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Health Risk Assessment of Heavy Metal Pollution in Subsurface Water Quality around Waste Dumpsite of the Upper Benue Floodplain in North-Eastern Nigeria

Vanke Ibrahim., Malgwi Gana. Samson., *Faruk Hammanadama Abubakar., Japhet Mikailu

Department of Agricultural and Bio-environmental Engineering Technology, Adamawa State Polytechnic Yola, PMB 2146 Yola Adamawa State, Nigeria.

***Corresponding author**

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ABSTRACT

Urbanization presents many challenges for developing countries, such as industrialization and over-population which can lead to indiscriminate dumping of waste. Refuse waste becomes a form of point source pollution if it affects the environment directly and non-point source pollution if it affects the environment indirectly. This leads to contamination of surface and groundwater and adversely impacts public health. Nigeria is a lower middle-income country which is facing a myriad of pollution and environmental health issues. Diseases which may lead to increased mortality are relative to gradual increases in arsenic (As), lead (Pb) and cadmium (Cd) in the environment originating from toxic waste in solid or liquid forms. Indiscriminate dumping of refuse has consequences on the environment, such as flooding due to waste blockage of water run-off channels, and emission of contaminants that leads to slight poisoning. Highly toxic waters (ground and surface) may lead to diseases such as asbestosis, respiratory problems, cancer and eventually death). A geochemical survey of metals in the groundwater around the exposed dumpsite was conducted to determine the impact on the environment. The groundwater in the study area was used for drinking and domestic purposes. The study was carryout at Jimeta along Yola-Mubi road, two samples were chosen at each location for cation and anion analysis, those chosen for cation analysis were acidified with concentrated hydrochloric acid to preserve the elements in the samples, while those chosen for anion analysis were not acidified. Total dissolved solids (TDS), electrical conductivity (Ec), pH and temperature were measured in situ. Analysis of water quality in the study area illustrates the nature of pollutants found in groundwater as a result of continuous random dumping of hazardous waste and discharge of effluents by agriculture and municipal waste in the community and surrounding environment. The results of this study suggest that groundwater close to the study area is no longer potable for drinking due to the moderate-abundant amounts of carbonate, which causes water hardness, and could lead to cosmetic and aesthetic effects on taste, odor and color. There is also an elevated risk for carcinogenic and non-carcinogenic diseases for adults and children in the area due to high occurrence of Pb, As and Cd found in the water. It is therefore recommended that in the municipal, the government should distribute waste disposal bags and establish a waste collection service to reduce indiscriminate dumping of refuse in the area. In addition, a task force should be formed in the community to enforce existing waste disposal and water protection laws. Construction of a centralized, deep, double-cased well is recommended to ensure an uncontaminated water supply for drinking and domestic purposes in the study area.

Keywords: Subsurface, Water Quality, Risk, Health, Assessment and Refuse Dump

INTRODUCTION

Environmental Pollution

Urbanization presents many challenges for developing countries, such as industrialization and over-population which can lead to indiscriminate dumping of waste (Chu, A.M.Y. 2021). Haphazard dumping of domestic garbage, wood, polythene bags, plastics, broken glass, abandoned automobiles, ash, dust, agricultural, industrial, hospital, and human and animal waste can result in refuse in the environment (Ichipi, E.B.; Senekane, M.F, 2023). Refuse waste becomes a form of point source pollution if it affects the environment directly and non-point source pollution if it affects the environment indirectly (Ogundele Opeagbe, M.R.; Abiodun, 2018). This leads to contamination of surface and groundwater and adversely impacts public health (Adama, O. Garbage, 2022). Nigeria is a lower middle-income country which is facing a myriad of pollution and environmental health issues. Diseases which may lead to increased mortality are relative to gradual increases in arsenic (As), lead (Pb) and cadmium (Cd) in the environment originating from toxic waste in solid or liquid forms. Indiscriminate dumping of refuse has consequences on the environment, such as flooding due to waste blockage of water run-off channels, and emission of contaminants that leads to slight poisoning. Highly toxic waters (ground and surface) and may lead to diseases such as asbestosis, respiratory problems, cancer and eventually death (UNEP, 2018). The present study aimed to assess the impact of metal pollution on groundwater quality in hand-dug wells around an active dumpsite and to evaluate the long-term effects of this pollution on public health.

Studies have shown that dumpsites consist of metals, nylon, cans, syringes, electronic and animal wastes, municipal, commercial, hospital and mixed industrial wastes and threatens the quality of groundwater, which is the main source of drinking water for most communities (Kadafa, A.A. 2017). The usefulness of water to humans is especially dependant on its chemical status; thus, assessment of groundwater quality is important for the socio-economic development of most developing countries of the world, (J. Ishaku, 1995; Kumar et al., 2010). Groundwater is the primary source of potable water supply in most of Jimeta-Yola metropolis, which relies on low-cost domestic (private) boreholes or shallow hand-dug wells as well as tube wells in the alluvial deposit aquifer.

