IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG)
e-ISSN: 2321–0990, p-ISSN: 2321–0982.Volume 6, Issue 6 Ver. I (Nov. – Dec. 2018), PP 25-40
www.iosrjournals.org

Assessment Of Heavy Metal Contamination In Surface And Groundwater Resources Using Pollution Indices In Parts Of Barkin Ladi, North Central Nigeria

J.A.Ramadan[1] and A.I.Haruna[2]
[1]*Dept. of Minerals & Petroleum Resources Engineering, Plateau State Polytechnic, Barkin Ladi*
[2]*Dept. of Applied Geology, Abubakar Tafawa Balewa University, Bauchi*
Corresponding Author: J.A.Ramadan

Abstract: *The study area is part of the Jos Plateau, where extensive mining of cassiterite - columbite took place for a period of 70 years. This is evident with mine ponds, pits and dams scattered within it, of which most have become water reservoirs for domestic, irrigation and industrial purposes. Of much concern is the prevalent occurrences of cancers of various types, skin and kidney diseases and so on amongst the inhabitants living around these mine sites. This research work seeks to understand the heavy metal contamination in the surface and groundwater resources; and its far-reaching impacts on human health. The hydrochemical investigations were conducted with the main aim of discovering the source(s) of heavy metal concentration and also to identify the principal pollutants in the water resources of the study area. The surface water chemistry shows a mean concentration of heavy metals in the following order: Fe>Al>Mn>Ba>Zn>Cu>Pb>Co>Ni>As>Cd with a average temperature of 27.1^{0}C; EC of 818.4µs/cm; pH of 8.2 and TDS of 514.9ppm. Similarly, the mean concentration of heavy metals in groundwater is in the following order: Fe>Al>Zn>Ba>Mn>Cu>Ni>Pb>Co>As>Cd as the mean temperature, EC, pH and TDS are 25.9ºC, 372.2µs/cm, 6.7 and 235.5ppm respectively. Pearson's correlation analyses were performed on the hydrochemical data to determine the relationships between the metals in each case after which factor analyses, to identify groups, trends and further establish the source of the heavy metals. In surface water, Zn and Cd display a strong positive relationship with each other proposing an identical source (anthropogenic); however, there exist a strong positive inter-correlation amongst the other metals too which suggests a common source (weathering from parent rocks). Similarly, most of the metals in groundwater indicate a strong water-rock relationship except As, Pb, Ba and Mn which might be from different sources of anthropogenic activities. Contamination Index (CI) for surface water show that some of the ponds and streams are contaminated. However, the CI for groundwater shows all the sampled locations are not contaminated. Nemerow's Pollution Index (NPI) was also computed for surface and groundwater which revealed that the metals Al, Pb, Ba, Mn, Fe in surface water and Al, Fe, Pb in groundwater are responsible for the pollution experienced in the water resources.*

Keywords: *Hydrochemistry, Groundwater, Surface water, Contamination index, Nemerow's Pollution index*

Date of Submission: 30-10-2018 Date of acceptance: 15-11-2018

I. Introduction

The study area is part of the Jos Plateau, where extensive mechanized mining of cassiterite and columbite took place for a period of 70 years. Cassiterite – columbite mineralization was mined in association with other minerals such as thorite, zircon, wolframite as well as monazites (Masok et al., 2015). Unfortunately, the environmental damage and heavy metal contamination was not taken into consideration during the period of mining on the Jos Plateau. This is evident as over 2000 abandoned mining ponds/dams/pits and over 325 km^2 of degraded farmlands with several mining heaps and tailing dumps are seen littered on the Jos Plateau (Davou and Odeyemi, 2013). Efforts by government to reclaim land damaged by these mining activities on the Jos Plateau were unsuccessful (Masok et.al., 2015). Most of these mine ponds have become the available sources of water; and have been put to use by inhabitants for domestic, irrigation and industrial purposes owing to the fact that there is no pipe borne water supply by government in these communities.

Cassiterite - columbite mining and processing constitute a source of pollution to the environment (Adiuku et al., 1991) because the accessory minerals associated are harmful even to human beings and animals at low concentrations. Generally, mining activities tend to render the land unstable making it susceptible to erosion. Likewise, heavy metals seldom breakdown chemically in the environment and mostly settle at the bottom of streams and ponds, providing a long term source of contamination to the surrounding inhabitants causing damage even after mining has ceased (Chao et al., 2007).

This research involves an integrated approach of hydrochemistry, statistical analyses and computations of pollution indices with the sole aim of establishing the source (s) of heavy metal concentrations and further evaluating the extent of contamination to the environment and inhabitants.

II. Description of Study Area

The area of investigation is located in north-central Nigeria and is geographically bounded between latitudes $9^0$32'28''N and $9^0$43'29''N and longitudes $8^0$52'20''E and $8^0$56'12''E (Fig.1). It encompasses the Bisichi, Kuru Jenta, Foron, Heipang, Kassa and Barkin Ladi communities and covers a total land area of about 198 km^2.The study area is generally accessible through the Mararaban Jama'a - Mangu express road with some tarred feeder roads and footpaths linking the various communities.

III. Physiography and Geology

The landforms within the study area include hills, valleys and plains. The hills rise from 4000m to 5000m above sea level and correspond to outcrops of rocks located mostly at the extreme north-western, north-eastern and south-eastern parts of the study area (Fig. 2). Other areas like Heipang and Pahng located in the central and eastern part of the study area exhibit low relief with contour values ranging from 4000m – 4050m. The western areas are also low lying. The Jos Plateau as an isolated upland massif has naturally developed a radial pattern of drainage which flows into four major river systems: Chad (largely Delimi River), Gongola, Benue and Kaduna (Turner, 1989). However, the drainage within the study area is largely dentritic and partially trellis in pattern, generally controlled by the topography and lineaments, with minor stream channels flowing from the highland areas and joining up with major streams in the valleys (Fig. 2). Most of the streams also connect with the abandoned mine ponds within the study area. Jos Plateau is situated in part of the Precambrian to Mid-Cambrian and Jurassic northern Nigerian crystalline shield (Umaru and Schoeneik, 1992). The Basement Complex within this shield is of Precambrian to Mid-Cambrian age (600 ±150 Ma), whereas the Younger Granites, which are anorogenic and intrusive into the Basement, are of Jurassic age (150 Ma). The study area lies partly within the Jos-Bukuru Complex and partly within the Ropp Complex and consists of nine (9) lithologic units

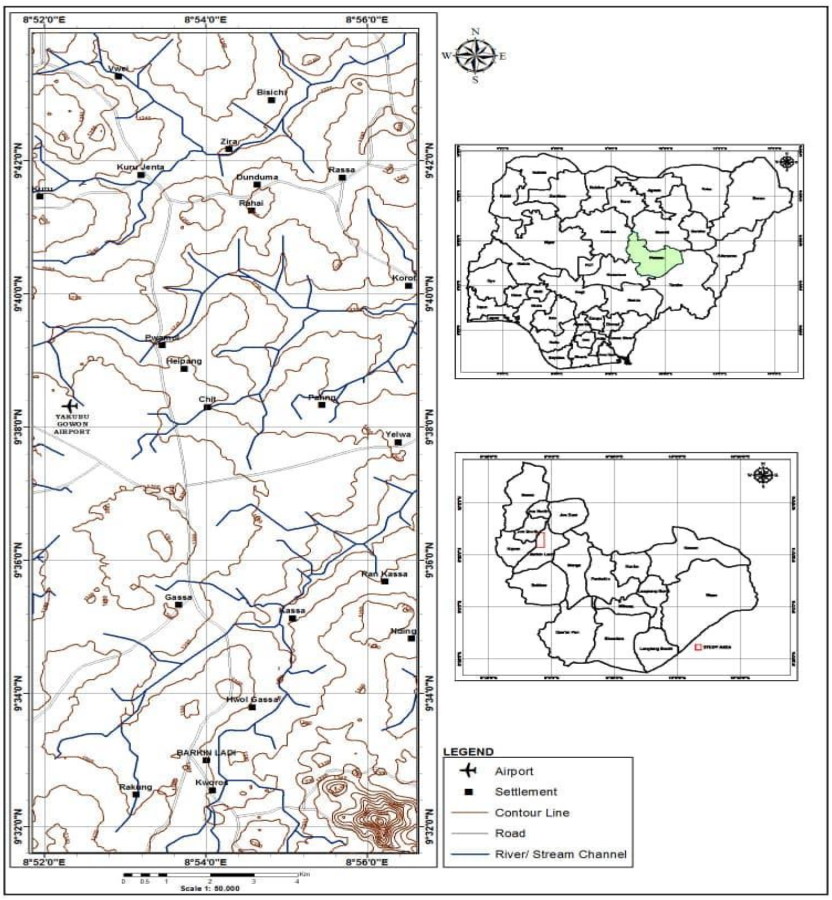

Fig. 1. Location Map of the Study Area.

differentiated on the basis of mode of formation, mineralogy and texture ((Ramadan and Haruna, 2017). These rock units include the newer basalts, microgranite, biotite granite, hornblende biotite granite. Others include the pyroxene granite, granite porphyry, granite gneiss, porphyritic biotite granite and migmatite.

IV. Materials and methods

The methods employed in this research are two-fold namely field methods and laboratory methods.

