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Evaluation of pollution status of heavy metals in the groundwater system around open dumpsites in Abakaliki urban, Southeastern Nigeria

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The occurrence of various heavy metals such as iron (Fe), nickel (Ni), cadmium (Cd), mercury (Hg), manganese (Mn), lead (pb) and arsenic (As) as major contaminants in the Abakaliki dumpsites has been established in this research. Four dumpsites namely the Waterworks, the New layout, the Rice mill and the Iyiokwu, all within the Abakaliki metropolis, were used for this research. Water samples (from bore holes, hand-dug wells, ponds and streams) were collected around these dumpsites and analyzed to ascertain the level of pollution. The atomic absorption spectrophotometer (AAS) was used for the determination of the concentration of heavy metals. Results show that the water works road dumpsite is a major source of contamination to the ground water system and should be relocated to a safer site. While dumping activities within the New layout dumpsite should be continued due to absence or low concentration of these metals in the groundwater system, it is recommended that resistivity methods of geophysical survey be carried out on the Iyiokwu and Rice mill dumpsites to ascertain the viability of the subsurface geologic layers to combat infiltration.

Key words: Pollution, heavy metals, groundwater, dumpsites, Abakaliki, Nigeria.

INTRODUCTION

Heavy metals are found naturally in the earth. These are metals with high atomic number, atomic weight and a specific gravity greater than 5.0. Heavy metals include some metalloids, transition metals, basic metals, lanthanides and actinides. Metals with high toxicity are considered as heavy metals. Heavy metals become concentrated as a result of human activities such as mining, industrial and domestic wastes. Other sources are vehicle emissions, lead-acid batteries and other materials from the automobile mechanic workshops, fertilizers, paints and treated woods.

Open waste dump is a land disposal site at which wastes are disposed off in a manner that does not protect the environment. They breed vectors of disease, reduce the aesthetic values of the environment, cause nuisance and produce leachate which infiltrate into the hydrogeological system. Different Sources such as garbages, spoilt foodstuffs, electronic goods, painting waste, used batteries among others, when dumped with municipal solid wastes raise the concentration of heavy metals in dumpsites. Dumping devoid of the separation of hazardous waste can further elevate noxious environ-

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mental effects. Environmental impact of land filling of municipal solid waste can usually result from the run-off of the toxic compounds into surface water and groundwater (Belevi and Baccini, 1989) which eventually leads to water pollution as a result of percolation of leachate (Beaven and Walker, 1997; Rajkumar et al., 2010). The occurrences of various heavy metals such as Mn, As, Cr, Cd, Ni, Zn, Co, Cu and Fe in manucipal solid waste dumpsites have been reported by many workers (Hoffmann et al., 1991; Esakku et al., 2003; Amusan et al., 2005; Ogundiran and Osibanjo, 2008). Due to the possible negative impact of heavy metals on the soils, an environmental study of this nature becomes necessary to nip it in the bud (Biswas et al., 2010).

In the Abakaliki metropolis, open wastes abound, ranging from small sizes generated by individuals and families to large sizes around market places, communities and streets. The poor method of dumping and evacuation by waste management authorities have made it possible for these waste to accumulate over time and deteriorate. This has led to the emission of odours and leachates from these dump sites especially the water works, Rice mill, New layout and Iyiokwu dumpsite.

As the years go by there is a geometric increase in the population of the inhabitants of the Abakaliki metropolis owing to the fact that it is a state capital. This development has in turn placed a very high demand on the water supply system in the town. The primary source of water supply for domestic purpose in the area is the ground water system which is made available through the proliferation of boreholes (both government and private owned) in the town. Considering the fact that the Abakaliki Urban is known for its shallow depth to groundwater (30 to 40 m) (Aghamelu et al., 2013), our interest in these waste dumps lies in assessing the pollution threat these wastes may pose to the health of individuals since they may contain hazardous substances (heavy metals) which may infiltrate with time, as pollutants, to the hydrological system (either surface or ground water) in these localities. This is necessary when considering the fact that some of the dumpsites are either near the Iyiokwu or the Iyiudele Rivers which provides an aqueous medium for these leachates to move in the environment. A text of the physical properties of the soils around these dumpsites has shown that they are prone to infiltration (Obasi et al., 2015a). Hence, the primary objective of this paper is to evaluate the pollution status of the heavy metals in the groundwater system around these open dumpsites in Abakaliki urban in order to establish if the presence of these waste dumps in their present locations is in anyway constituting a source of threat to human life by indirectly polluting the water supply system of the town.

Location of the study areas (the four dump sites)

The study area (Abakaliki urban and environs) is located within Abakaliki and Ebonyi Local Government areas of Ebonyi State, South Eastern Nigeria (Figure 1). It lies within latitudes $6°15^{1}$N and $6°20^{1}$ and longitude $8°05^{1}$E and $8°10^{1}$E. The Iyiokwu dumpsite (Figure 1 L4) is located along the Enugu – Abakaliki road, beside the Iyiokwu River but before the Spera In Deo junction. It is quite strategic and as well accessible anytime of the day. This dumpsite has been in use for more than thirty years now. The Rice mill dumpsite is located within the premises of the popular Abakaliki Rice mill, along old Ogoja road (now Sam Egwu way) Abakaliki (Figure 1, L3). The major waste disposed here is rice husk which are produced from the mills. The New layout dumpsite is located very close to the New layout primary school Abakaliki (Figure 1, L2). It has existed for more than 20 years and is believed to have been in constant use as a refuse disposal site all through these years. Its proximity to the tarred road makes it accessible to both young and old. The Water works road dumpsite is located along the road but very close to the Ebonyi State University College of Agricultural Science (CAS) school gate (Figure 1, L1). It is at the base of the popular Juju hill in Abakaliki. The Juju hill is a conical hill formed by the outcropping of the volcanic rocks that characterize the Abakaliki area. The dumpsite is as old as the city of Abakaliki.