Groundwater is the most reliable water supply source for domestic, agricultural and industrial use in most of Nigeria and other developing countries of the world, (Adekeye and Ishaku, 2004; J. Ishaku and Ezeigbo, 2000; Yenika et al., 2003). However, despite its reliability, this precious vital resource is under increasing threats due to anthropogenic activities related to incessant waste disposal and poor management, (Surendraa, M, 2020; Allison and Richards, 1944; Carlos et al., 1997; Cooper and Lipe, 1992).

Many studies have been conducted on the effects of heavy metals on groundwater around dumpsites, but few have investigated the long-term health risk of metals such as Pb, As and Cd on children and adults. The present study will help to fill this gap with findings on health risks due to indiscriminate dumping of refuse.

The present study aimed to assess the impact of metal pollution on groundwater quality in hand-dug wells around an active dumpsite and to evaluate the long-term effects of this pollution on public health.

MATERIAL AND METHOD

A geochemical survey of metals in the groundwater around the exposed dumpsite was conducted to determine the impact on the environment. The groundwater in the study area was used for drinking and domestic purposes.

Study Area

The study area is located between longitude 12^0 22’ and 12^0 28’ E and latitude 9^0 16 and 9^0 and 19’; which is bounded to the North East by river Benue which flows in a westerly direction, Fig. 1. While to the South and southeast is the limit of Jimeta town in Adamawa state. The area has two distinct seasons, dry and wet season with temperature and humidity varying with the seasons. The wet season begins in May and ends in September 70% of the total rainfall in the area falls within June to August. The mean annual rainfall for the area is 982mm, while the temperature ranged from 27^0c to 40^0c. The vegetation is the savannah type (Sudan Savanah). The soil is fertile alluvial with poorly developed soil deposits due to the probable geological youthfulness of the soil (UBRDA, 1983).

It is situated along the Numan-Mubi Bye-pass within the flood plain of the Upper Benue River just before the Jimeta Bridge. According to (T. Hess, 1998; T.M. Hess, 1994; Tim M Hess, 1999), the climate of the region is

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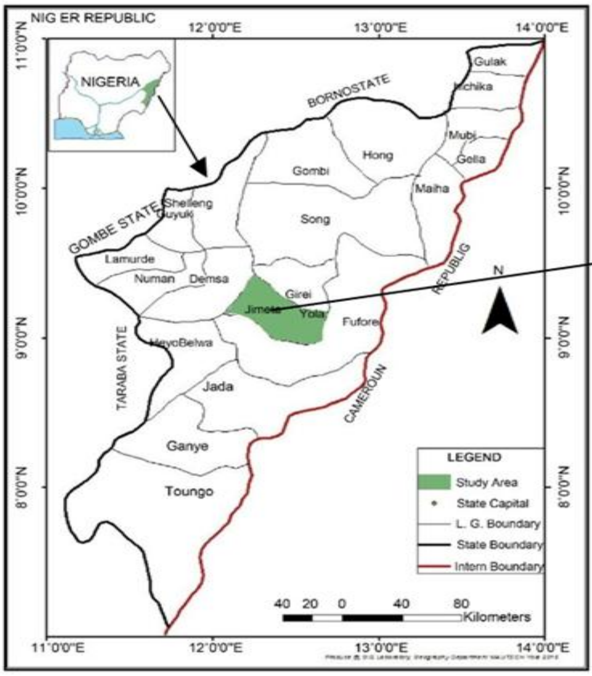
characterized by a cool dry season (October-February), hot season March to May and raining season (June to September). The area is vulnerable to desertification, (Dibal, 2002). The study area dominantly derives its groundwater sources from the Benue alluvial aquifer in which tube wells and shallow boreholes are used for domestic and agricultural water supply.



The area has a moderately high relief; it is easily accessible. The drainage pattern is dendritic, showing irregularity in direction. The area is part of the northern part of the Mandara hills of Cameroun and is of the Nigerian basement complex terrain. It is representative of both a migmatite gneiss complex and older granite, which shows structural disposition (………). The migmatite gneiss complex occupies the south-western and southeastern part of the study area, while older granite occupies the north, east and a portion of the western area. Rock found in the area occurs directly above or is covered by a shallow mantle of superficial deposits.

The dumpsite serves as the main location for waste disposal for Jimeta and the surrounding area. Presently, however, the dumpsite poses a major threat to soils and human health, as it is located on the Mubi – Numan bypass road just before the Jimeta bridge where many irrigated farms and hand-dug wells/shallow boreholes are located. During the rainy season leachates from the dumpsite are transported and accumulated in groundwater. Various wastes such as vegetable matter, domestic wastes, human and animal wastes, organic and inorganic matter, wood, paper, cloth, glass, plastic of various types, unclassified metal scraps, empty cans of various chemicals, and other household trash are some of the refuses that is found on the dumpsite that is operated as an open dump with intermittent open-air incineration.

Field Data Collection

Desks Study:

Desk's study of the area was conducted through the acquisition of maps, reports, and various literatures from the Upper Benue River Basin Development Authority (UBRBDA), Ministry of Land and Survey and Modibbo Adama University of Technology (MAUTECH). The materials were used to review the work. Verbal communications with the people were also conducted. The history of the study area was also investigated to get adequate knowledge and background information about the project area.

