 1.5Km distance range west and south of the dumpsite reflect that groundwater in the regolith aquifer in the area is contaminated from a point source constituted by the dumpsite. The pH values in the groundwater flow convergence areas ranges from 6.8 -7.0. This indicates dilution effects in these areas.

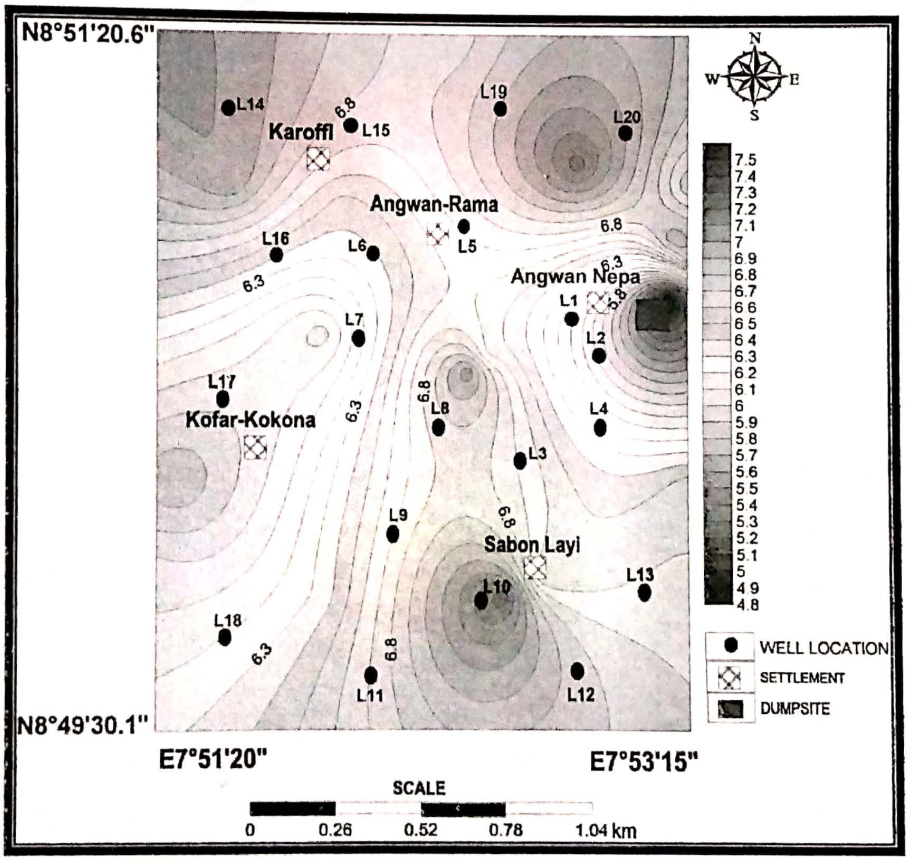

Figure 16. pH value contour map of Angwan-Nepa dumpsite and its environs

Groundwater's Electrical Conductivity (EC) map (Fig.17) reflects that EC decreases with decreasing pH, away from the dumpsite and following groundwater flow direction. This trend is reversed at about 0.7Km SE of Karoffi, where the groundwater divide from the dumpsite terminates. The regolith groundwater system present south of Karoffi is thus apparently unrelated to groundwater flow from the dumpsite, and therefore unlikely to be affected by migrating, contaminating dissolved solids from the dumpsite. The lowest EC around 2.5Km SW of the dumpsite coincides with a groundwater convergence zone and reflects effect of dilution on EC. EC value (>1200 μS/cm) is above WHO (2011) permissible limit within 1Km range south and southwest of the dumpsite, and 0.5Km range NW of the dumpsite. This indicates groundwater contamination in these areas.