Physiology/climate

Abakaliki and its environs are generally characterized by flat topography due to the underlying shale with very few elevated points resulting from igneous activities in the area which led to the formation of few conical hills. The highest elevation in the study area is represented by the popular Juju hill which is about 300 m above sea level (Aghamelu et al., 2011). The predominant shale has favored the low erodability of the lithology, resulting in absence or near absence of deep cut valleys and erosion channels (Aghamelu et al., 2011). The major river that drains the area is the Ebonyi River and its tributaries; Udene and Iyiokwu Rivers. Both tributaries are perennial and usually overflow their banks at the peak of wet seasons. This area is characterized by two climatic seasons; the wet and dry seasons, also known as the rainy and harmattan seasons. The rainy or wet season starts in April and last till October with heavy rainfalls recorded in the months of June, July and September. There is usually decline of rainfall in August. This is usually referred to as “August break”. The rainy season is usually a period of high humidity, generally low temperatures and low evapo-transpiration. The main soil types found in Abakaliki area are silty - hydromorphic soil. This soil has moderate to reddish-brown silty-clay subsoil. This soil has moderate to low drainage properties with a fairly high natural fertility rate. It provides very good yields of crops ranging from vegetables to tubers. This accounts for the major occupations of the people. The vegetation of the area is mostly characterized by tree

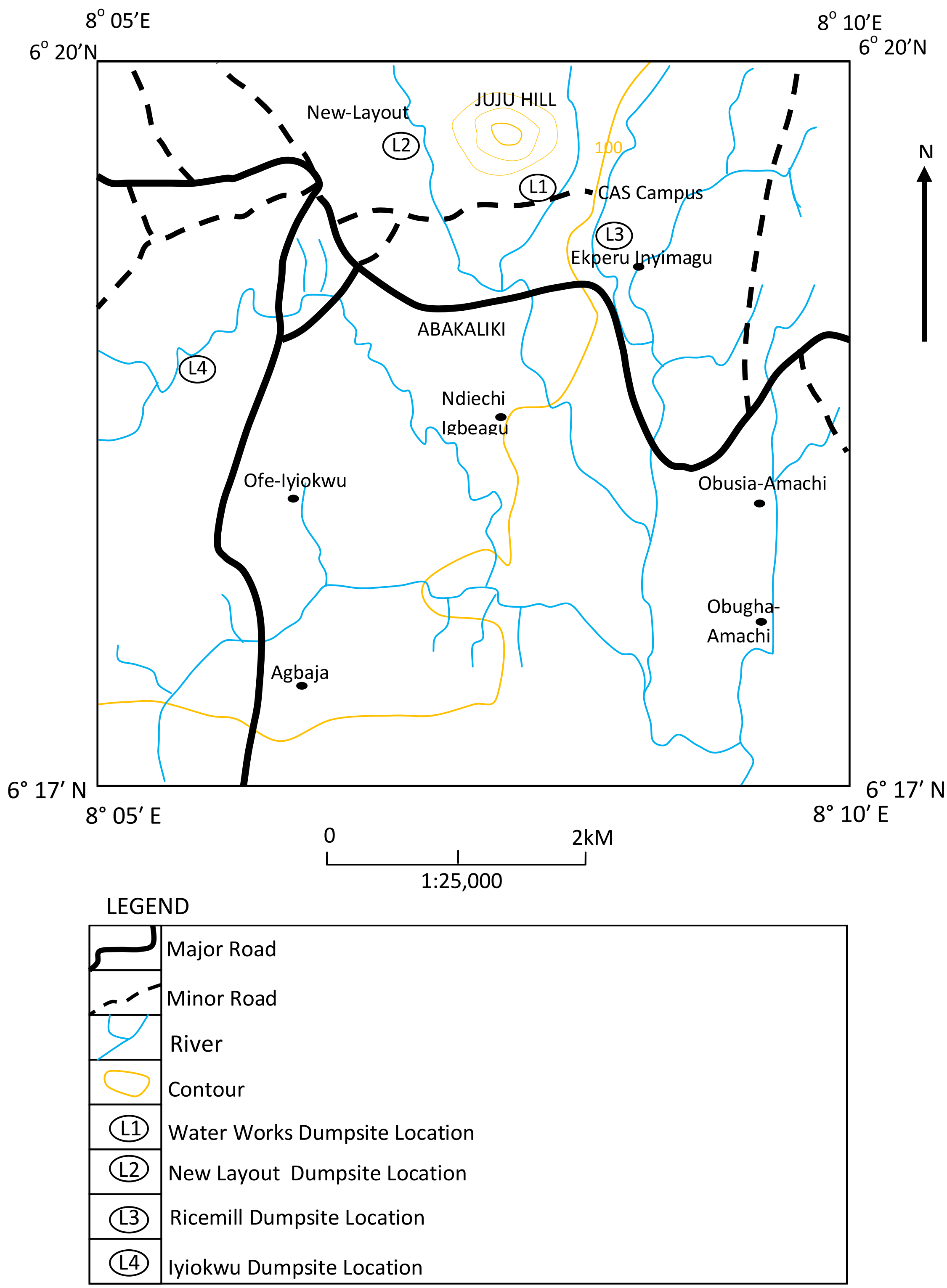

Figure 1. Topographic map of the study area with study points indicated.

shrubs and a variety of other trees such as palm trees. Most of the vegetations are ever-green while some are deciduous.