Water sampling and analysis.

Sampling was carried out in June 2016; all the instruments used in the field were cleaned with de-ionized water before use. A water level recorder (indicator) was used to determine the depth from the water surface to

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the wellhead and measurements were recorded at each location. A new, clean fetcher was used to draw water samples from each well and global positioning system was used to coordinate each location. A control sample was taken from groundwater in a relatively clean area. The samples were collected 20 m away from the dumpsite. Two samples were chosen at each location for cation and anion analysis, those chosen for cation analysis were acidified with concentrated hydrochloric acid to preserve the elements in the samples, while those chosen for anion analysis were not acidified. Total dissolved solids (TDS), electrical conductivity (Ec), pH and temperature were measured in situ.

A sterilized 750mlplastic bottle container was used to collect the water samples from shallow hand dug wells and boreholes. Samples totalling fifteen (15) were collected, properly labelled and transported to MAUTECH Geology Laboratories laboratory for analysis. The samples were spread across the refuse dump area (Demsawo and Shinko wards) The parameters analysed were physiochemical and heavy metals. The method used was that of the procedure described by (APHA, 2005; Chopra and Kanwar, 2010). Total dissolved solids (TDS) were determined by the evaporation-changing method. Calcium and magnesium were estimated by EDTA titration method, while K and Na by flame photometry. Sodium Carbonate and bicarbonate were obtained by volumetric titration method. The anions Cl, SO4, and NO3 were read on LED photometer while Boron was determined by the calorimetric indigo- carmine method.

The parameters examined for heavy metals concentration in the samples include copper (Cu), Zinc (Zn), Iron (Fe), manganese (Mn), Chromium (Cr) mercury (Hg) and lead (Pb). The qualitative analysis was carried out at the soil science and geology laboratories of the Adamawa State University (ADSU). The concentrations of heavy metals such as Cu, Zn, Fe, Mn, Cr and Pb in the water and waste samples were determined with flame atomic absorption spectrophotometer.

Waste sampling and analysis

Five (5) waste samples were taken from two (2) dumpsites each totalling Ten (10). Physical analysis (the composition of the waste) was carried out. The weight percentage analysis of the waste was carried out for various components namely: - leaves, polythene, garbage metals, etc. The results are shown in Table 1. For heavy metals, five (5) composite waste samples were collected and taken to the laboratory for heavy metals analysis and the result indicated in table 2.

Statistical evaluation

Enrichment Factor

Evaluation of contamination according to metal enrichment or the enrichment factor (EF) proposed by Sinex and Helz (Dibal, 2002) was employed to assess the degree of contamination and to understand the distribution of the elements of anthropogenic origin from sites via individual elements in sediments. Iron (Fe) was chosen as the normalizing element for determining EF values, as it is one of the widely used reference elements (Dibal, 2002). Other widely used reference metals or elements included aluminium (Al) and manganese (Mn). The formula for EF and its classifications are stated in Equation 1.

Equation 1:

$$EF = C/Fe_{sample} / C/Fe_{background}$$

Where, C is the element concentration. In this case, the background value is the concentration of groundwater in the control site and is categorized as ≤ 1, background concentration; 1-2, depletion to minimal enrichment; 2-5, moderate enrichment; 5-20, significant enrichment; 20-40, very high enrichment; and ≥ 40, extremely high enrichment.

Contamination factor

Contamination factor (CF) was used to determine the contamination status of the groundwater. The formula for the contamination factor used is in Equation 2:

Equation 2:

CF = Cn / Bn

Where, Cn is the concentration of heavy metals in groundwater, and Bn is the background concentration at the control site.

The following categories are suggested for classifying the CF: CF<1, low contamination factor;1 ≤ CF< 3, moderate contamination;3 ≤ CF< 6, considerable contamination factor; CF ≥ 6, very high contamination factor.

Geo-accumulation index:

Geo-cumulation index as proposed by Muller, the geo-accumulation index (Igeo) has been widely used to evaluate the degree of heavy metal contamination in terrestrial and aquatic environments. Igeo is expressed in Equation 3.

Equation 3:

$Igeo = \log2C_n / 1.5B_n$

Where, Cn is the concentration of the examined metal in the groundwater, Bn is the background concentration of a given metal, and 1.5 is a factor accounting for possible variation in the background concentration due to lithological differences. The geo-accumulation index is classified into seven descriptive classes as follows: ≤ 0, practically uncontaminated; 0-1, uncontaminated to slightly contaminated; 2-3, moderately to highly contaminated; 4-5, highly to very strongly contaminated; and ≥5, very strongly contaminated.