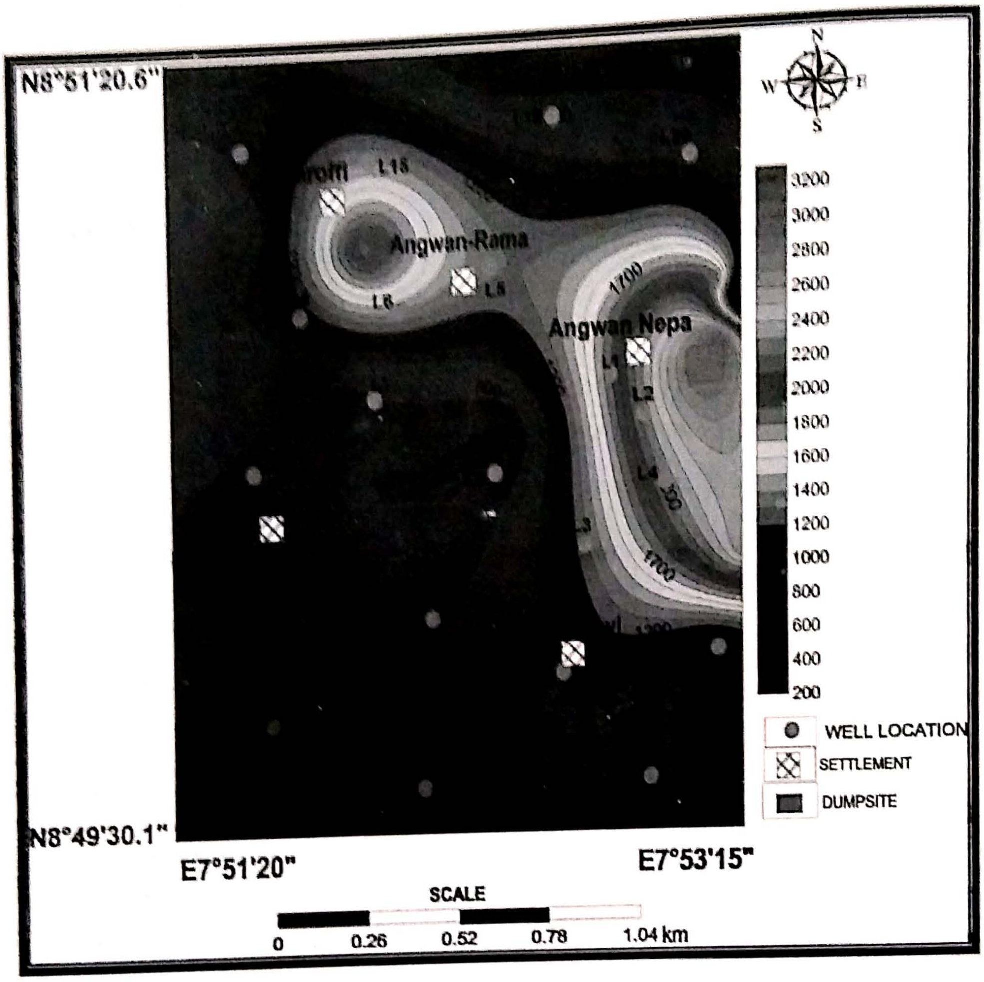

Figure 17. EC value contour map of Angwan-Nepa dumpsite and its environs

Figure 18(Total Dissolved Solids, TDS map) shows highest values of TDS at the dumpsite. TDS decreases rapidly away from the dumpsite, following the pattern of acidity and EC. Groundwater convergence zone at south of the dumpsite has very low amount of TDS, due to dilution effect. The portion of the study area with amount of TDS outside WHO (2011) permissible limit (500-1500mg per litre) coincides with portions with portions with prohibitive EC values (above 300µmhos per cm) and acidity level(outside 6.8-7.0 pH) . The reversal in the trend of TDS values between Agwan-Rama and Karoffi is similar to trend reversal for pH and EC values in the same area. This is likely because the area is unaffected by groundwater flow from the dumpsite.