Geology

The Abakaliki area falls within the Southern Benue Trough

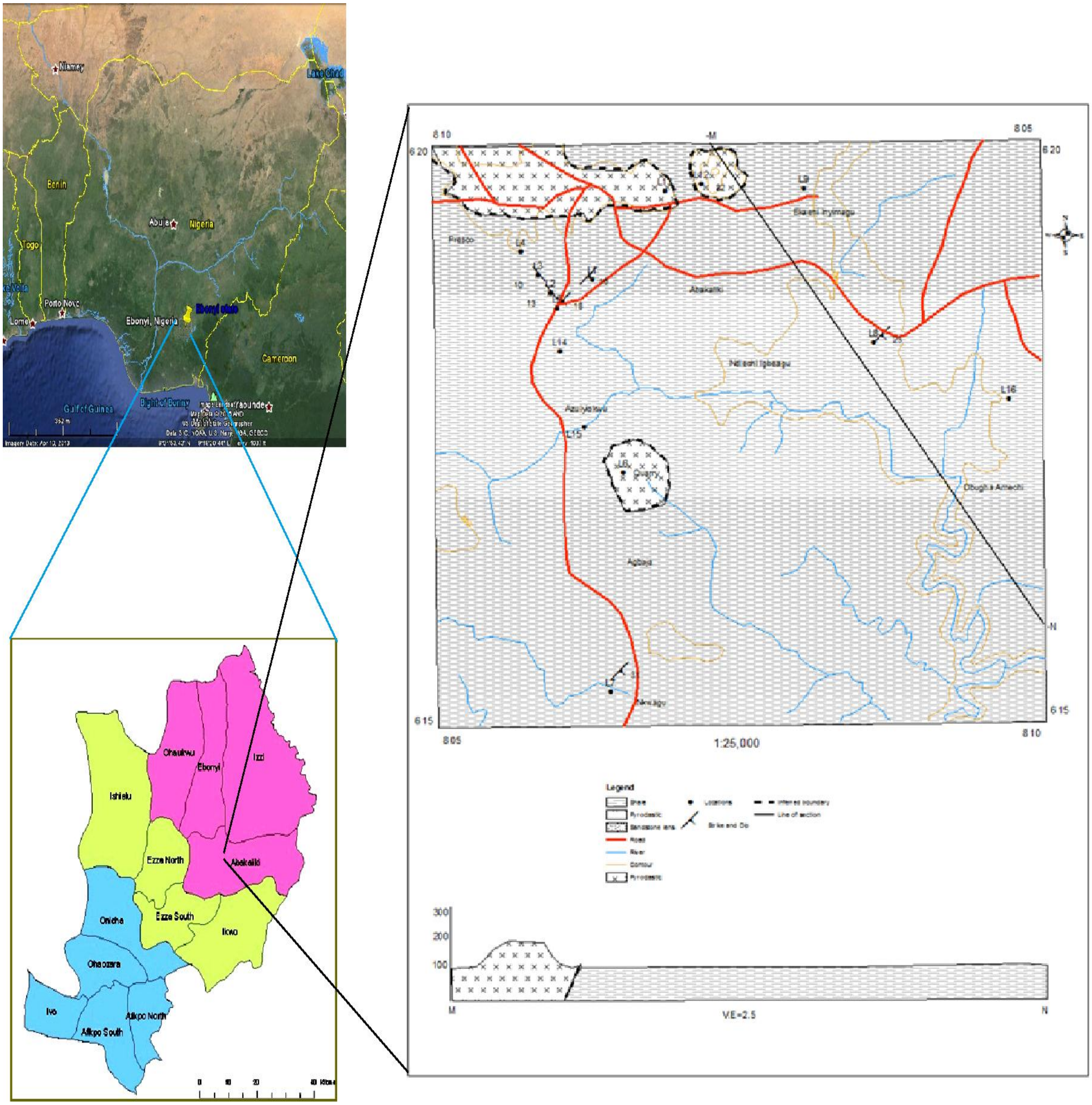

Figure 2. Geologic map of Abakaliki urban Southeast Nigeria.

of Nigeria (Figure 2). Burke et al. (1971) gave evidences to support the fact that the origin of the Benue Trough was closely associated with the breakup of western Gondwanaland during the separation of the African and South American Plates, and opening of the South Atlantic Ocean, in the early Cretaceous. Murat (1972) pointed out that the first marine transgression of the Benue Trough started around the middle Albian period, with the deposition of the Asu River Group (Abakaliki Shale Formation and other undifferentiated sediments) in the Southern Benue Trough. The Asu River Group sediments are predominantly shales and localized development of sandstone, siltstone and limestone facies as well as extrusives and intrusives (Reyment, 1965). The group

Figure 3. Pictorial view of (L4) Iyiokwu dumpsite.

Figure 4. Pictorial view of (L3) rice mill dumpsite.

Figure 5. Pictorial view of (L2) New layout dumpsite.

has average thickness of about 2000 m and rests unconformably on the Precambrian Basement (Benkhelil et al., 1989). The Santonian tectonic phase resulted in series of folding and fracturing of these rocks, giving rise

Figure 6. Pictorial view of (L1) water works dumpsite.

to chains of anticlines known as the “Abakaliki Anticlinorium” (Reyment, 1965). Occurrence of lead zinc (Pb - Zn) mineralization in the area has been well reported in the Literature (Olade and Morton, 1980; Akande et al., 1990). However, it should be noted that there has not been any established presence of the Pb – Zn veins within the Urban area. The major fracture system which houses the lead-zinc minerals are in the NW/NNW SE/SSE (Farrington, 1952). The Abakaliki Shale Formation, which has an average thickness of about 500 m, is dominantly shale, dark grey in color (weathers to brownish material in the greater part of the formation), blocky, and indurate in most locations, yet fissile and laminated in some locations (Agumanu, 1989). From the chemistry of the shales, which are the host rocks, there was no bias that the heavy metals could have been precipitated from the host rocks.