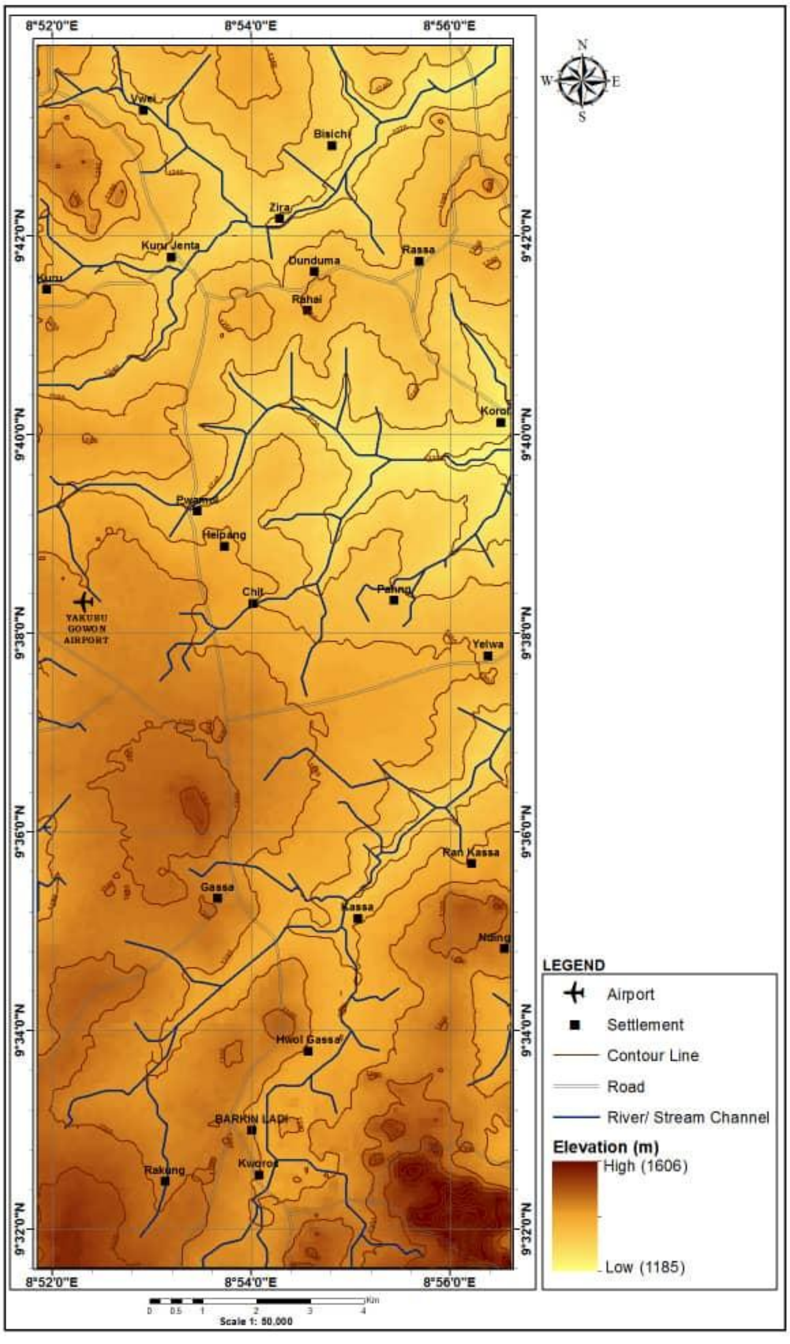

Fig. 2. Map of the Study Area Showing Relief and Drainage

4.1 Field methods

A total number of forty six (46) water samples were collected within the study area at the peak of the dry season in the month of March in order to avoid dilution by the rain waters. Twenty three (23) of these were drawn from ponds and streams and another set of twenty three (23) from hand dug wells and boreholes in polyethylene containers previously washed and repeatedly rinsed with distilled water. Until collection, the containers were kept in sealed polythene bags and at collection point

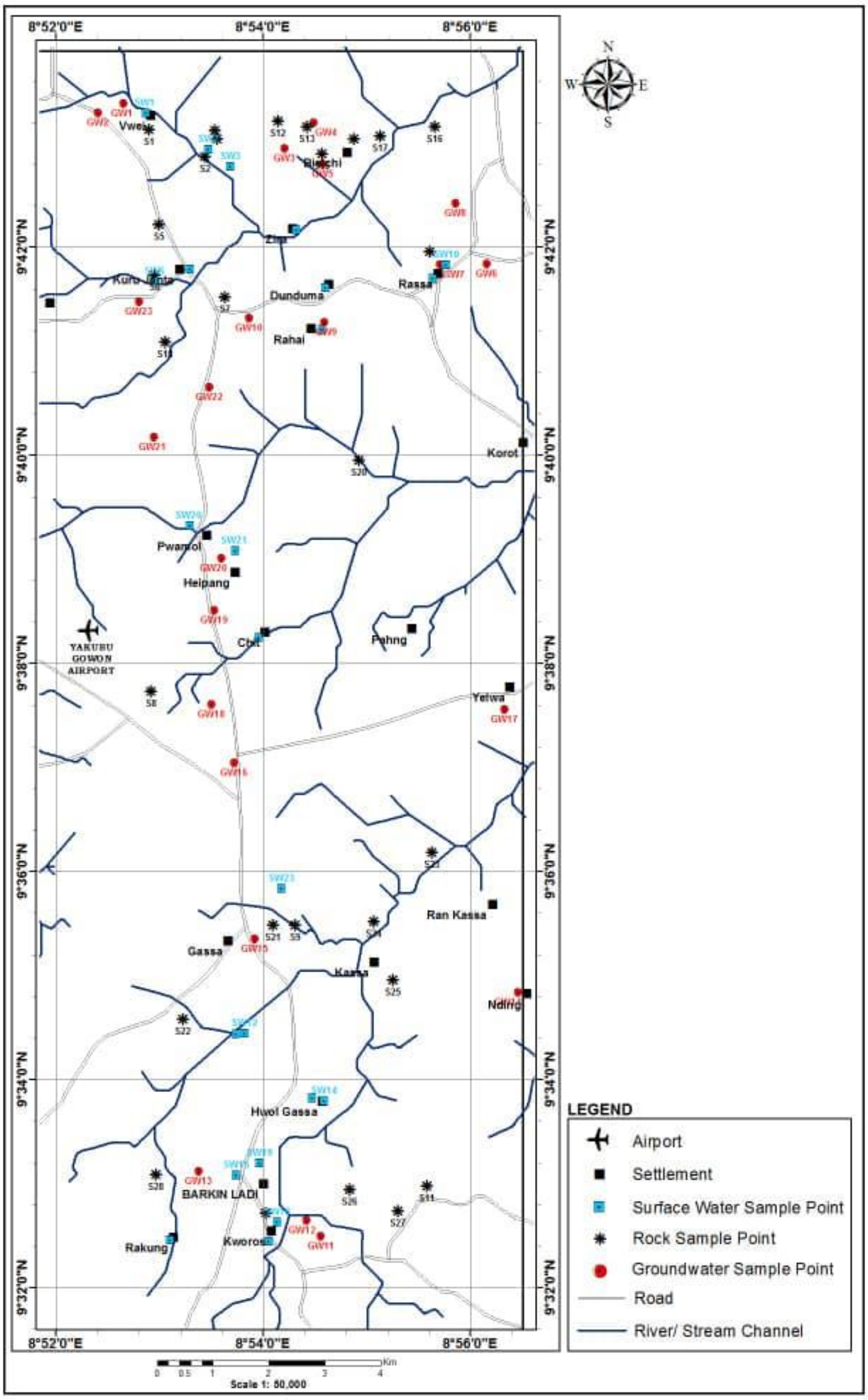

Fig. 3. Map of the Study Area showing Sample Location Points

rinsed twice with the sample to be collected before the final collection. On-site measurements of pH, temperature, conductivity and Total Dissolved Solids (TDS) were obtained using a potable handheld waterproof pH/EC/Temp/TDS tester. Furthermore, the Garmin Global Positioning System (GPS) was used to locate positions where each sample was collected (Fig. 3).

4.2 Laboratory methods

All the water samples collected were filtered with 0.45micrometer disposable filter paper. The filtered samples were acidified with 0.5mls of nitric acid (HNO_3) which stabilizes the metals present in the samples; and kept cool at a temperature of about 4^0C for about two (2) weeks before being sent to the laboratory. The filtered and acidified water samples were analyzed in ACME laboratory, Vancouver, Canada. The samples received were first analyzed by ICP-MS (Inductively Coupled Plasma-Mass Spectrometry) to determine trace and ultra trace concentrations of elements using ELAN9000. The same samples were also analyzed by ICP-ES to confirm higher concentrations using the Spetro/Ciros Vision machine. These analyses provide a detection limit of 0.01-50ppb needed to define background and anomalous levels of cations in the water samples. And data for seventy (70) elements were reported.

4.3 Statistical Analysis

The information obtained from analytical methods were evaluated statistically using SPSS software version 23.0. Descriptive data analysis was performed including the calculation of mean, standard deviation, minimum and maximum. Pearson correlation matrix was carried out to identify relationships between heavy metals and physical parameters. This relationships could be positive or negative (Elumalai et al., 2017).

Factor analysis was also employed to deduce the supposed source of heavy metals. This is advantageous as it makes it possible for the sources of trace and heavy metals in the water sources to be discovered i.e whether of natural and/or anthropogenic origin (Arunachalam et al., 2014). Generally, factor loading values > 0.75 are considered strong, between 0.75 and 0.5 regarded as moderate and between 0.5 and 0.3 considered weak (Bhardwaj et al., 2017).

4.4 Data Evaluation

Contamination index (CI) was employed to discover the metal enrichment within the water sources with respect to the maximum admissible limit of the Nigerian standard guideline. This was achieved by calculation using:

$$\mathrm{CI} = \frac{\frac{As}{0.01} + \frac{Al}{0.2} + \frac{Ba}{0.7} + \frac{Cd}{0.003} + \frac{Cr}{0.05} + \frac{Cu}{1} + \frac{Fe}{0.3} + \frac{Mn}{0.2} + \frac{Ni}{0.02} + \frac{Pb}{0.01} + \frac{Zn}{3}}{11} \qquad [1]$$

Where CI is the contamination index and the numerator is the determined concentration of As, Al, Ba, Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn at each sampling location divided by the Nigerian permissible standard value for each metal; all summed up and then divided by the number of elements considered. Contamination index is categorized as CI>5 (Contaminated), CI 1-5 (slightly contaminated) and CI <1 (not contaminated) (Adamu et al., 2015).