Risk assessment

Risk assessment is used to estimate the impact of carcinogens and the future rate at which an individual is affected by carcinogenic metals. The risk (Risk pathway) is the probability of an individual developing cancer resulting from exposure to the potential carcinogenic metal. A Possible pathway includes ingestion, inhalation or dermal contact (Equation **4).**

Equation 4:

Risk pathway = Σ NK=1ADIkCSFk

Where, Risk pathway is the unit less probability of an individual developing cancer over a lifetime; ADIk (mg/kg/ day) is the mean daily intake; CSFk (mg/kg/day)-1 is the cancer slope factor; k is the kth metal; and n is the number of metals.

The human health risk is then calculated by the addition of all results from the three pathways which is the results of risk in inhalation, ingestion and dermal contact (Equation 5):

Equation 5:

Risk pathway = Risk(ing) + Risk (inh) + Risk (dermal)

The results of exposure were assessed using Table 1.

RESULTS

The mean concentrations of metals and physical parameters were compared with the World Health Organization (WHO) standard limits in Table 2. All the samples were found to be within the WHO maximum

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permissible limits of drinking water except for As (0.13 mg/L), potassium (K) (29.94 mg/L), Pb (0.38 mg/L), Cd (0.003 mg/L) and average temperature (31.93oC).

Contamination assessment of groundwater

The EF of background concentrations for calcium (Ca), magnesium (Mg), sodium (Na), K, copper (Cu), Cd, As, Pb, and zinc (Zn) were found in 8, 6, 1, 6, 7, 8, 5, 6 and 10 samples, respectively. Depletion to minimal enrichment for Ca, Mg, Na, K, Cu, Cd, Fe, As, Pb and Zn were found in 5, 7, 5, 4, 6, 4, 15, 8, 7 and 3 samples, respectively. Moderate enrichment for Na, K, and Cd were found in 6, 3, and 1 sample, respectively. Significant enrichment was found with regard to Ca, Mg, Na, K, Cu, Cd, As, Pb and Zn. Very high enrichment was observed for 2 samples in Na (Table 3).

Contamination factor

Results of the contamination factor analysis show that a low contamination factor was observed in Ca, Mg, Na, K, Cu, Cd, Fe, As, Pb and Zn in 11, 1, 0, 3, 2, 8, 6, 1, 2, 1and 14 samples, respectively, while a moderate contamination factor for Ca, Mg, Na, K, Cu, Cd, Fe, As, Pb and Zn was observed in 4, 14, 12, 11, 13, 7, 9, 14, 11 and 1 samples, respectively. Considerable contamination factor was found in Na and K in 3 and 1 samples, respectively.

Only Pb was found to have high degree contamination factor. The degree of contamination in groundwater in the study area was found to have a moderate degree of contamination (Table 3).

Geo-accumulation index

The Igeo results showed Ca, Mg, Cu and Zn to be practically uncontaminated, while Na, K, Cd, Fe and As ranged from practically uncontaminated to slightly contaminated. Only Pb was moderately to highly contaminated in the sampled groundwater (Table 3).

Composition of Solid Waste dumps

For the classification of waste, ten waste components were considered. These were food/putrescible, vegetables, paper, plastic, glass/ceramic, fabrics, wood, metal, electronic waste, and "others". Others represent solid waste that is not identified or do not fall into the first nine categories. Sorting and weighing of collected waste were done at the dumpsite. The composition of the refuse waste dump on a trash weight basis is presented in table 4.1.

Table 4.1: Composition of Refuse dump from Two Representative Public Dumpsite in the study (on Fresh Weight Basis)

Table 4. Components of Waste by Percentage

Components	Site I	Site II
Leaves (%)	3.37	4.23
Papers (%)	8.41	6.64
Rags (%)	3.35	0.00
Garbage (From Waste (%))	22.80	70.60
Wood (%)	1.10	0.00
Metals (%)	1.50	3.79
Glass (%)	0.70	0.95
Grit And Dust (%)	51.70	9.01

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Polythene and Other Plastics (%)	7.10	4.78
TOTAL	**100.00**	**100.00**

Heavy Metal Concentrations in Refuse waste dump

The result of the analysis indicates that heavy metal concentration of iron, zinc, copper and magnesium as well as chromium are all slightly above the standard limit of WHO and may likely affect the groundwater quality, (Rakash Kumal P et al, 2013; Nkem A et al, 2012; Aderemi O A et al, 2011 and Shanti P et al, 3012 and Rahul and Chhipa, 2014). Lead and mercury were not detected, table 3.2

Table 5. Heavy Metals mean Concentration of refuse waste dumps in Study Area

Sample	Fe	Zn	Pb.	Cu	Mn.	Cr	Hg
WHO	0.03	75-200	0.01	2.0	0.01	-	-
Dump Site I	0.05	8.00	ND	0.80	0.04	ND	ND
Dump Site II	0.06	19.00	ND	0.30	0.06	ND	ND