MATERIALS AND METHODS

Sampling

In order to assess the level of groundwater contamination by solid waste leachate, water quality analysis was conducted on the samples collected from hand dug wells, stream and boreholes near the open dumpsites. For quality assurance, all plastic bottles used were washed with liquid soap, rinsed thoroughly with distilled water and later rinsed with same water sample from the hand dug well, stream or borehole during sampling. Prior to the collection of the water samples, the physical parameters were determined in the field using standard equipment (temperature was measured with mercury thermometer, electrical conductivity was measured with the electrical conductivity meter DDS 307 model and Hanna model H1991300 was applied in the measurement of pH).

Ten (10) water samples were collected from water sources close to the four (4) different open dumpsites understudy, using the APHA (1998) guidelines. The distribution of the samples in the four locations are Iyiokwu dumpsite (2 samples), water works road dumpsite (3 samples), new layout dumpsite (3 samples) and rice mill dumpsite (2 samples) (Figures 3 to 6). The choice of the number of samples per location highly depended on the availability

Table 1. Concentration (mg/l) of heavy metals in water samples from hand dug well, boreholes, streams and ponds around the dumpsites.

Parameter (Mg/l)	Water works dumpsite			New layout dumpsite			Rice mill dumpsite		Iyiokwu dumpsite		WHO std
	Sample1 borehole	Sample 2 (well)	Sample 3 borehole	Sample 4 borehole	Sample 5 (well)	Sample6 borehole	Sample 7 pond	Sample 8 Pond	Sample 9 (well)	Sample 10 stream	
Iron	0.048	0.026	0.032	0.071	0.016	0.045	16.236	4.387	0.014	0.107	0.3
Zinc	0.0533	0.086	0.3077	ND	0.0644	ND	0.3517	0.2198	0.0337	0.0932	3
Copper	ND	2	ND	ND	ND	ND	0.012	0.005	ND	ND	2
Nickel	0.019	ND	0.018	ND	0.015	ND	0.005	0.047	0.012	0.001	0.03
Cadmium	0.021	0.011	0.036	ND	0.058	ND	0.077	0.087	0.212	0.045	0.003
Mercury	0.5	0.069	0.7	ND	ND	ND	ND	ND	ND	ND	0.006
Manganese	0.348	0.0	0.441	0.134	0.236	0.379	4.609	1.758	ND	ND	0.4
Aluminum	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.2
Lead	ND	0.04	0.08	ND	ND	ND	ND	ND	ND	ND	0.01
*Calcium	27.82	30.13	30.70	28.31	27.71	31.04	20.90	32.95	32.95	30.41	75
Arsenic	ND	0.51	ND	ND	0.64	ND	ND	ND	0.43	ND	0.01

*Calcium was considered as part of the elements to be tested for considering the bedrock type (shale). ND = not detected; WHO= World Health Organization; Std = standard; Sample 1 = a borehole at no 1 Ukwansi street; Sample 2= hand dug well beside divine throne of praise mission Incorporated. Sample 3 = a borehole behind Divine throne of praise mission Incorporated adjacent to Ukwansi Street; Sample 4 = a borehole opposite Christ embassy church; new layout Sample 5 = a hand dug well opposite PHCN office at Awolowo Street; Sample 6 = borehole behind PHCN office at Awolowo street; sample 10 = Iyiokwu river.

of a water source and its proximity to the dumpsite. After the collection, the water was stored in a cool environment and later taken to the Spring Board Research Laboratories, Road 3, House 1, Udoka Housing Estate Awka, Anambra State Nigeria, for the determination of ions and heavy metals. The Atomic Absorption spectrophotometer (AAS) was used for the determination of the concentration of heavy metals which include Iron (Fe), zinc (Zn), copper (Cu), Nickel (Ni), Cadmium (Cd), Mercury (Hg), Manganese (Mn), Aluminum (Al), Lead (Pb), and Arsenic (As). The steps for carrying out the AAS, for heavy metals, and flame analyses, for calcium (Ca) ions, were done using the various standard methods and procedures (APHA, 1995).

Methods for the heavy metal analysis of water samples

Heavy metal analysis was conducted using Varian AA 240 Atomic Absorption Spectrophotometer according to the method of APHA, 1998. To carry out this analysis, the sample was thoroughly mixed by shaking and 100 ml of it was transferred into a glass beaker of 250 ml volume, to which 5 ml of concentrated Nitric acid was added and heated to boil till the volume was reduced to about 15–20 ml, by adding concentrated Nitric acid in increments of 5 ml till all the residue is completely dissolved. The mixture was cooled, transferred into a conical flask and made up to 100 ml using metal free distilled water. The sample was aspirated into the oxidizing air acetylene flame. When the aqueous sample is aspirated, the sensitivity for 1% absorption is observed.

Pollution index

Pollution Index (PI) was calculated as the ratio of concentration of individual metal in water samples and the WHO maximum tolerable value for that metal. PI expresses how many times the concentration of the individual metal is higher than the WHO maximum tolerable value for that metal in the water samples. PI was calculated by the use of the formula below: the values for the pollution index are presented in Table 2. Pollution index is designated as €.

$$€ = c/who \tag{1}$$

Where, c is concentration of individual metal in water sample, who $=$ The World Health Organization (WHO) standard; $€ =$ Pollution index.

RESULTS

The results of the analyses are presented in Table 1. Table 2 is the computation of the pollution indices of the various elements in each sample. For an enhanced understanding of the percentage occurrences of the elements, the results were further represented in graphical forms (Figures 7 to 10).