Additionally, the Nemerow's Pollution Index (NPI) which is a single-factor pollution index was applied to determine the contribution of each metal to the toxicity of the water sources. In general, pollution index is a powerful tool for assessing water quality (Sudhakar et.al., 2015). The NPI is given as one of the simplified pollution index and it can be determined by the following equation:

$$\mathrm{NPI} = \frac{C_i}{L_i} \qquad [2]$$

Where C_i = Observed concentration of i^{th} parameter and L_i = Permissible limit of i^{th} parameter. Each value of NPI shows the relative pollution contributed by a single parameter. NPI value exceeding 1.0 indicates the presence of impurity in water. The Nemerow's Pollution Index (NPI) was calculated for each station.

V. Results and Discussions

5.1 Hydrochemistry

The details of the sampling locations, descriptions and geographic coordinates are presented in Table 1& 2. From the data collected, the mean concentration of heavy metals in surface water is in the following order: Fe>Al>Mn>Ba>Zn>Cu>Pb>Co>Ni>As>Cd (Table 1). And the mean temperature is 27.1ºC; the pH ranges between 7.2 to 8.8 with a mean value of 8.2, tending towards alkalinity. However the pH values of some pond waters located at SW2, SW11, SW12, SW15 and SW18 were measured as 8.6, 8.6, 8.8, 8.6 and 8.7 and so obviously do not agree with the Nigerian standard range of 6.5 to 8.5. The total dissolved solids (TDS) ranges between 117 to 1187 with a mean value of 514.9 which exceeds the maximum permitted value of 500 of the Nigerian standard guideline. Likewise, the Electrical Conductivity (EC) with range of values between 182 to 1856 with a mean value of 818.4µs/cm. The mean concentration of heavy metals in groundwater is in the following order: Fe>Al>Zn>Ba>Mn>Cu>Ni>Pb>Co>As>Cd with the mean temperature, EC, pH and TDS recorded as 25.9ºC, 372.2µs/cm, 6.7 and 235.5ppm respectively as shown in Table 2

5.2 Correlation Analysis And Factor Analysis

Correlation measures the linear relationships between two random variables. The Pearson's correlation matrix of heavy metals and physical parameters in surface water as shown in Table 3 reveals that Al, Fe, Ba, Co, Cr and Mn correlate positively with each other and the other heavy metals considered except Zn and Cd. On the other hand, Zn and Cd correlate perfectly with each other as well as the TDS and EC. Generally, there exists a strong positive intercorrelations between heavy metals forming groups as: Al-Fe-Ba-Co-Cr-Mn; Zn-Cd and Cu-Ni-As which suggests that each group of metals have an identical source. Arunachalam et al., in 2014 stated that positive correlations between metals indicate that they are probably derived from the same source.

Table 1: Heavy Metal Concentration and Physical Parameters In Surface Water

Sample location	Sampl code No	Des.	Long	Lat	Al mg/l	As mg/l	Ba mg/l	Cd mg/l	Cr mg/l	Cu mg/l	Fe mg/l	Mn mg/l	Ni mg/l	Pb mg/l	Zn mg/l	Tem (°C)	EC (µs/cm)	pH	TDS (ppm)
Vwei	SW1	Pond	8.8811	9.7216	2.948	0.0005	0.2024	0	0.0034	0.0155	2.661	0.1204	0.0030	0.0343	0.0671	23.6	880	8,5	563
Bisichi	SW2	Pond	8.8911	9.7158	1.845	0.0009	0.1141	0.00064	0.0045	0.0355	1.668	0.1836	0.0098	0.0262	0.2858	25.9	884	8.6	566
Bisichi	SW3	Pond	8.8947	9.7131	0.992	0	0.0229	0	0.0029	0.0092	0.326	0.0346	0.0022	0.0053	0.0263	26.1	1024	8.5	655
Dunduma	SW4	Pond	8.9100	9.6936	0.134	0	0.0211	0.00006	0.0021	0.0061	1.200	0.1257	0.0022	0.0020	0.0310	25.9	546	8.4	349
Zira	SW5	Pond	8.9053	9.7029	0.571	0	0.0683	0	0.0028	0.0103	0.557	0.0621	0.0020	0.0033	0.0194	27.4	716	8.2	458
Kuru Jenta	SW6	Pond	8.8825	9.6947	0.939	0	0.0920	0.00006	0.0028	0.0173	1.947	0.2148	0.0030	0.0060	0.0667	24.9	892	8.1	571
Kuru Jenta	SW7	Pond	8.8881	9.6966	2.522	0.0008	0.1101	0.00028	0.0044	0.0265	3.755	0.1213	0.0056	0.0153	0.1120	29.1	1856	8.1	1187
Rahai	SW8	Pond	8.9094	9.6869	0.108	0	0.0083	0	0.0025	0.0068	0.084	0.0192	0.0018	0.0010	0.0134	28.0	932	8.2	597
Rassa	SW9	Pond	8.9272	9.6951	10.15	0.0013	1.2257	0.00029	0.0185	0.0453	20.20	2.8665	0.0146	0.0852	0.0963	26.8	1596	8.4	1021
Rassa	SW10	Pond	8.9294	9.6973	1.358	0.0009	0.1063	0.00005	0.0037	0.0162	8.333	0.3913	0.0041	0.0117	0.0362	29.5	876	8.5	561
Gassa	SW11	Pond	8.8956	9.5741	1.520	0	0.0826	0.00017	0.0041	0.0151	1.865	0.1508	0.0036	0.0083	0.0813	29.5	264	8.8	169
Gassa	SW12	Pond	8.8969	9.5742	0.186	0	0.0290	0	0.0026	0.0045	0.470	0.0726	0.0017	0.0014	0.0134	27.6	486	8.6	311
Britvic	SW13	Pond	8.9078	9.5638	0.135	0	0.0153	0	0.0019	0.0054	0.201	0.0301	0.0013	0.0010	0.0103	28.2	300	8.4	193
Hwol Gassa	SW14	Pond	8.9097	9.5634	0.412	0	0.0383	0.00006	0.0027	0.0101	0.774	0.0589	0.0023	0.0026	0.0318	26	1620	7.6	1037
Pol.BarrK B/Ladi	SW15	Pond	8.8956	9.5515	0.244	0	0.0314	0	0.0021	0.0065	0.105	0.0327	0.0016	0.0014	0.0154	28.7	444	8.6	284
Rakung	SW16	Pond	8.8850	9.5411	1.698	0	0.1502	0.00009	0.0034	0.0139	1.842	0.0997	0.0031	0.0120	0.0484	28.2	334	8.4	214
Kworos	SW17	Pond	8.9008	9.5409	0.819	0	0.0782	0	0.0029	0.0071	1.032	0.0643	0.0023	0.0049	0.0339	27.2	1444	8.5	924
Kworos	SW18	Pond	8.9022	9.544	0.191	0	0.1194	0	0.0031	0.0057	0.301	0.0446	0.0020	0.0015	0.0173	28.4	852	8.7	341
Kworos	SW19	Pond	8.8994	9.5535	0.189	0	0.0483	0	0.0029	0.0077	0.249	0.0342	0.0018	0.0017	0.0161	28.2	600	8.4	384
Pwamol	SW20	Stream	8.8881	9.6555	0.099	0	0.0460	0	0.0040	0.0127	3.478	0.0527	0.0043	0.0007	0.0320	26.8	182	7.8	117
Pwamol	SW21	Stream	8.8955	9.6515	0.165	0.0012	0.0950	0	0.0040	0.0042	10.95	0.7324	0.0027	0.0011	0.0157	22.8	1580	7.2	1011
Chit	SW22	Stream	8.8992	9.6376	0.156	0	0.0868	0	0.0033	0.0022	2.277	0.0609	0.0022	0.0005	0.0077	26.1	210	7.7	135
Kassa	SW23	Stream	8.9029	9.5974	0.106	0	0.0728	0	0.0031	0.0054	3.849	0.4113	0.0028	0.0005	0.0152	27.5	304	7.8	195
Nigerian Standard Guideline Value					0.200	0.01	0.7	0.003	0.05	1	0.3	0.2	0.02	0.01	3			6.5-8.5	500
Minimum					0.099	0	0.0083	0	0.0019	0.0045	0.084	0.0192	0.0013	0.001	0.0103	22.8	182	7.2	117
Maximum					10.15	0.0013	1.226	0.00064	0.0185	0.0453	20.20	2.8665	0.0146	0.0852	0.2858	29.5	1856	8.8	1187
Mean					1.195	0.0002	0.125	0.00007	0.0039	0.0139	2.504	0.2990	0.0039	0.0137	0.0604	27.1	818.35	8.2	514.9
Standard deviation					2.12	0.0004	0.245	0.00015	0.0036	0.0110	4.700	0.7168	0.0037	0.0221	0.0704	1.74	504.61	0.4	324.9