DISCUSSION

The mean Fe+ and Cd values (0.05 and 0.003 mg/L, respectively) in the groundwater indicate that most metals did not originate from the weathering of silicate-bearing rocks underlying the area, and thus are from anthropogenic activities (dumpsites) close to the well. Zinc, Cu, Pb, As, and Cd had mean values of 10.80, 1.22, 0.38, 0.130, and 0.003 mg/L, respectively. The concentration of metals in the groundwater in the area occurred in the order of Zn =10.80 > Cu = 1.22 > Pb = 0.38 > As = 0.13 > Fe = 0.05> Cd = 0.003. All of the wells in the study area had values for Pb > 0.2 mg/L, K>12 mg/L, while some had concentrations of Cd> 0.1, which is higher than the WHO permissible limits. Elevated amounts of Pb may have resulted from batteries and lead pipes in the dumpsite, as when leachates become acidic, the acid is released into the groundwater. Cadmium could be linked with the dispersal of heavy metals produced from electronic wastes disposed of in the dumpsite. High values of K may be linked to leachates, which were also affirmed in the spatial distribution of metals in groundwater in the area (Figures 2a and 2b). The general trend showed higher metal pollution in the wells close to the dumpsite and decreased with distance from the dumpsite.

Table 6. Mean Concentration values of Parameters

Elements	Mean concentration	WHO (2012)	T°C	pH	EC	TDS	Depth to water table (m)
Cu	1.22	2	**32**	8.3	0.5	0.2	27.6
Cd	0.003	0.003	**32**	8.7	0.3	0.1	37.4
As	**0.13**	0.01	**34**	9.2	0.2	0.1	42.4
Pb	**0.38**	0.01	**33**	7.5	0.4	0.2	57.7
Zinc	10.8	75-200	**30**	8.2	0.1	0.1	34.5
Fe	0.05	0.3	**32**	9.2	0.4	0.7	23.3
Ca^{2+}	8.87	75-200	**31**	8.7	0.06	0.3	36.3
Mg^{2+}	10.43	150	**33**	8.4	0.4	0.2	23.6
Na^{+}	10.8	200	**34**	8	1.3	0.6	8
K^{+}	**29.94**	12	**35**	8.1	1	0.5	28.9
SO_4^{2-}	6.88	400	**32**	8.8	0.4	0.2	12
NO^{3-}	7.15	50	**34**	8.2	0.3	0.1	52
Cl^{-}	25.32	250	**30**	7.9	0.3	0.1	64.9
CO_3^{2-}	104	240	**29**	9	0.1	0	51.9
HCO_3	278.57	500	**28**	9	0.7	0.3	18.4
WHO[35]			27	6.5-9.2	300	500	

Abbreviations: Ca^{2+}, calcium(2+), Cu, copper; Mg^{2+}, magnesium(2+); Na^{+}, sodium(1+); SO_4^{2-}, sulfate(2-); NO^{3-} nitrate(1-); Cl^{-}, chlorine(1-); CO_3^{2-},carbonate; HCO_3,bicarbonate; T°C, temperature; EC, electrical conductivity; WHO, World Health Organization.

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Hydrochemical results of the anion

The high abundance of bicarbonate (HCO3) and carbonate (CO32-) may be caused by discarded carbonate rich products in the dumpsites and underlying rocks, where interaction between rock and water occur. The high presence of chlorine (1-) (Cl-) and sodium (1+) (Na+) was attributed to domestic effluents, fertilizers, septic tanks and leachates from sewage in the waste dumpsite. Low Fe+ concentrations revealed an oxidizing environment that is attributed to the oxidation of ferrous to the ferric form.

Table 7. Enrichment and Contamination Factors

Indices	Classification	Ca	Mg	Na	K	Cu	Cd	Fe	As	Pb	Zn
Enrichment factor	<1: Background concentration	8	6	1	6	7	8	-	5	6	10
	1-2: Depletion to minimal enrichment	5	7	5	4	6	4	15	8	7	3
	2-5: Moderate enrichment	-	-	6	3	-	1	-	-	-	-
	5-20: Significant enrichment	2	2	1	2	2	2	-	2	2	2
	20-40: Very high enrichment	-	-	2	-	-	-	-	-	-	-
	>40: Extreme enrichment	-	-	-	-	-	-	-	-	-	-
Contamination factor	CF < 1: Low contamination factor	11	1	-	3	2	8	6	1	2	14
	1 < CF < 3: Moderate contamination factor	4	14	12	11	13	7	9	14	11	1
	3 ≤ CF ≤ 6:Considerable contamination factor	-	-	3	1	-	-	-	-	-	-
	CF ≥ 6: Very high contamination factor	-	-	-	-	-	-	-	-	1	-
Igeo	< 0: Practically uncontaminated	15	15	3	1	15	13	14	13	-	15
	0-1: Uncontaminated to slightly contaminated	-	-	12	14	-	2	1	2	14	-
	2-3: Moderately to highly contaminated	-	-	-	-	-	-	-	-	1	-
	4-5: Contaminated	-	-	-	-	-	-	-	-	-	-
	>5: Very strongly contaminated	-	-	-	-	-	-	-	-	-	-

Groundwater classification

A Piper diagram (Figure 3) illustrates the hydrochemical evolution of groundwater by plotting the cations and anions. The Piper diagram consists of three major fields: the cation ternary (left), anion ternary (right) and diamond fields (center). The groundwater samples were plotted on the Piper diagram to determine water types in the area. The plot indicates that 93% of groundwater samples in the study area fall within the (HCO3, Cl + sulfate (SO4)) - (HCO3+carbon trioxide (CO3)) groundwater type, while 3% fall into (Na+K) - (calcium (Ca) + magnesium (Mg)) water type. Dumpsites, landfill leachates, and sewages are major sources of bicarbonates in groundwater.