DISCUSSION

Around the four dumpsites studied (Table 1), ten (10) water samples was obtained and analyzed for eleven (11) parameters thereby producing 110 results in all. Table 1 shows that the major pollutants within these four (4) dumpsites are iron (Fe), cadmium (Cd), Mercury (Hg), Manganese (Mn), Lead (Pb) and Arsenic (As). Most of

Table 2. Pollution indices of the heavy metals.

Parameter	Water works dumpsite			New layout dumpsite			Rice mill dumpsite		Iyiokwu dumpsite	
	Sample 1 borehole	Sample 2 (well)	Sample 3 borehole	Sample 4 borehole	Sample 5 well	Sample 6 borehole	Sample 7 pond	Sample 8 pond	Sample 9 well	Sample10 stream
Iron	0.16	0.09	0.11	0.24	0.05	0.15	54.12	14.62	0.05	0.36
Zinc	0.02	0.03	0.10	ND	0.02	ND	0.12	0.07	0.01	0.03
Copper	ND	1	ND	ND	ND	ND	0.01	0.005	ND	ND
Nickel	0.63	ND	0.6	ND	0.5	ND	0.17	1.57	0.4	0.03
Cadmium	7	3.6	12	ND	19.3	ND	25.6	29	70	15
Mercury	83.3	11.5	116.6	ND	ND	ND	ND	ND	ND	ND
Manganese	0.87	0.0	1.1	0.34	0.59	0.95	11.52	4.39	ND	ND
Aluminum	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Lead	ND	4	8	ND	ND	ND	ND	ND	ND	ND
Calcium	0.37	0.40	0.41	0.38	0.37	0.41	0.28	0.44	0.44	0.41
Arsenic	ND	51	ND	ND	64	ND	ND	ND	43	ND

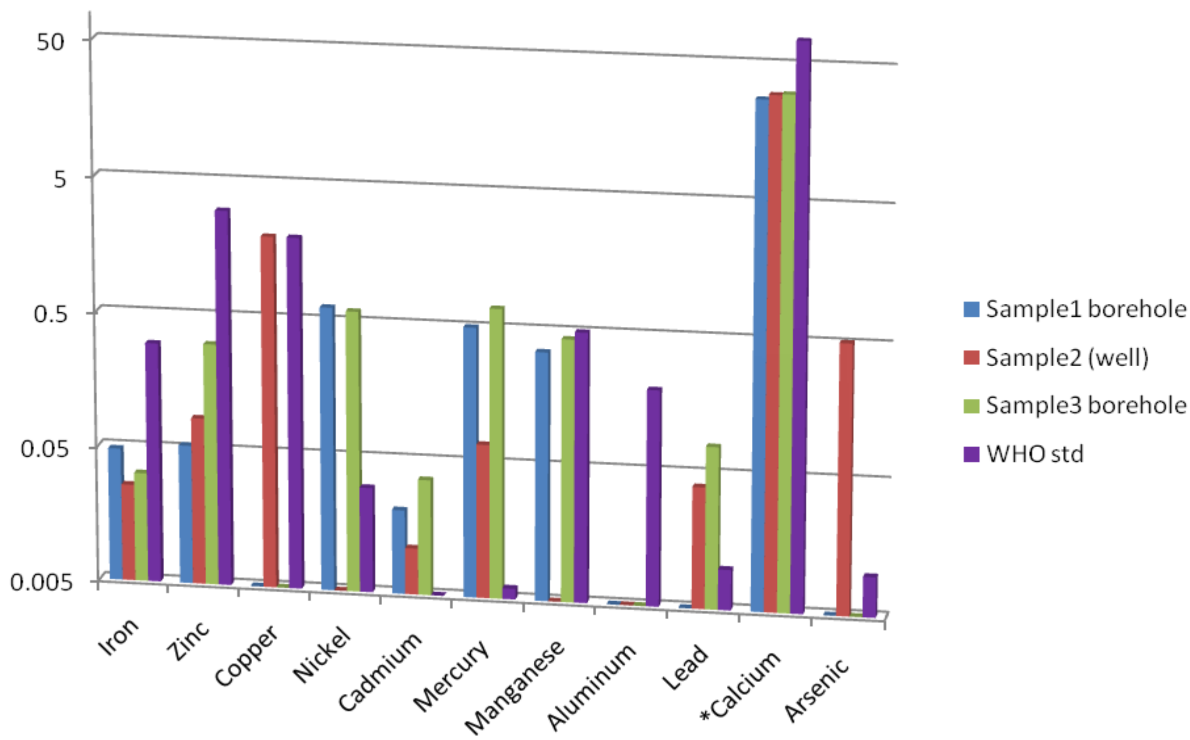

Figure 7. Water works dumpsite.

the water samples indicated the presence of virtually all the heavy metals, however majority of them are below the WHO standard.

Cadmium, mercury, lead and arsenic were observed in high concentration as the major pollutants from water points around water works road dumpsite (Figure 7). Their ranges of occurrence are cadmium (0.011-0.036 mg/l with pollution indices of 11.5-116.6%), mercury (0.069-0.7 mg/l with pollution indices of 0.0-1.1%), lead (0.4-0.8 mg/l with pollution indices 4-8%) and arsenic