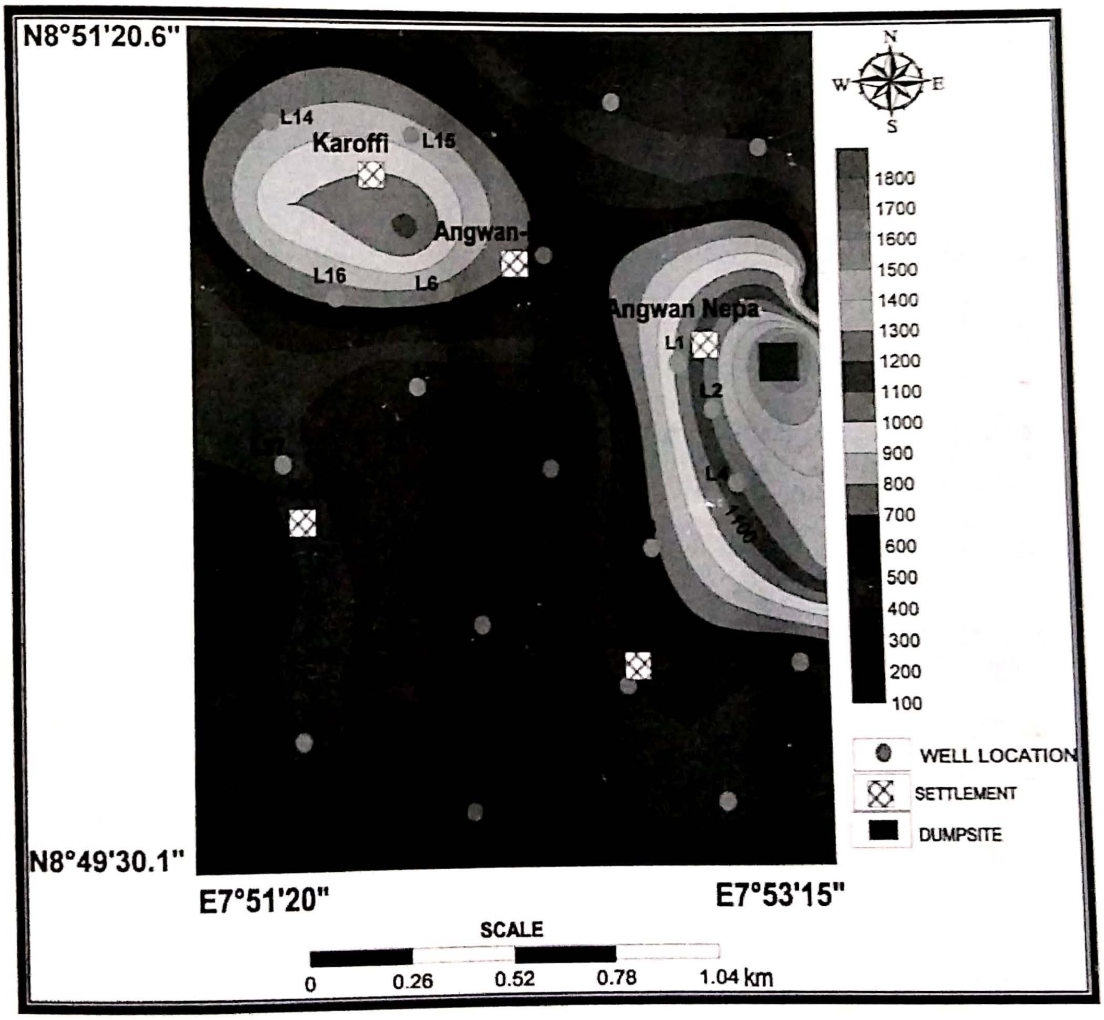

Figure 18. Amount of TDS contour map of Angwan-Nepa dumpsite and its environs

CONCLUDING REMARKS

Measured hydro-physical parameters have been combined with static water elevation data to establish the existence of a contamination plume at the dumpsite and identify contaminated areas around the dumpsite. Groundwater flow directions have been employed to identify groundwater convergence zones. Groundwater within the convergence zone at 2.5Km SW of the dumpsite has been revealed to be uncontaminated and fit for drinking.

Continued contamination should be arrested by relocating the dumpsite to the major groundwater convergence zone at 2.5km southwest of the its present site. The effect of dilution combined with thick intervals of soil and weathered would hinder contamination of groundwater contained in the regolith in this zone.

High-tech water purification systems employing reverse osmosis, deionisation and membrane reactor techniques are very expensive and beyond affordability of inhabitants of Agwan-Nepa, who commonly obtain water from hand-dug wells for daily use. Groundwater in the contaminated area can be purified cheaply by pumping water from the hand-dug wells into water collecting tanks, through perforated polymer –plastic discs lined with activated carbon. The dissolved contaminants would be adsorbed onto the surfaces of the activated carbon particles, and thereby cleanse the water of its contaminants before being collected in the tanks. This easy method is called carbon adsorption water purification technique. The activated carbon is produced by heating any plant in an airproof oven.

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Geo-chemical Assessment of Heavy Metals in Stream Sediments of Okun-Oshin Stream, in Ilorin, North-Central Nigeria.

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ABSTRACT

Contamination factor, degree of contamination, modified degree of contamination, geo-accumulation, ecological risk factor and pollution index, as well as statistical analyses were used to investigate hydrogeochemistry of some heavy metals in stream sediment along Okun Stream, a tributary of Asa-River in Ilorin. Six (6) different locations were sampled analyzed for heavy metals using atomic absorption spectrophotometer (AAS). The Contamination factor level revealed low degree of contamination with nil to very low degree level for modified degree of contamination for all locations. Geo-accumulation Index indicated that the study area was unpolluted for Pb, Cu, Cd, and Ni for the sediments collected at the point of wastewater discharge. Geo-accumulation Index revealed that the sediments were slightly polluted for heavy metals contamination for all sampling locations. Samples around the pharmaceutical industrial discharge point showed high ecological risk potential for Pb, very high risk for Cr and moderate risk potential for Ni. While, Pb and Cu showed high to considerable ecological risk level for most locations. Also, location 7 showed high potential for Ni, upstream and downstream Okun river revealed considerable ecological risks potential for Cr. Pollution Index were found to be generally less than One (<1) for all location. The mean concentration in mg/kg of heavy metals in the river sediments indicated Pb, Cd and Cr are above the world shale values and therefore constitute pollution threat in the study area. Strong positive correlations were observed between, Pb, Mn, Ni Cr,Cu, Cd and Zn, indicating similar geochemical source or common sink. The result of cluster analysis shows two cluster groups, in which Cd, Ni, Pb, Cu, Cr, Zn, and Mn to originate from mixed sources or a retention process, based on similarity coefficients. So, Okun- Oshin stream is facing probable environmental pollution especially with toxic heavy metals, such as Pd, Cr and Ni, which result from increased rate of domestic and industrial wastewater discharged into the rivers. This may have consequence on Asa-River downstream, which is the major river for groundwater recharge in the area.