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Table 8. Range and Class of Samples

Parameters	Range	Class	Number of Samples	% of Samples
EC	< 250	Excellent	15	100
	250-750	Good	0	0
	750-2000	Permissible	0	0
	2000-3000	Doubtful	0	0
	> 3000	Unsuitable	0	0
TDS	< 1000	Fresh	15	100
	1000-10000	Brackish	0	0
	10000-100000	Saline	0	0
	> 100000	Brine	0	0
SSP	< 20	Excellent	0	0
	20-40	Good	0	0
	40-60	Permissible	5	33
	60-80	Doubtful	9	60
	> 80	Unsuitable	1	7
SAR	0-10	Excellent	15	100
	10-18	Good	0	0
	18-26	Permissible	0	0
	>26	Doubtful	0	0
MAR	≤ 50	Suitable	7	47
	> 50	Unsuitable	8	53
KR	> 1	Unsafe	0	0
	< 1	Safe	15	100

Abbreviations: SSP, soluble salt percentage; SAR, sodium adsorption ratio; MAR, magnesium adsorption ratio; KR, Kelly ratio.

Bivariate correlation analyses

Bivariate analysis (Supplemental Material) between physicochemical parameters revealed strong a relationship (r=0.634) between TDS and salinity. This implies that the overall salinity in groundwater may have originated from the same sources. This was also reflected by the relationships between salinity and other parameters, SO4 (r = 0.516), Cl (r = 0.597), HCO3 (r = 0.501), Ca (r = 0.621), Mg (r = 0.520), Na (r = 0.603), Cu (r = 0.763) and Zn (r = 0.603). The association of salinity with SO4, Cl, HCO3, Ca and Mg reflects possible anthropogenic influence and may come from the dumpsite; it could also come from the use of agricultural nitrogen (N), phosphorus (P) and K fertilizers and recycled irrigation water. Total dissolved solvents had an extremely strong relationship with pH (r = 0.915), revealing that TDS determines the degree of acidity and alkalinity in the groundwater of the study area. Similar relationships were found with TDS and SO4 (r = 0.911), TDS and nitrate (NO3) (r = 0.994), TDS and Cl (r = 0.761), TDS andCO3 (r = 0.899), and TDS and HCO3 (r = 0.874). The relationship between TDS with NO3 indicates pollution from sewage wastes, domestic effluents, and it also suggests the presence of bicarbonate. Chloride and nitrates strongly influenced TDS and electrical conductivity (EC) in the study area. Sulphate also had a strong relationship with NO3 (r = 0.650), CO3 (r = 0.606), Ca (r = 0.838), Mg (r = 0.828), Na (r = 0.550), K (r = 0.797), Cd (r = 0.953), As (r = 0.608), Pb (r = 0.665) and Zn (r = 0.550), which reflects a possible anthropogenic source. A very strong correlation was noticed between CO3 and HCO3(r = 0.907), which indicates chemical interactions between rainwater and the aquifer as the former percolates the subsurface. Strong relationships between Pb with Cu (r = 0.721), Cd (r = 0.544), Fe (r = 0.613) and As (r = 0.633) reflect the contribution of heavy metals from the nearby dumpsite.

Factor analysis

Factor analysis is another form of correlation that helps to describe the possible source of pollution in groundwater. Seven components were extracted for analysis (Table 4). Component 1 revealed that the

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parameters have a common origin which is possibly anthropogenic in nature. Component 2 showed the pollution could originate from agricultural practices and activities at the dumpsite. Component 3 reflects an anthropogenic source, possibly from various wastes discarded in the dumpsites. This component shows that pH-Ca-Cu-Pb has had a negative impact and their presence in the groundwater may be hazardous to human health. In component 4, salinity-pH-SO4-Fe are strongly related and may have originated from either a natural or anthropogenic source of contamination. In component 5, associations reflect an anthropogenic source of groundwater contamination. The presence of NO3 shows a possible agricultural source, while the presence of Pb shows possible contamination from the dumpsite. In component 6, EC-K-As formed an association revealing an anthropogenic source of contamination from the dumpsite.