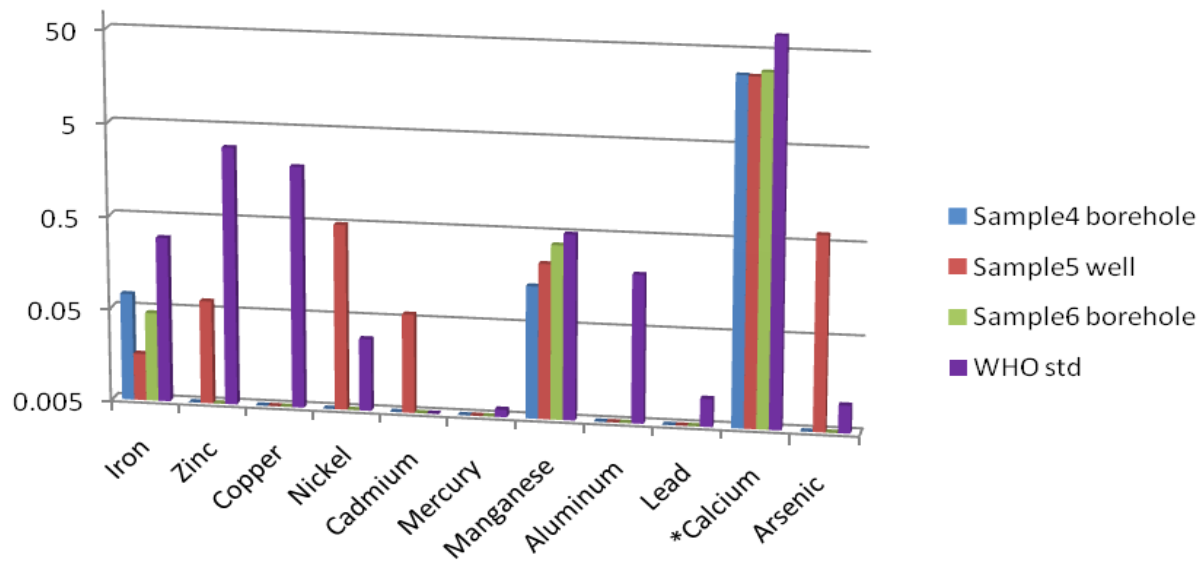

Figure 8. New Layout dumpsite.

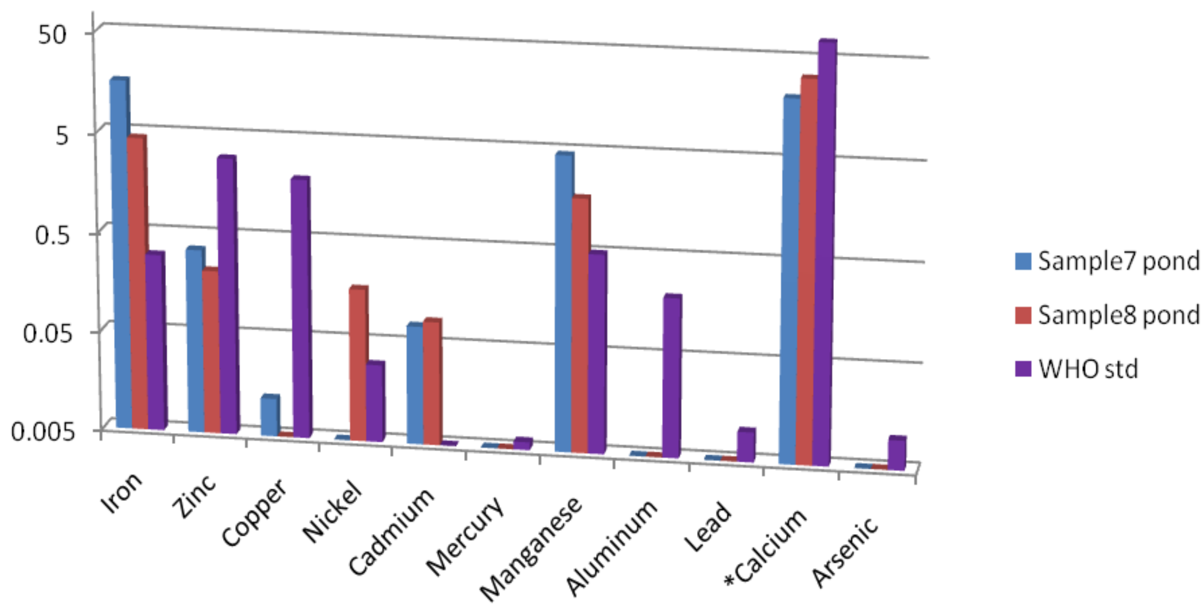

Figure 9. Rice mill dumpsite.

(0.51 mg/l with pollution indices of 51%). These values exceed their respective WHO standards of 0.003 mgl for cadmium, 0.006 mg/l for mercury, 0.01 mg/l for lead and 0.01 mg/l for arsenic (Table 1), thus making them the contaminants of this zone. The occurrence of these metals at a risky rate in the samples can be understood owing to the fact that the greater percentage of the contents of the waste dumps are automobile wastes which are generated from the proximally situated mechanic workshops.

Other heavy metals observed are iron (0.026-0.048mg/l), zinc (0.0533-0.3077mg/l), copper (2 mg/l), nickel (0.018 -0.019 mg/l), manganese (0.0-0.441 mg/l), calcium (27.82-30.70 mg/l) which are all below their respective WHO standards (Table 1 and Figure 7). Only the well water point around this dumpsite showed the presence of arsenic. This suggests that the occurrence of arsenic in the area started long after other contaminants have accumulated. Hence, with time, it can as well find its way into the groundwater system, since it is quite evident