Table 2: Heavy Metal Concentration and Physical Parameters In Groundwater

Sample location	Sampl No	Descrip	Long	Lat	Al mg/l	As mg/l	Ba mg/l	Cd mg/l	Cr mg/l	Cu mg/l	Fe mg/l	Mn mg/l	Ni mg/l	Pb mg/l	Zn mg/l	Tem (°C)	EC (µs/cm)	pH	TDS (ppm)
Vwei	GW1	HDW	8.8775	9.7231	0.404	0	0.05831	0	0.0029	0.0015	0.134	0.03665	0.0018	0.0011	0.023	23.3	365	6.5	168
Vwei	GW2	HDW	8.8734	9.7216	0.366	0	0.02013	0	0.0037	0.0022	0.218	0.02883	0.0019	0.0017	0.0179	23.6	160	6.6	102
Bisichi	GW3	HDW	8.9034	9.7159	0.046	0	0.01687	0	0.0152	0.0012	0.216	0.01497	0.0077	0.0012	0.0139	25.3	345	6.4	221
Bisichi	GW4	HDW	8.9081	9.7200	0.053	0	0.00957	0	0.0029	0.0011	0.078	0.00601	0.0015	0.0013	0.439	26.1	286	6.3	183
Bisichi	GW5	HDW	8.9096	9.7134	0.187	0	0.0488	0	0.0026	0.0021	0.269	0.03652	0.002	0.0007	0.0188	26.3	209	6.5	134
Rassa	GW6	HDW	8.9360	9.6974	0.089	0	0.01663	0	0.0025	0.001	0.064	0.04946	0.0017	0	0.0204	31.9	412	6.0	264
Rassa	GW7	BH	8.9285	9.6973	0.138	0	0.02892	0	0.0021	0.0017	0.184	0.04254	0.0015	0.0005	0.0437	26.5	290	6.6	186
Rassa	GW8	BH	8.9310	9.7071	0.112	0	0.02058	0	0.0062	0.0721	0.141	0.01128	0.0038	0.0035	0.0697	26.2	220	6.0	141
Dunduma	GW9	HDW	8.9099	9.6881	0.109	0	0.00986	0	0.0029	0.0036	0.984	0.01314	0.002	0.0006	0.0102	24.6	291	6.4	186
Dalor	GW10	BH	8.8977	9.6888	0.059	0	0.02424	0	0.0034	0.0184	0.276	0.00746	0.0017	0.0013	0.0246	26.5	772	6.2	494
Zat	GW11	HDW	8.9093	9.5417	0.197	0	0.06057	0	0.0026	0.0014	0.684	0.04983	0.0018	0.0012	0.0263	23.3	644	6.4	412
Zat	GW12	HDW	8.9070	9.5442	0.058	0	0.02152	0	0.002	0.0007	0.107	0.01592	0.001	0.0003	0.0083	25.3	272	6.3	174
Sabon layi	GW13	BH	8.8896	9.5521	0.203	0	0.09572	0	0.0043	0.0817	0.674	0.02118	0.0049	0.0036	0.0393	26.0	344	6.1	220
Nding	GW14	HDW	8.9410	9.5807	0.114	0	0.03873	0	0.0027	0.0011	0.831	0.0978	0.0018	0.0006	0.0184	24.8	399	6.6	255
Kassa	GW15	HDW	8.8987	9.5893	0.220	0.0011	0.046	0.00006	0.0035	0.0016	0.105	0.16763	0.0032	0.0041	0.0272	23.6	840	6.2	538
Rayogot	GW16	HDW	8.8953	9.6175	0.609	0	0.02315	0	0.0028	0.0038	0.102	0.02806	0.0018	0.0004	0.0134	22.6	495	8.7	317
Rachess	GW17	HDW	8.9389	9.6261	0.275	0	0.04135	0	0.0026	0.0132	2.339	0.07393	0.003	0.003	0.0376	25.3	833	7.1	539
Chit	GW18	BH	8.8917	9.6269	0.085	0	0.03932	0	0.0044	0.0041	0.043	0.02825	0.0014	0.0009	0.018	26.1	337	7.7	216
Heipang	GW19	BH	8.8922	9.6419	0.061	0	0.02258	0	0.0054	0.0184	0.023	0.0012	0.0029	0.001	0.0258	26.0	190	7.3	123
Pwamol	GW20	BH	8.8933	9.6503	0.041	0	0.132	0.00009	0.0021	0.0054	0.009	0.01613	0.007	0.0017	0.1041	26.1	252	6.7	161
Ban	GW21	BH	8.8825	9.6697	0.066	0	0.01611	0	0.0055	0.0119	0.051	0.02501	0.0028	0.0041	0.0176	31.0	160	6.2	102
Yow	GW22	BH	8.8906	9.6778	0.146	0	0.01519	0	0.0023	0.0423	0.219	0.01265	0.002	0.0127	0.1671	29.7	192	7.0	124
Kuru Jenta	GW23	HDW	8.8800	9.6914	0.129	0	0.03075	0	0.0025	0.015	0.042	0.02334	0.001	0.0004	0.0066	24.8	253	7.5	162
Nigerian Standard Guideline Value					0.2	0.01	0.7	0.003	0.05	1	0.3	0.2	0.02	0.01	3			6.5-8.5	500
Minimum					0.041	0	0.00957	0	0.002	0.0007	0.009	0.0012	0.001	0	0.0066	22.6	160	6	102
Maximum					0.609	0.0011	0.132	0.00009	0.0152	0.0817	2.339	0.1676	0.0077	0.0127	0.439	31.9	840	8.7	538
Mean					0.164	0	0.03639	0	0.0038	0.0133	0.339	0.03512	0.0026	0.002	0.0518	25.9	372.2	6.7	235.5
Standard Deviation					0.138	0.0002	0.02892	0	0.0027	0.0223	0.515	0.03662	0.0018	0.0027	0.0918	2.31	207.8	0.64	133.8

Table 3. Correlations Matrix For Surface Water Metals And Physical Parameters

Parameters	Al	Fe	Ba	Co	Cu	Pb	Zn	Ni	As	Cd	Cr	Mn	pH	EC	TDS
Al	1														
Fe	.783*	1													
Ba	.959*	.841*	1												
Co	.925*	.880*	.983*	1											
Cu	.841*	.598*	.732*	.692*	1										
Pb	.981*	.755*	.936*	.892*	.856*	1									
Zn	.397	.158	.249	.189	.780*	.480	1								
Ni	.871*	.744*	.835*	.818*	.943*	.887*	.692*	1							
As	.618*	.806*	.592*	.612*	.615*	.644*	.445	.699*	1						
Cd	.469	.244	.349	.305	.808*	.528*	.965*	.765*	.515*	1					
Cr	.946*	.867*	.982*	.980*	.769*	.915*	.304	.884*	.637*	.419	1				
Mn	.886*	.929*	.957*	.985*	.660*	.855*	.187	.806*	.678*	.299	.962*	1			
PH	.194	-.237	.089	.040	.217	.216	.250	.103	-.149	.233	.040	-.065	1		
EC	.421	.430	.358	.356	.415	.389	.237	.372	.521	.258	.376	.389	-.230	1	
TDS	.432	.443	.356	.362	.431	.399	.250	.384	.542	.267	.380	.397	-.260	.991*	1

**Correlations are significant at p=0.05*

The correlation matrix was used to achieve the factor analysis for the same dataset and described in Table. 4. The factor components that have Eigen values higher than one (1) were extracted, this is because the Eigen values indicate the significance of the components (Bhardwaj et al., 2017). Therefore, the component with the highest Eigen value was selected to be the most significant for proper considerations during the factor analysis. Three (3) significant factors with Eigen values and cumulative variance of 89.73% were accomplished. Factor 1 accounts for 62.995% of data variance with strong factor loadings on Al, Fe, Ba, Co, Cu, Pb, Ni, As, Cr and Mn which could be geogenic since the mineralogy of the geological system controls, to a large extent, the chemical quality of water permeating through the system (Singh, 1987); and/or anthropogenic as a result of mining activities within the area. Correspondingly, factor 2 which is responsible for 14.561% of data variance has strong factor loadings of Zn and Cd which suggests anthropogenic activities possibly from the application of fertilizers. Factor 3 accounts for 12.177% variance and strong factor loadings on EC and TDS also interpreted to be dissolution of ions in water through weathering and leaching from rocks. Figure 4 shows the factor plot in rotated space for the distribution of heavy metals in surface water. From this, the metals Al, Ba, Co, Cu, Ni, As, Cr and Pb could be grouped as a set derived from the weathering of surrounding rocks with no considerable anthropogenic source. On the other hand, the concentration of the metals Zn and Cd might strongly be emanating from anthropogenic activities.

The Pearson's correlation matrix (Table 5) was also performed for heavy metals and physical parameters in groundwater after which, a factor analysis. These revealed that factor 1 accounts for 44.825% variance of the data with strong positive loadings on Fe, Co, Cu, Zn, Ni, Cd and Cr implying water-rock interaction leading to a high concentration of metals in the groundwater samples (Table 6). Factor 2 accounts for 16.718% variance with high positive loading on EC and TDS. Factor 3 shows a strong positive loadings on As and weak loadings on Pb and Ba explains 12.305% variance of the data suggesting the source from anthropogenic activities of fertilizer application and mining. Factor 4 shows strong factor loadings on pH explaining 9.974% variance which means different sources of geogenic and anthropogenic activities have contributed to the alkalinity/acidity level of the water. Figure 5 demonstrates a factor plot in rotated space for metal distribution in groundwater.

5.3 Contamination Index And Nemerow's Pollution Index

The contamination index aims to provide the measure of the degree of contamination by heavy metals within the water bodies. From the results of the computation of contamination index (CI), the water samples collected from ponds and streams show some measure of contamination and range from 0.11 – 13.11. Sample collected at Rassa (SW 9) is highly contaminated with CI of 13.11 (Table 7).