Table 9. Parameters Components

	Component						
	1	2	3	4	5	6	7
Temp.	**0.751**	0.123	**0.433**	-0.135	0.243	-0.208	-0.025
Salinity	**0.567**	**0.504**	0.064	**0.488**	0.102	0.082	-0.116
TDS	**0.440**	**0.616**	-0.150	0.092	**0.424**	0.266	0.207
pH	-0.044	0.027	**-0.477**	**0.814**	-0.099	-0.087	0.028
EC	**0.590**	**0.462**	0.137	-0.215	-0.100	**0.466**	0.214
SO_4	-0.390	**0.402**	0.388	**0.438**	-0.381	0.324	0.189
NO_3	**-0.493**	**0.437**	0.028	-0.225	**-0.437**	0.371	0.376
Cl	0.150	**-0.522**	-0.298	0.132	0.218	-0.055	**0.606**
CO_3	**-0.644**	0.065	0.343	-0.224	**0.602**	0.180	-0.021
HCO_3	**-0.669**	0.143	0.360	-0.094	**0.534**	0.194	-0.207
Ca	0.130	**0.586**	**-0.580**	-0.327	-0.253	0.100	-0.252
Mg	**0.434**	0.167	**0.529**	-0.199	0.217	-0.090	0.387
Na	**0.612**	**-0.588**	**0.422**	0.095	-0.168	0.146	-0.092
K	0.104	**-0.629**	0.046	0.314	0.140	**0.408**	-0.028
Cu	**0.420**	-0.150	**-0.667**	-0.502	-0.094	0.109	0.025
Cd	**-0.536**	**-0.675**	-0.153	0.195	0.004	0.146	0.199
Fe	-0.054	**0.618**	**0.494**	**0.450**	-0.187	-0.157	-0.105
As	-0.250	0.062	**0.462**	-0.234	-0.331	**-0.571**	0.287
Pb	0.128	**0.422**	**-0.473**	0.322	**0.418**	-0.286	0.200
Zn	**0.612**	**-0.588**	**0.422**	0.095	-0.168	0.146	-0.092
Total	4.220	4.011	3.071	2.206	1.815	1.354	1.094
%Variance	21.10	20.05	15.35	11.03	9.08	6.771	5.472

Abbreviation: Temp., temperature.

Hierarchical cluster analysis

The diagram (Figure 4) classifies parameters in the groundwater into 3 groups. In group 1, Na, Zn, pH, Ca, Mg, SO4, NO3, salinity, Fe, Cd, As, and TDS have a common source of contamination. This may be linked to anthropogenic sources which may be from agricultural practices in the area or from the dumpsite. Group 2 includes K, Cl, CO3, TDS, EC, Pb, Cu, and temperature and group 3 consists of HCO3, Cu, temperature, K, Cl, and CO3. These groupings reflect a possibly natural source of contamination arising from rock-water interactions in the area.

Fig. 4

Evaluation of groundwater for irrigation purposes

Irrigation water indices such as EC, TDS, soluble salt percentage, sodium adsorption ratio, magnesium adsorption ratio and Kelly ratio were used to assess the suitability of groundwater in the area for irrigation purposes.

Salinity

To determine the amount of dissolved ionic salts, present in the groundwater, EC was used, which also measures salinity hazard to crops, as it affects the TDS in groundwater. The results showed that EC and TDS in all of the groundwater samples was lower than 250 and 1000 mg/l, respectively, and groundwater is

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therefore safe for irrigation purposes. Soluble salt percentage also evaluates the sodium hazard and was calculated using Equation 6:

Equation 6:

SSP = (Na + K) X 100) / (Na + K + Ca + Mg)

Where, SSP is the soluble salt percentage. The results revealed that 33% of the samples are permissible for use in irrigation, 60% are of uncertain suitability, and 7% of the groundwater samples were unsuitable for irrigation. Sodium adsorption ratio is the best parameter to determine the suitability of groundwater for irrigation, as it evaluates the alkali/sodium hazards in crops. Sodium adsorption ratio can be measured using Equation 7, as characterized by Karanth.

Equation 7:

SAR = Na / (√Ca+Mg/2)

The results revealed that 100% of groundwater samples were suitable for irrigation. The magnesium adsorption ratio was calculated using Equation 8.

Equation 8:

MAR = (Mg x 100) / (Ca+Mg)

The findings showed that 47% of the samples were suitable for irrigation while 53% were unsuitable. The Kelly ratio values were calculated using Equation 9.

Equation 9:

KR = Na / (Ca+Mg)

Where, KR is the Kelly ratio. Kelly ratio values <1 showed suitability, while KR > 1 showed unsuitability for irrigation purposes. All of the samples were safe for irrigation (Table 5).

Health risk assessment

Health risks in adults and children (Table 6) for Pb and As revealed that Pb represents a high carcinogenic health hazard in the area, through oral or dermal contact, as the values of the health hazards are above 10-4 and 10-8, which is the acceptable range. Use of groundwater for drinking and bathing in this area for long periods of time poses a risk for the development of carcinogenic diseases (Figure 5).

Cadmium, Pb and As present non-carcinogenic health risks (Table 7) in both adults and children since the values are above the threshold of 1 recommended by the United States Environmental Protection Agency (USEPA) for non-carcinogenic health diseases, but the effects are greater for children, as revealed by the results in Figure 6.