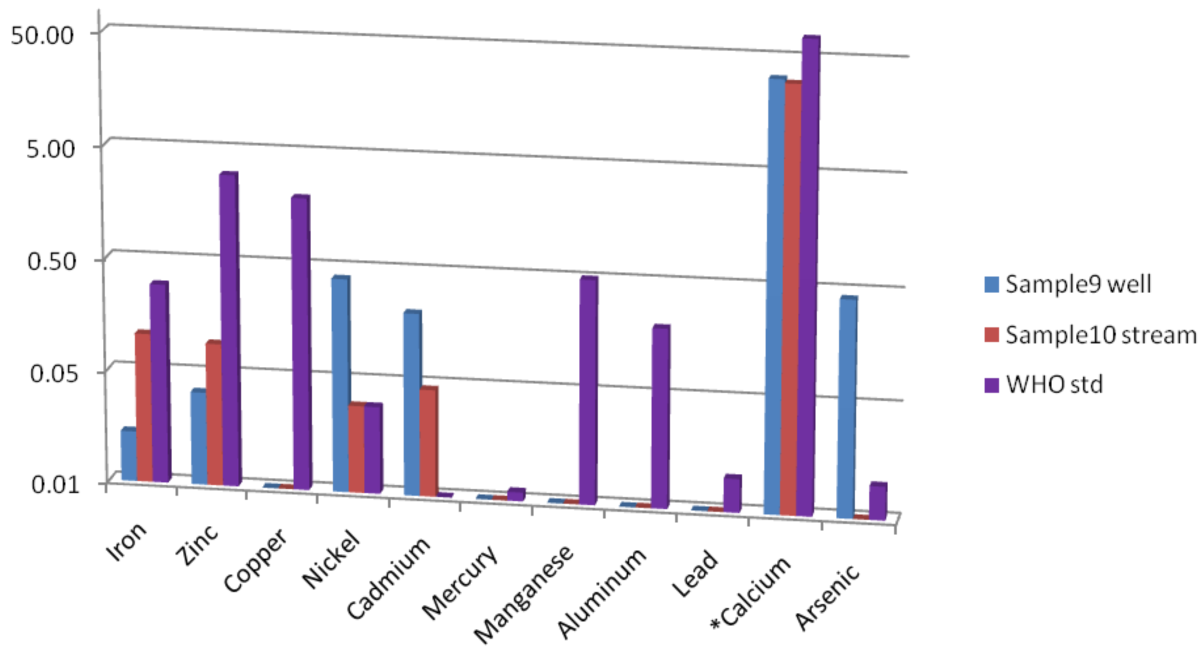

Figure 10. Iyiokwu dumpsite

that the subsurface geology of the area gives room for infiltration.

Within the new layout dumpsite, majority of the heavy metals been discussed were undetected especially in the borehole water samples. At the well water point, cadmium and arsenic as contaminants showed high concentration of 0.058mg/l and 0,64mg/l with pollution indices of 19.3% and 64% as against 0.003mg/l and 0.01mg/l of WHO standard respectively. Other metals observed from the dumpsite are zinc (0.0644 mg/l), nickel (0.015 mg/l), iron (0.016-0.071 mg/l), manganese (0.134-0.379 mg/l) and calcium (27.71-31.04 mg/l) (Figure 8), which did not occur at a harmful rate. The absence of these contaminants from the borehole samples suggests the presence of an impervious geologic layer which inhibited the vertical downward percolation of the filtrates into the groundwater system. Hence, it can be inferred that the New layout waste dumpsite is good for such purpose. However, the inhabitants of the area should be advised not to use water from the hand dug wells for domestic purposes.

Around the rice mill dumpsite, high concentration of iron metal was observed from the water sources as a pollutant with a value of 16.236 and 4.387 mg/l with pollution indices of about 54 and 14.62% respectively (Table 1, Figure 9). These exceed the WHO standard of 0.3 mg/l, thereby making the rice mill dumpsite an iron metal contamination zone. The occurrence of iron in the water samples around this dumpsite may not necessarily be inferred based on the chemical properties of the waste dumps that are primarily rice husks. Since the rice husk which is the major component of the waste dumps do not form a major source of metals, it is suggested that the dump site remains on its present location as it holds no threat to the groundwater system. However, the water points which are ponds, it is inferred that such high concentration is as a result of surface run-offs of metallic effluents and other solid wastes partially degraded from the mechanic village suited within the rice mill cluster. Also around this dumpsite, high concentrations of nickel, cadmium and manganese were observed. Their respective range occurrences are; nickel (0.005-0.047mg/l with pollution indices of 1.67-15.67%), cadmium (0.077-0.087 mg/l with pollution indices of 25.6-29%) and manganese (1.758-4.609 mg/l with pollution indices of 4.39-11.52%). These are also attributed to surface run-offs from the earlier stated mechanic village.

Cadmium and arsenic was observed to be the major pollutants around Iyiokwu dumpsite. Their ranges of occurrences are cadmium (0.045-0.212 mg/l with a pollution index range of 15-70.7% exceeding the WHO standard of 0.003 mg/l) and arsenic (0.43 mg/l with pollution index of 43% exceeding the WHO standard of 0.01 mg/l). This high concentration of cadmium and arsenic were observed only at well water point around the dumpsite (Figure 10). It will be attributed to high human and industry activities going on around there such as welding, automobile mechanic workshops, car wash, shops and offices that dump solid wastes that are carried off the surface by run-offs. Other heavy metals shown from Table 1 are iron (0.014-0.107 mg/l), zinc (0.0337-0.0932 mg/l), nickel (0.001-0.012 mg/l) and calcium (30.41-32.95 mg/l) (Figure 10). However, copper, mercury, manganese, aluminum and lead were undetected in this area. Unfortunately, the absence of a groundwater borehole within the homes close to the dumpsite could not give us information about the groundwater system. The absence or low concentration of the contaminants in the stream sample (Figure 10) around this dumpsite could be attributed to steady inflow and outflow of water.

Conclusion

Within the four dumpsites studied, heavy metal pollutants observed are iron, nickel, cadmium, mercury, manganese, lead and arsenic. The major hit zone of high pollution noted was water works road dumpsite, while New layout dumpsite was observed to accommodate this activity due to the inferred impervious geologic layer inhibiting vertical downward percolation. Rice mill dumpsite shows no threat to the groundwater system. Since these dumpsites are nowhere close to mineralization, it is obvious that the presence of these heavy metals in the water samples is from the dumpsites. The nature / type of pollutants observed depends on what constitutes these wastes in their respective sites.