Table 4: Factor Analysis For Heavy Metals And Physical Parameters In Surface Water

Metal/physical Parameters	Factor 1	Factor 2	Factor 3
Al	**.949**	-.068	-.152
Fe	**.848**	-.365	.030
Ba	**.930**	-.245	-.222
Co	**.919**	-.315	-.204

Cu	**.884**	.393	-.028
Pb	**.944**	.017	-.166
Zn	.518	**.844**	.080
Ni	**.948**	.238	-.097
As	**.743**	.001	.232
Cd	.596	**.754**	.047
Cr	**.951**	-.199	-.181
Mn	**.914**	-.345	-.125
pH	.052	.326	-.354
EC	.519	-.091	**.779**
TDS	.535	-.092	**.832**
Eigen value	9.449	2.184	1.826
Total Variance (%)	62.995	14.561	12.177
Cumulative Variance (%)	62.995	77.555	89.732
Possible Source	Leaching from surrounding rocks	Anthropogenic activities	Geological and anthropogenic activities

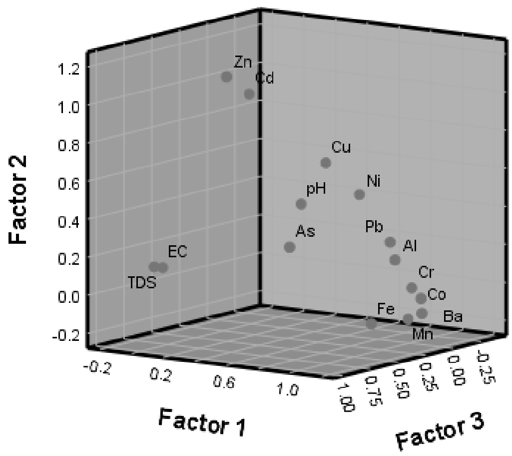

Fig. 4. Factor Plot in rotated space for heavy metal distribution in surface water

Table 5. Correlations Matrix For Heavy metals in Groundwater And Physical Parameters

Correlation Matrix	Al	Fe	Ba	Co	Cu	Pb	Zn	Ni	As	Cd	Cr	Mn	pH	EC	TDS
Al	1														
Fe	.028	1													
Ba	-.104	.345	1												
Co	.180	.949	.258	1											
Cu	-.117	.714	.480	.683	1										
Pb	.033	.498	.618	.477	.644	1									
Zn	.124	.950	.372	.960	.753	.541	1								
Ni	.176	.949	.245	.999	.671	.466	.954	1							
As	-.067	.104	.320	.014	.166	.347	-.045	.014	1						
Cd	.114	.945	.395	.940	.754	.579	.987	.933	.018	1					
Cr	.037	.731	.121	.770	.567	.253	.821	.768	-.453	.798	1				
Mn	.063	-.174	-.087	-.124	-.182	-.155	-.119	-.136	.069	-.094	-.221	1			
pH	.423	-.217	-.106	-.220	-.256	-.204	-.295	-.214	.225	-.273	-.423	-.104	1		
EC	.089	-.100	-.194	-.137	.004	-.196	-.075	-.156	.072	-.027	-.062	.608	-.003	1	
TDS	.131	-.088	-.177	-.129	-.016	-.181	-.062	-.147	.078	-.013	-.048	.603	.005	.995	1

**Correlations are significant at p=0.05*

Table 6: Factor Analysis For Heavy Metals And Physical Parameters In Groundwater

Metal/Physical parameters	Factor 1	Factor 2	Factor 3	Factor 4
Al	.053	.139	-.048	.583
Fe	**.944**	.067	.027	.085
Ba	.410	-.154	.502	-.189
Co	**.955**	.065	-.084	.193
Cu	**.778**	.068	.252	-.180
Pb	.602	-.127	.504	-.133
Zn	**.988**	.115	-.059	.052
Ni	**.950**	.048	-.093	.201
As	.015	.024	**.745**	.081
Cd	**.977**	.155	.014	.047
Cr	**.806**	.091	-.516	-.111
Mn	-.199	.576	.077	-.072
pH	-.309	-.072	.226	**.719**
EC	-.178	**.980**	.072	-.044
TDS	-.168	**.979**	.076	-.012
Eigen Value	6.724	2.508	1.846	1.496
Total \Variance (%)	44.825	16.178	12.305	9.974
Cumulative Variance (%)	44.825	61.542	73.847	88.822
Possible source	Geogenic	Geological and anthropogenic activities	Anthropogenic	Geological and anthropogenic activities

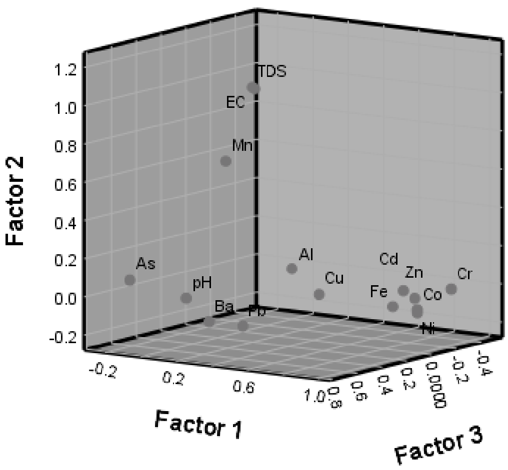

Fig. 5. Factor Plot in rotated space for heavy metal distribution in groundwater

Furthermore, water samples from SW1, SW2, SW6, SW7 and SW10 which represent Vwei, Bisichi, Kuru Jenta and Rassa respectively are considered slightly contaminated with CI values between 1-5. Other slightly contaminated locations include SW11, SW16, SW20, SW21 and SW23 which correspond to Gassa, Rakung,, Pwamol and Kassa respectively. It is also worth of mentioning that all of these water reservoirs are abandoned mine ponds/ stream channels that are still in use by the inhabitants for domestic and irrigation purposes. However, samples collected at SW3, SW4, SW5, SW8, SW9, SW12 and SW13 which stand for Bisichi, Dunduma, Zira, Rahai, Rassa, and Gassa respectively are uncontaminated as shown in table 7 below. Other uncontaminated sample locations include SW14, SW15, SW17, SW18, SW19 and SW22 representing Britvic, Hwol Gassa, police barracks in Barkin ladi, Kworos and Chit in that order with CI of less than 1.

Figure 6 shows a spatial distribution of the contamination levels in surface water sources within the research area. The distribution pattern of the heavy metal contamination as regards surface water within the study area reveals very high contamination levels in the north-eastern section around Rassa. High levels of contamination also occur in the north eastern and central parts of the study area located around Rassa and Heipang. While moderate contamination levels are seen around the north eastern, eastern and central parts of the study area encompassing parts of Bisichi, Yelwa, Pahng, Heipang and Pwamol as shown in Fig. 6.

The Nemerow's Pollution index calculated for each location revealed that all the sample locations for surface water except SW8 (Rahai) and SW13 (Britvic) are polluted to some extent. And the metals responsible for this pollution include Al, Pb, Mn, Fe and Ba (Table 7). These were compared with the Nigerian standard for water quality. Line charts were plotted for each element responsible for pollution against the locations with respect to the Nigerian standard value as shown in Fig.7a – e below. Aluminium exceeds the permissible standard in most locations. It is highest in Rassa. Similarly, it exceeds the maximum permissible level at Vwei, Bisichi, Kuru Jenta, Gassa, Rakung and Kworos as shown in Fig. 7a. Likewise, Barium exceeds the permissible standard value at Rassa (Fig.7b), also the line chart for Pb is also highest in Rassa and moderate in Vwei and Bisichi areas (fig. 7c). In the same way, manganese exceeds the standard value in Rassa, Pwamol and Kassa (Fig. 7d). Fe exceeds the standard value in the following order from highest to lowest: Rassa, Pwamol, Kassa, Chit, Kuru jenta, Vwei, Bisichi, Pahng, Kworos, Dunduma and Hwol Gassa (Fig. 7e).

On the contrary, the groundwater samples collected do not show any contamination in terms of CI computations as all values were less than 1 (Table 9); the spatial distribution is shown in Fig.8. However, the Nemerow's Pollution Index (NPI) computed for each groundwater sample collected shows Al, Fe and Pb are in excess as compared to the standards values in some locations (Table 9). These are vividly represented in Figs. 9a-c below.

Table 7. Contamination Index (CI) and Nemerow's Pollution Index (NPI) in surface water