Table 10. Ingestion Level of Heavy Metal

Heavy Metal	Oral *RfD*	Dermal *RfD*	Inhalation *RfD*	Oral *CSF*	Dermal *CSF*	Inhalation *CSF*	References
Pb	3.60E-03	-	-	8.50E-03	-	4.20E-02	34,35
Chromium (VI)	3.00E-03	-	3.00E-05	5.00E-01	-	4.10E+01	36,34
Cobalt	2.00E-02	5.70E-06	5.70E-06	-	-	9.80E+00	36
Nickel	2.00E-02	5.60E-03	-	-	-	-	34
Copper	0.037	0.037	-	-	-	-	34,36
Zinc	3.00E-01	7.50E-02	-	-	-	-	34,36

Abbreviations: RfD, reference dose; CSF, cancer slope factor

	Oral Ingestion				Dermal				Health Hazard
	HQ Cd	HQ As	HQ Pb	HI	HQ Cd	HQ As	HQ Pb	HI	
Adults	34.88	0.0009	73.83	108.7	69.75	1.00E-05	20.51	90.3	198.97
	42.51	0.0008	79.89	122.4	85.02	1.00E-05	22.2	107	229.61
	19.63	0.0015	47.14	66.76	39.25	1.00E-05	13.1	52.4	119.11
	17.74	0.0016	39.25	56.98	35.47	1.00E-05	10.91	46.4	103.36
	31.81	0.001	71.37	103.2	63.62	1.00E-05	19.83	83.5	186.63
	17.44	0.0017	363	380.4	34.88	1.00E-05	100.8	136	516.14
	49.15	0.0007	115.4	164.5	98.3	1.00E-05	32.05	130	294.87
	17.3	0.0017	34.6	51.91	34.6	1.00E-05	9.62	44.2	96.13
	8.24	0.0036	18.9	27.14	16.47	1.00E-05	5.25	21.7	48.87
	9.77	0.0033	18.51	28.29	19.54	1.00E-05	5.14	24.7	52.98
	17.6	0.0017	32.25	49.85	35.19	1.00E-05	8.96	44.2	94
	17.07	0.0033	18.12	35.2	34.14	1.00E-05	5.04	39.2	74.39
	42	0.0014	45.48	87.48	83.99	1.00E-05	12.64	96.6	184.11
	29.36	0.001	60.08	89.44	58.72	1.00E-05	16.69	75.4	164.85
	34.63	0.0009	79.61	114.2	69.25	1.00E-05	22.12	91.4	205.6
Children	6.98	9.00E-04	14.77	21.75	13.95	2.854	4.93	21.74	43.48
	8.51	8.00E-04	15.98	24.49	17.01	2.447	5.33	24.79	49.27
	3.93	0.002	9.43	13.36	7.85	5.118	3.15	16.12	29.48
	3.55	0.002	7.85	11.4	7.1	5.461	2.62	15.19	26.59
	6.37	0.001	14.28	20.64	12.73	3.355	4.76	20.85	41.49
	3.49	0.002	72.6	76.09	6.98	5.657	24.2	36.84	112.9
	9.83	7.00E-04	23.08	32.91	19.66	2.153	7.7	29.51	62.42
	3.46	0.002	6.92	10.39	6.92	5.858	2.31	15.1	25.49
	1.65	0.004	3.78	5.44	3.3	12.2	1.26	16.77	22.21
	1.96	0.003	3.71	5.67	3.91	11.29	1.24	16.46	22.12
	3.52	0.002	6.45	9.98	7.04	5.811	2.15	15.01	24.99
	3.42	0.003	3.63	7.05	6.83	11.19	1.21	19.25	26.3
	8.4	0.001	9.1	17.5	16.8	4.634	3.04	24.48	41.98
	5.88	0.001	12.02	17.89	11.75	3.299	4.01	19.06	36.95
	6.93	9.00E-04	15.93	22.85	13.85	2.771	5.31	21.94	44.79

Abbreviations: HQ, health hazard; HI, health index

CONCLUSIONS

Analysis of water quality in the study area illustrates the nature of pollutants found in groundwater as a result of continuous random dumping of hazardous waste and discharge of effluents by agriculture and municipal waste in the community and surrounding environment. The results of this study suggest that groundwater close to the study area is no longer potable for drinking due to the moderate-abundant amounts of carbonate, which causes water hardness, and could lead to cosmetic and aesthetic effects on taste, odor and color. There is also an elevated risk for carcinogenic and non-carcinogenic diseases for adults and children in the area due to high occurrence of Pb, As and Cd found in the water. It is therefore recommended that the municipal government distribute waste disposal bags and establish a waste collection service to reduce indiscriminate dumping of refuse in the area. In addition, a task force should be formed in the community to enforce existing waste disposal and water protection laws. Construction of a centralized, deep, double-cased well is recommended to ensure an uncontaminated water supply for drinking and domestic purposes in the study area.

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It is recommended that the Adamawa State Ministry of Environment should put in place good waste management and disposal systems. It is also recommended that further evaluation of the subsurface water be carried for at least two (2) years or more. For the conclusive result to be obtained for the impact of a refuse waste dump on subsurface water quality of the shallow aquifer of the alluvial deposit of the Upper Benue.

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