At the New layout dumpsite, samples from the hand dug wells were observed to be unfit for domestic usage, while those from borehole samples are good for domestic uses. The dominance of these metals in the hand-dug wells suggests that the leachates have migrated to the depth of hand-dug wells in the area (which is usually about 30 ft ≈10 m). This suggests that the filtrates are concentrated within about 0-10 m depth around these areas. Hence, the inhabitants are advised not to use water from hand dug wells. The Iyiokwu dumpsite appeared to be free of the major contaminants been studied but however shows the contamination of the surface water samples.

Recommendations

The authors wish to recommend that resistivity methods of geophysical survey be carried out in the dumpsites to confirm the presence or absence of an impervious geologic layer underlying the dumpsites. This would assist in confirming whether these pollutants actually migrated vertically down to the groundwater zone or were transported from other areas.

Conflict of interest

The authors did not declare any conflict of interest.

REFERENCES

Aghamelu OP, Ezeh HN, Obasi AI (2013). Groundwater exploitation in the Abakaliki metropolis (southeastern Nigeria): Issues and challenges. Afr. J. Environ. Sci. Technol. 7(11):1018-1027.

Aghamelu, OP, Nnabo, PN, and Ezeh HN (2011). Geotechnical and Environmental problems related to shales in the Abakaliki Area, Souteastern Nigeria. Afr. J. Environ. Sci. Technol. Vol. 5(2). pp. 80-88.

Agumanu AE (1989). The Abakaliki and Ebonyi Formations: sub – divisions of the Albian Asu River Group in the southern Benue Trough, Nigeria. J. Afr. Earth Sci. Vol. 9. No 1, pp. 195-207. http://dx.doi.org/10.1016/0899-5362(89)90021-3

Akande SO, Mucke A, Umeji AC (1990). Mineralogical, textural and paragenetic studies of the lead – zinc – copper ore in the lower Benue Trough and their genetic implications. J. Mining Geol. Vol. 26(2):157-163.

Amusan AA, Ige DV, Olawale R (2005), Characteristics of soils and crops uptake of metals in municipal waste dump site in Nigeria. J. Human Ecol. 17(3):167-171.

APHA (1995). Standard Methods for the Examination of Water and Waste Water,20th Edition. American Public Health Association, Washington DC.

APHA (1998). Standard Methods for the Examination of Water and Waste Water,20th Edition. American Public Health Association, Washington DC.

Beaven RP, Walker AN (1997). Evaluation of the total pollution load of MSW, Proceedings Sardinia '97, 6th International Landfill Symposium. CISA: Cagliari, Italy. pp. 57-71.

Belevi H, Baccini P (1989). Long-term behavior of municipal solid waste landfills. Waste Manage. Res. 7:43-56. http://dx.doi.org/10.1177/0734242X8900700106

Benkhelil J, Guiraud M, Ponsard JF, Saugy L (1989). The Bornu – Benue Trough, the Niger Delta and its offshore: Tectono-sedimentary reconstruction during the Cretaceous and Tertiary from geophysical data and geology. In: Kogbe CA (ed) Geology of Nigeria. 2nd ed. Rockview, Jos.

Biswas AK, Kumar S, Babu SS, Bhattacharya JK, Chakrabarti T (2010). Studies on environmental quality in and around municipal solid waste dumpsite. Resour Conservation and Recycling. 55: 129-134. http://dx.doi.org/10.1016/j.resconrec.2010.08.003

Burke KC, Dessauvagie TF, Whiteman AJ (1971). The Geological History of the Benue Depression and adjacent area. In Africa Geology (Dessauvagie and Whiteman, eds). University of Ibadan Press. 187-202.

Esakku S, Palanivelu K, Joseph K (2003). Assessment of heavy metals in a municipal solid waste dumpsite, Workshop on Sustainable Landfill Management. 3–5 December, Chennai, India. 139-145.

Farrington JI (1952). A preliminary description of the Nigerian lead-zinc field. Econ. Geol. Vol. 17:583-608. http://dx.doi.org/10.2113/gsecongeo.47.6.583

Hoffmann L, Christiansen K., Petersen C (1991). Lead and cadmium contamination of compostable waste derived from source-separated household waste, In: Farmer JG, editor, International conference on heavy metals in the environment, vol. 2. Edinburgh: CEP Consultants Ltd. 264-267.

Murat RC (1972). Stratigraphy and paleogeography of the cretaceous and late Tertiary in Southern Nigeria. In Desauvagie T.F. and Whiteman, A.J. (edt), African Geology. University of Ibadan press. 251-266.

Obasi AI, Ekpe II, Igwe EO, Nnachi EE (2015a). The Physical Properties of Soils within Major Dumpsites in Abakaliki Urban, Southeastern Nigeria, and Their Implications to Groundwater Contamination. Int. J. Agric. Fores. 5(1): 17-22.

Ogundiran MB, Osibanjo O (2008). Heavy metal concentrations in soils and accumulation in plants growing in a deserted slag dumpsite in Nigeria, African Journal of Biotechnology, 7(17): 3053–3060.

Olade MA, Morton, RD (1980). Temperature of ore formation and origin of the Ishiagu lead – zinc deposit, southeastern Benue Trough, Nigeria. J. Mining Geol. 17(2): 119-127.

Rajkumar N, Subramani T, Elango L (2010). Groundwater contamination due to municipal solid waste disposal – A GIS Based Study in Erode City. Int. J. Environ. Sci. 1(1): 39-55.

Reyment RA (1965). Aspects of Geology of Nigeria. Ibadan university press: 145.