S/n	Sample ID	Location	CI	Al	As	Ba	Cd	Cr	Cu	Pb	Mn	Ni	Fe	Zn	Remark
1	SW1	Vwei	**2.55**	**14.74**	0.05	0.29	0	0.07	0.02	**3.43**	0.60	0.15	**8.7**	0.02	Al, Pb,Fe
2	SW2	Bisichi	**1.78**	**9.23**	0.09	0.16	0.21	0.09	0.04	**2.62**	0.92	0.49	**5.6**	0.10	Al, Pb, Fe
3	SW3	Bisichi	0.63	**4.96**	0	0.03	0	0.06	0.01	0.53	0.17	0.11	**1.09**	0.01	Al, Fe
4	SW4	Dunduma	0.52	0.67	0	0.03	0.02	0.06	0.01	0.20	0.63	0.11	**4.0**	0.01	Fe
5	SW5	Zira	0.51	**2.86**	0	0.10	0	0.06	0.01	0.33	0.31	0.10	**1.86**	0.01	Al, Fe
6	SW6	Kuru Jenta	**1.21**	**4.70**	0	0.13	0.02	0.06	0.02	0.60	**1.07**	0.15	**6.49**	0.02	Al, Mn, Fe
7	SW7	Kuru Jenta	**2.55**	**12.61**	0.08	0.16	0.09	0.09	0.03	**1.53**	0.61	0.28	**12.52**	0.04	Al, Pb, Fe
8	SW8	Rahai	0.11	0.54	0	0.01	0	0.05	0.01	0.10	0.10	0.09	0.28	0.01	
9	SW9	Rassa	**13.11**	**50.75**	0.13	**1.75**	0.10	0.37	0.05	**8.52**	**14.33**	0.73	**67.34**	0.10	Al, Ba, Pb, Fe, Mn
10	SW10	Rassa	**3.48**	**6.79**	0.09	0.15	0.02	0.07	0.02	**1.17**	**1.96**	0.21	**27.78**	0.01	Al, Pb, Mn, Fe
11	SW11	Gassa	**1.45**	**7.6**	0	0.12	0.06	0.08	0.02	0.83	0.75	0.18	**6.22**	0.03	Al, Fe
12	SW12	Gassa	0.29	0.93	0	0.04	0	0.05	0.01	0.14	0.36	0.09	**1.57**	0.01	Fe
13	SW13	Britvic	0.16	0.68	0	0.02	0	0.04	0.01	0.10	0.15	0.07	0.67	0.003	
14	SW14	Hwol Gassa	0.50	**2.06**	0	0.06	0.02	0.05	0.01	0.26	0.30	0.12	**2.58**	0.01	Al, Fe
15	SW15	Pol. BarrK B/Ladi	0.19	**1.22**	0	0.05	0	0.06	0.01	0.14	0.16	0.08	0.35	0.005	Al,
16	SW16	Rakung	**1.53**	**8.49**	0	0.22	0.03	0.07	0.01	**1.20**	0.50	0.16	**6.14**	0.02	Al, Pb, Fe
17	SW17	Kworos	0.79	**4.10**	0	0.11	0	0.06	0.01	0.49	0.32	0.12	**3.44**	0.01	Al, Fe
18	SW18	Kworos	0.25	0.96	0	0.18	0	0.06	0.01	0.15	0.22	0.10	**1.00**	0.01	Fe
19	SW19	Kworos	0.21	0.95	0	0.07	0	0.06	0.01	0.17	0.17	0.09	0.85	0.005	
20	SW20	Pwamol	**1.12**	0.50	0	0.07	0	0.08	0.01	0.07	0.26	0.22	**11.59**	0.011	Fe
21	SW21	Pwamol	**3.78**	0.83	0.12	0.14	0	0.08	0	0.11	**3.66**	0.14	**36.48**	0.005	Mn, Fe
22	SW22	Chit	0.82	0.78	0	0.12	0	0.07	0	0.05	0.31	0.14	**7.59**	0.003	Fe
23	SW23	Kassa	**1.44**	0.53	0	0.10	0	0.06	0.01	0.05	**2.06**	0.14	**12.83**	0.005	Mn, Fe
Maximum			13.11	50.75	0.13	1.75	0.21	0.37	0.05	8.52	14.33	0.73	67.34	0.1	
Minimum			0.11	0.5	0	0.01	0	0.04	0.01	0.05	0.1	0.07	0.28	0.003	
Mean			1.70	6.0	0.02	0.18	0.04	0.09	0.02	0.99	1.30	0.18	9.87	0.020	
Standard Deviation			2.30	10.61	0.04	0.35	0.06	0.09	0.01	1.86	2.96	0.15	15.35	0.027	

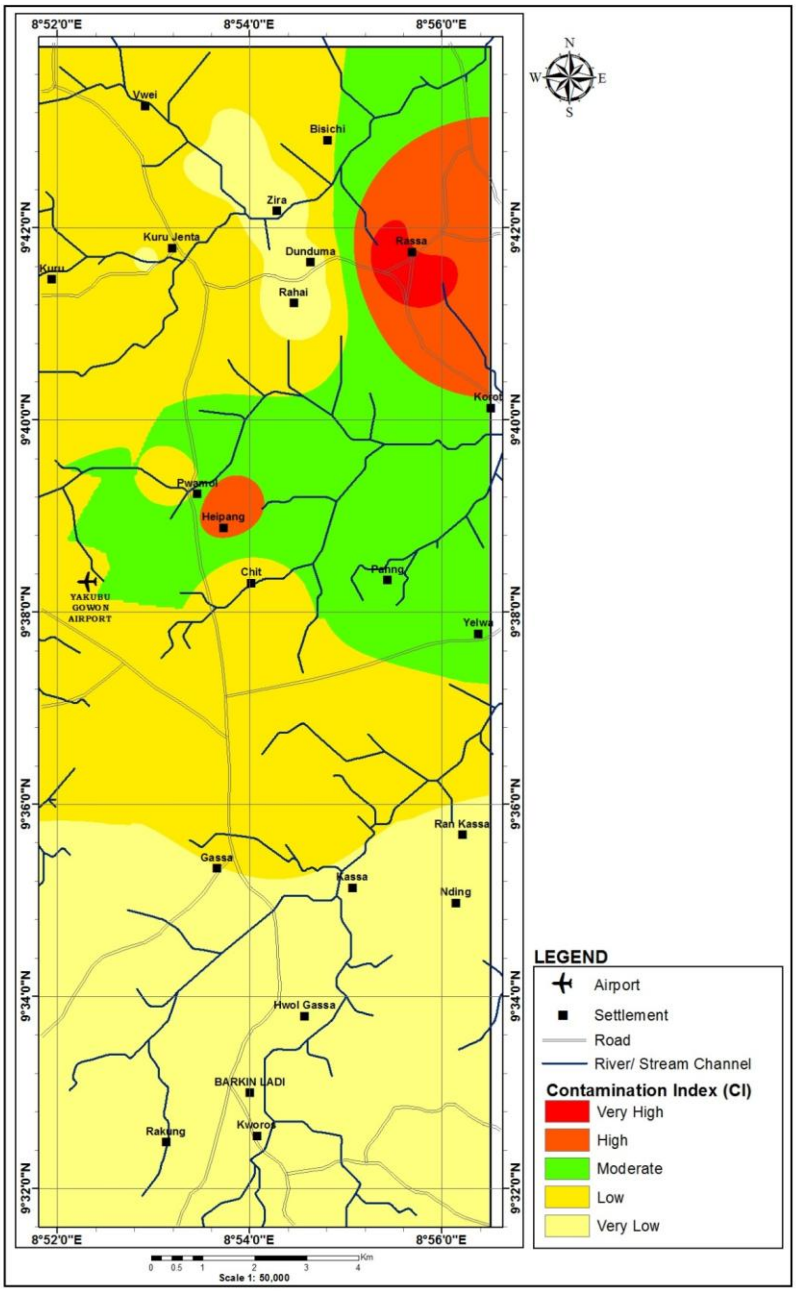

Fig. 6 . Spatial Distribution of Contamination Levels in Surface water within the Study area

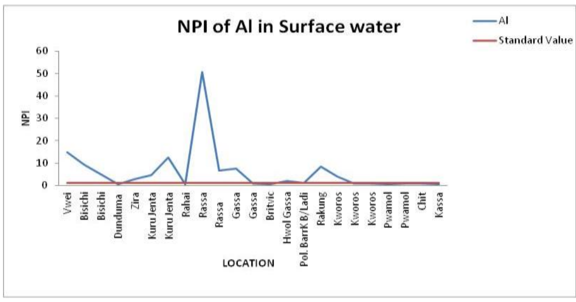

Fig. 7a

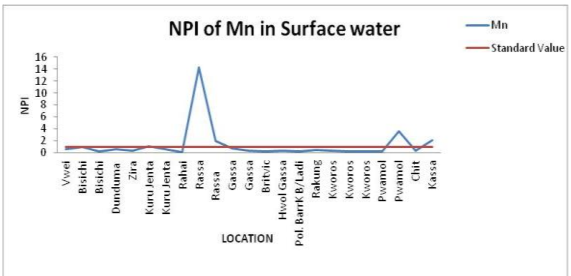

Fig. 7b

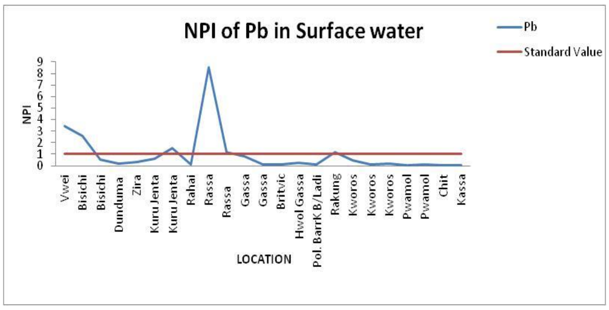

Fig. 7c

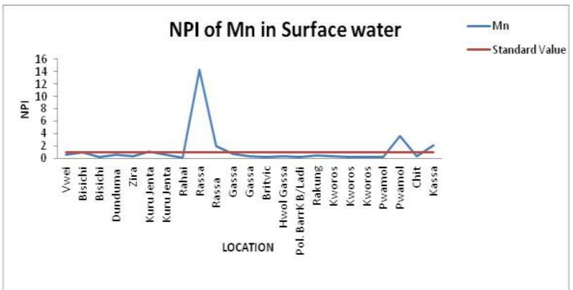

Fig. 7d

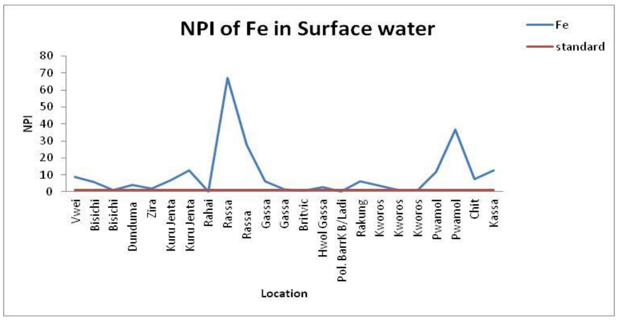

Fig. 7e

Table 9. Contamination Index (CI) and Nemerow's Pollution Index (NPI) in Groundwater