Keywords: Hydrogeochemical assessment, Heavy metal, Stream sediment Geochemistry, contamination, Asa river

INTRODUCTION

Toxic heavy metals such as Cd, Cu, Zn, Ni, Pb, Cr, Mn and so on, are associated with waste water from industries that create environmental problem. This untreated industrial discharge or poorly treated industrial waste water, effluent and sludge into the surrounding, which decrease soil quality by elevating concentrations of heavy metals in sediments rather than natural enrichment of the sediments by geogenic processes. These heavy metals accumulate in the sediments through complex physical and chemical adsorption mechanisms depending on the nature of the sediment matrix and properties of the adsorbed compounds. So it is imperative to find out the toxic status and heavy metals in the river sediments for subsequent environmental problems redress, in order to adopt a future mitigation strategy. In developing countries like Nigeria, in which most industries dispose their effluents without treatment, these effluents are hazardous, reduced water quality. Pharmaceutical effluents are wastes generated by pharmaceutical industries during the process of drugs manufacturing and these wastes contain substantial amounts of heavy metals. Most pharmaceutical effluents are known to contain varying concentrations of organic compounds, total solids including heavy metals, such as Hg, Cd, Cu, Zn, Ni, Pb, Cr, (Foess and Ericson, 1980).

Olade(1987) observed that as West Africa becomes industrialized and urbanized, heavy metal pollutions is likely to reach disturbing level and that soil pollution are quite similar to those for water. Over the years, so many research studies on pollution on Asa River. Ibrahim, *et al.*, 2013 assesses trace element indices in the characterization of hydrogeochemical condition of Asa River and revealed high trace elements concentration when compared with standards. Others includes; Adekola *et al.*, 2006, Uka et al., (2012), Ige et al., (2010). In other geographical area, Sekabira *et al.*, (2010) assessed heavy metal pollution in the urban stream sediments and its tributary in Nakivubo Channel Kampala, Uganda. So, this study tends to investigate heavy metal pollution status in sediments of Okun and Oshin stream, as a result of waste water discharges from a pharmaceutical industry, using statistics and pollution single indices (contamination factors), geo-accumulation, pollution load index and ecological risk factor.

Plate 1: Point at which waste discharges into the stream

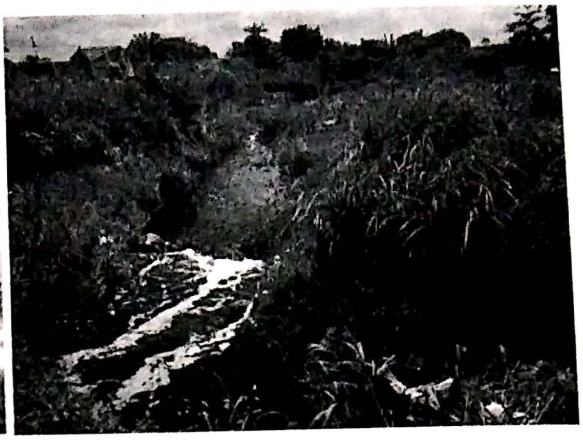

Plate 2: Oshin river flow to join River. Okun

Plate 3. Pharmaceutical Effluents from Tuyil firm

Plate 4. Okun flowing to join Asa-River

MATERIAL AND METHODS

The Study Area

Location and Site description

The study area lies within Longitude 4^0 32′E – 4^0 35′E and Latitude 8^0 26′ 30"N– 8^0 29′30"N (Fig.1), part of sheet 223NW Ilorin. Sample points are located along the Okun-Oshin River, as shown in (Fig.1). Okun and Oshin rivers are tributaries of Asa-River, the former takes its source in Adewole area and flow through sawmill area while the latter takes source around Irewolede, flow through global detergent factory area along Asa-Dam Road. Both streams later join behind the state stadium complex, Taiwo Road and flow behind the pharmaceutical industry, along Yidi brigde before joining Asa-River around Nigerian Bottling Plant in Coca-Cola Road.