S/n	Sample ID	Location	CI	Al	As	Ba	Cd	Cr	Cu	Pb	Mn	Ni	Fe	Zn	Remark
1	GW1	Vwei	0.27	**2.02**	0	0.08	0	0.06	0	0.10	0.18	0.09	0.45	0.007	Al
2	GW2	Vwei	0.28	**1.83**	0	0.03	0	0.07	0	0.17	0.14	0.10	0.73	0.006	Al
3	GW3	Bisichi	0.17	0.23	0	0.02	0	0.30	0	0.12	0.08	0.39	0.72	0.005	
4	GW4	Bisichi	0.09	0.25	0	0.01	0	0.06	0	0.13	0.03	0.08	0.26	0.15	
5	GW5	Bisichi	0.21	0.94	0	0.07	0	0.05	0	0.07	0.18	0.10	0.90	0.006	
6	GW6	Rassa	0.10	0.45	0	0.02	0	0.05	0	0	0.25	0.09	0.21	0.007	
7	GW7	Rassa	0.16	0.69	0	0.04	0	0.04	0	0.05	0.21	0.08	0.61	0.015	
8	GW8	Rassa	0.17	0.56	0	0.03	0	0.12	0.07	0.35	0.06	0.19	0.47	0.023	
9	GW9	Dunduma	0.38	0.55	0	0.01	0	0.06	0	0.06	0.07	0.10	**3.28**	0.003	Fe
10	GW10	Dalor	0.15	0.30	0	0.04	0	0.07	0.02	0.13	0.04	0.09	0.92	0.008	
11	GW11	Zat	0.35	0.99	0	0.09	0	0.05	0	0.12	0.25	0.09	**2.28**	0.009	Fe
12	GW12	Zat	0.08	0.29	0	0.03	0	0.04	0	0.03	0.08	0.05	0.36	0.013	
13	GW13	Sabon layi	0.39	**1.02**	0	0.13	0	0.09	0.08	0.36	0.11	0.25	**2.25**	0.006	Al, Fe
14	GW14	Nding	0.37	0.57	0	0.06	0	0.05	0	0.06	0.49	0.09	**2.77**	0.009	Fe
15	GW15	Kassa	0.28	**1.1**	0.11	0.07	0.02	0.05	0	0.41	0.84	0.16	0.35	0.005	Al
16	GW16	Rayogot	0.34	**3.05**	0	0.03	0	0.06	0	0.04	0.14	0.09	0.34	0.013	Al
17	GW17	Rachess	0.92	**1.38**	0	0.06	0	0.05	0.01	0.30	0.37	0.15	**7.80**	0.006	Fe
18	GW18	Chit	0.09	0.43	0	0.06	0	0.06	0	0.09	0.14	0.07	0.14	0.009	
19	GW19	Heipang	0.08	0.31	0	0.03	0	0.11	0.02	0.10	0.02	0.15	0.08	0.035	
20	GW20	Pwamol	0.10	0.21	0	0.19	0.03	0.04	0.01	0.17	0.04	0.35	0.03	0.034	
21	GW21	Ban	0.11	0.33	0	0.02	0	0.11	0.01	0.41	0.01	0.14	0.17	0.006	
22	GW22	Yow	0.27	0.73	0	0.02	0	0.03	0.04	**1.27**	0.01	0.10	0.73	0.056	Pb
23	GW23	Kuru Jenta	0.09	0.65	0	0.04	0	0.05	0.02	0.04	0.01	0.05	0.14	0.002	
Maximum			0.92	3.05	0.11	0.19	0.03	0.3	0.08	1.27	0.84	0.39	7.8	0.003	
Minimum			0.02	0.21	0	0.01	0	0.03	0	0	0.01	0.05	0.03	0.15	
Mean			0.24	0.82	0.01	0.05	0.09	0.09	0.02	0.20	0.16	0.13	1.18	0.0085	
Standard Deviation			0.19	0.69	0.02	0.04	0.08	0.08	0.03	0.27	0.19	0.09	1.74	0.032	

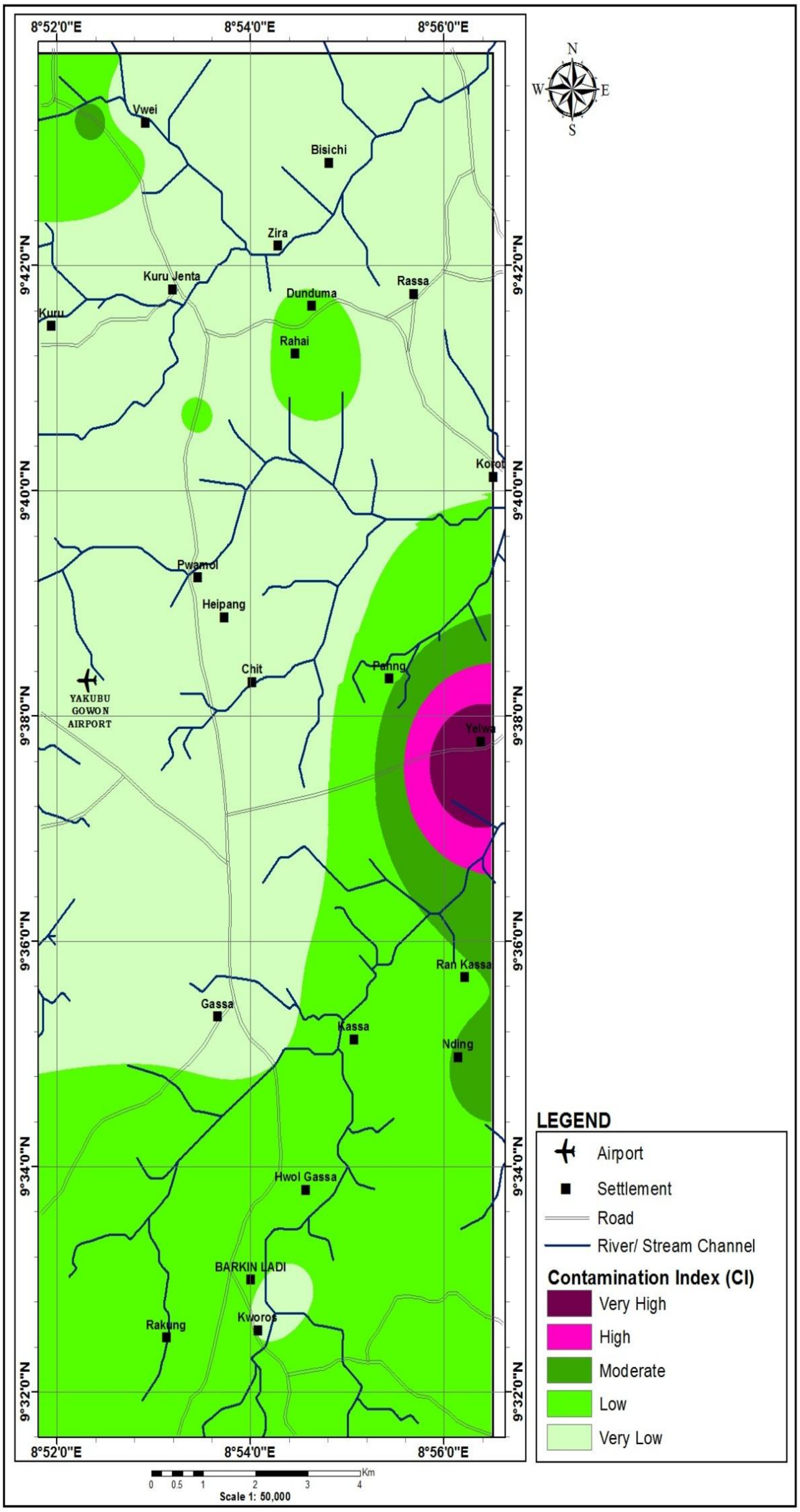

Fig. 8. Spatial Distribution of Contamination Levels in Groundwater within the Study area.

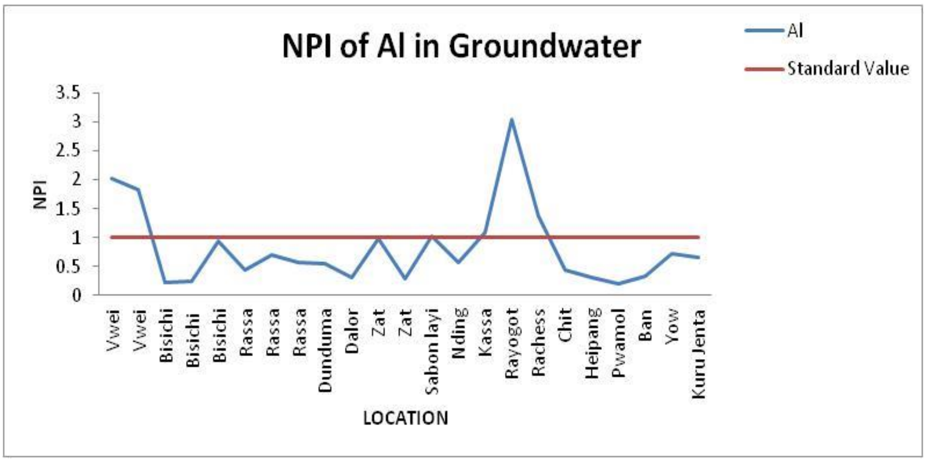

Fig. 9a

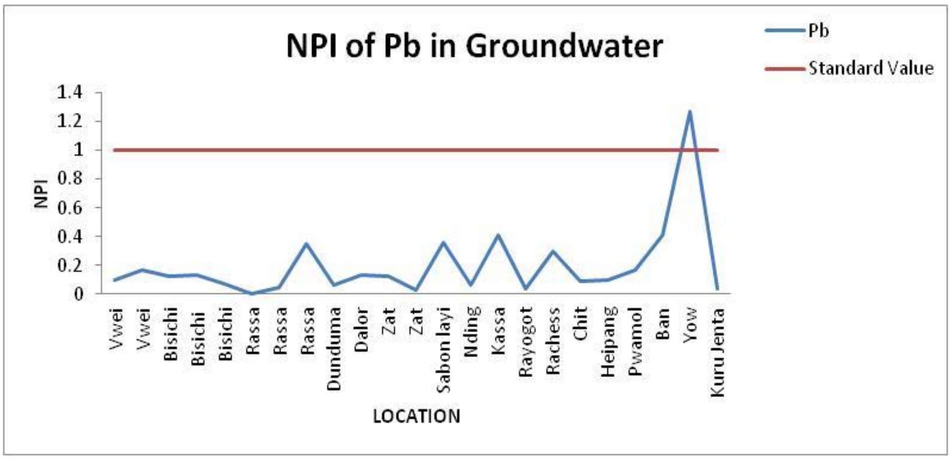

Fig. 9b

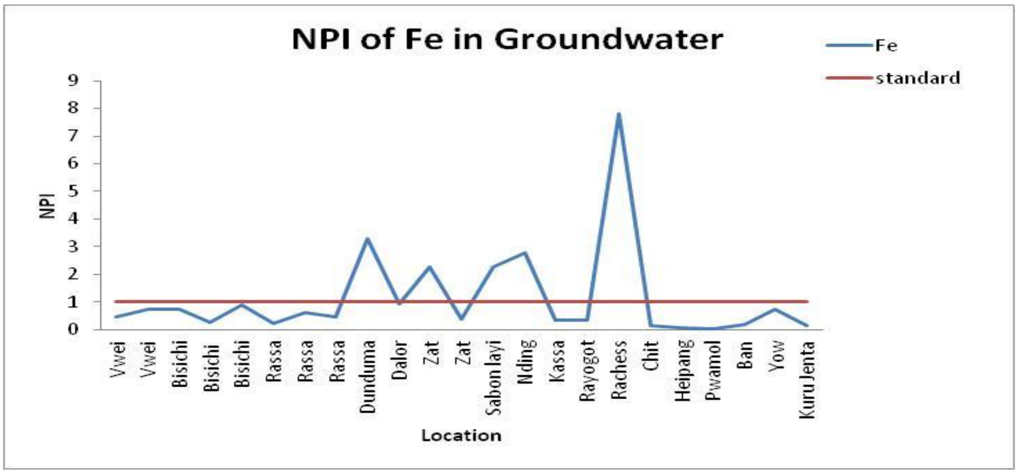

Fig. 9c

V. Conclusion and Recommendation

From the correlation matrix and subsequent factor analysis of heavy metals in surface and groundwater, three (3) and four (4) factors respectively were identified and interpreted to be geogenic (related to geological processes of weathering, leaching from the parent rocks) and anthropogenic (mining and agricultural activities).

Contamination Index (CI) in surface water revealed that both ponds and stream channels are contaminated. The Nemerow‘s Pollution Index (NPI) for the surface water further disclosed the heavy metals responsible for the contaminated locations to be Al, Pb, Mn, Fe and Ba. However, the CI for groundwater did not show any contamination as all the values were <1; On the contrary, the NPI for groundwater showed evidence of some pollution in few locations with excess Al, Fe and Pb.

Consequently, the incessant use of these water sources by residents over time would lead to serious health problems as this study has established varying trends of contamination by different metals (Al, Pb, Mn, Fe, Ba, Co).

Lead (Pb) can damage the nervous connections in humans and cause blood, brain and kidney disorders; miscarriages in pregnant women and reduced infertility (Golub, 2005).

Barium may cause a person to experience breathing difficulties, increased blood pressures, heart rhythm changes, stomach irritation, muscle weakness, changes in nerve reflexes, swelling of brains and liver, kidney and heart damage https://www.lenntech.com/. Consuming water with excess aluminium may cause adverse effects on the nervous system such as Parkinson's disease, amyotrophic lateral sclerosis, Alzheimer's disease. Intake of large amounts of aluminium can also cause anaemia, osteomalacia (brittle or soft bones) and cardiac arrest in humans. https://esemag.com/archive/0197/facts.html. Human exposure to high levels of manganese involve the nervous system which include movements that may become slow and clumsy; in men, loss of sex drive and sperm damage has also been observed as a result of consuming high levels of manganese. Also, manganese may cause irritation of the lungs which could lead to pneumonia (ATSDR, 2012). Elevated levels of iron in water meant for consumption stimulate the growth of bacteria and viruses, so too much iron can increase the risk of infections (Anarson, 2017). Consumption of excess iron causes iron poisoning and early symptoms may include stomach pain, nausea and vomiting. Gradually, it accumulates in internal organs, causing potentially fatal damage to the brain and liver (Anarson, 2017). The toxicity of cobalt is quite low compared to many other metals. Exposure to very high levels of cobalt can cause health effects on the lungs, including asthma, pneumonia and wheezing (Ontario MOE, 2001).

It is recommended that a source of potable water supply be provided to these localities by government especially, because of the fact that at some point in time the products of these mining was the main stay of the state and country's economy.

Conflict of Interest

There is no conflict of interest.

Acknowledgements

This research was supported by TETFund grant through Plateau state Polytechnic, Barkin ladi, Nigeria. The authors are also grateful to the anonymous reviewers for their useful suggestions and criticisms.

References

[1]. Adamu C.I., Nganje T.N. & Edet A. 2014. Heavy Metal Contamination And Health Risk Assessment Associated with Abandoned Barite Mines in Cross River State, Southeastern Nigeria. Journal of Environmental Nanotechnology, Monitoring & Management. Vol. 3. pp.10-21.

[2]. Adiukwu –Brown, M.E., Ogezi, A.E (1991): Heavy metal Pollution from Mining Practices: A case study of Zurak. Journal of Mining and Geology. Vol.8(1)pp. 71-77.

[3]. Anarson A. 2017. The dark side of Iron. Healthline Newsletter.

[4]. Arunachalam K. D., Annamalai S.K., Baskaran K.V., Rajaram S., Jha S.K. & Sreedevi. 2014. Spatial and Multivariate Analysis of Trace Elements in the Surface Water and Deep Sediments Of Fresh Water Aquatic Ecosystem. American Journal of Environmental Science. 10(2): 102-122

[5]. ATSDR (Agency for Toxic Substances and Disease Registry). 2012. Public Health Statement. CAS # 7439-96-5.

[6]. Bhardwaj R., Gupta A., Garg J.K. 2017. Evaluation Of Heavy Metal Contamination using Environmetrics and Indexing Approach for River Yamuna, Delhi Stretch, India. Water Science Journal. Vol.31. Pp. 52-66.

[7]. Chao W, Xiao CL, Pei FW & Zhi YG 2007: Pb, Cu, Zn and Ni concentrations in vegetables in relation to their extractable fractions in soils in suburban areas of Nanjing, China. *Polish J. Environ. Stud*. 2007, 16, 199-207.

[8]. Davou, D.D. and Odeyemi, I.B.F. (2013): Environmental Impacts of Mining on Jos Plateau, Nigeria. Congress of Geological society of Africa. http://www.CAG24.org.et

[9]. Elumalai V. \brindha K. & Lakshmanan E. 2017. Human exposure risk assessment due to heavy metals in groundwater by pollution index and multivariate statistical methods. A case study from south Africa. Water journal 2017,9,234.

[10]. Golub M.S. 2005."Summary" Metals, Fertlity and Reproductive Toxicity. CRC press. Taylor and Francis group. Pp 153

[11]. https://www.lenntech.com/

[12]. https://esemag.com/archive/0197/facts.html. Facts about human health and Aluminum in drinking water.

[13]. Masok, F.B.,Ike-Ogbonna, M.I., Dawam, R.R., Jwanbot, D.I. and Yenle, N.M (2015):Cancer Risk due to Radionuclides concentration in Tin ores and Sediments at Barkin Ladi, Plateau state, North central Nigeria. International Journal of Environmental Monitoring and Analysis. Vol. 3(5).pp. 260-264.

[14]. MOE (Ontario Ministry of the Environment) 2001. Fact sheet. Cobalt in the Environment, Ontario.

[15]. Ramadan J.A & Haruna A.I. 2017. The background concentrations of Major and Trace elements in rocks around Barkin ladi and environs, north-central Nigeria. IOSR Journal of Applied Geology and Geophysics. Vol.5 iss.4 ver. III. Pp 41-47.

[16]. Singh G (1987) Mine water quality deterioration due to acid mine drainage. Int J Mine Water 6:49–61

[17]. Sudhakar G.,Swarna l.G., Vijayakumar G., Rao P. B. & Venkatarathnamma V. 2015. Application of Nemerow's Pollution Index (NPI) for groundwater quality assessment of Bapatla Mandal west region, coastal Andhra Pradesh, India. Int. Journal of Applied Sciences and Engineering Research, Vol. 4(4).
[18]. Turner, D.C. (1989): Structures and petrology of the Younger granite ring complexes. In Geology of Nigeria (Kogbe, C.A. ed.), Rock view (Nig.) Limited, Jos, Nigeria, pp. 175-189.
[19]. Umaru F.M. & Shoeniek K. 1992. Hydrogeological investigations of the aquifers of Bauchi area. Jour. Min. and Geol., vol. 28 (1), pp. 45-53

J.A.Ramadan " Assessment Of Heavy Metal Contamination In Surface And Groundwater Resources Using Pollution Indices In Parts Of Barkin Ladi, North Central Nigeria"IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG) 6.6 (2018): 25-40.