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Water Quality Determination Around Gold and Manganese Mining Area Using Metal Pollution Index and Water Quality Index in South-western Part of Tegina Sheet 142 North Central Nigeria

M. O. Okanlawon
Senior Examination Office, National Examinations Council, Minna, Nigeria
P. I. Olasehinde
Professor, Department of Geophysics, University of Ilorin, Nigeria
Dr. I. N. Abdullahi
Senior Lecturer and HOD, Department of Geology, Federal University of Technology, Minna, Nigeria
Dr. A. N. Amadi
Senior Lecturer, Department of Geology, Federal University of Technology, Minna, Nigeria
Dr. N. M. Waziri
Senior Lecturer, Department of Geology, Federal University of Technology, Minna, Nigeria
Dr. C. I. Unuevho
Senior Lecturer, Department of Geology, Federal University of Technology, Minna, Nigeria

Abstract:
Water quality around gold and manganese mine sites in Kawo and Maigiro was investigated; Water Quality Index (WQI) and Metal Pollution Index (MPI) were computed to evaluate suitability for human and animal consumptions. The essence of this research is to interpret complex water data into a simple and understandable language for human benefits. Concentration of determined heavy metal parameters for surface water, hand dug well and borehole waters were done using Inductively Coupled Plasma Optical Emission Spectrometry (ICPOES) and titrimetric methods for the determination of ions in the three water types (surface, hand dug well and borehole water). The WQI result showed that the water suitable for drinking is borehole water while the MPI result revealed that Fe, Mn and Pb contaminated both surface and hand dug well water as a result of mining activities in the area. The result implies that the concentration Fe, Mn and Pb pose a serious threat to people living within the vicinity of mines and this call for urgent attention to remedy the impending danger in the study area.

Keywords: *Water quality index, metal pollution index, contamination, heavy metals*

1. Introduction

Water is one of the precious resources on earth that we cannot do without. Water is life and therefore it plays a pivotal role to our health, food security, well-being, social and economic development of any society. Water quality is mostly affected by a wide range of natural and human influences. The most important of the natural influences are geological, hydrological, topographical, meteorological and climatic. Human influence on water quality varied in the degree, agricultural (application of pesticides, organic and inorganic fertilizer), industrial (effluent discharge and atmospheric pollution), forestry and mining activities. These factors significantly affect chemistry of both surface and underground water. Contamination of water with light and heavy metals are mainly determined by natural weathering, erosion of bed rocks and ore deposits and anthropogenic processes (Ettler *et al*., 2011; García-Lorenzo *et al*., 2011; Muhammad *et al*., 2011; Sracek *et al*., 2011). These processes degrade water quality and impair their use for drinking, domestic, agricultural and industrial purposes (Krishna *et al*., 2009).

Heavy metal as natural components of the earth's crust has specific gravity that is at least five times the specific gravity of water. Some of these heavy metals include; arsenic, 5.7; cadmium, 8.65; iron, 7.9; lead, 11.34; and mercury, 13.546 (Lide 1992). Certain heavy metals are nutritionally essential for healthy living in minute quantities. However, at higher concentrations they can lead to poisoning. Poisoning could result for instance from drinking water contamination, higher ambient air concentration, near emission sources or intake via food chain. These metals are no degradable and improper disposal can lead to pollution. The effect of mine activities on water quality have been investigated by a number of researchers in many parts of the world; they generally acknowledge water quality deterioration due to the discharge of partially or untreated mine effluents, and/or accidental discharges, which can change the chemistry of water (McKinnon, 2002 ; Kaye, 2005).

According to Ogezi (2005), mining activities has degraded water quality because mining waste were released into the water bodies in the course of ore processing which resulted to changes in water color and increase concentration of different elements above recommended standard. However, research conducted by Eze and Chukwu (2011) on abandoned Enyigba Lead-Zinc mines in Abakaliki South Eastern Nigeria revealed how indiscriminately dumped mines tailing resulted to environmental pollution. Therefore, the aim of this study is to determine water quality using water quality index and metal pollution index in order to establish the contaminants, assess any changes in water quality and to interpret complex water data into a simple and understandable language for human benefit.

2. Study Area

This study area is geographically sited within Latitude 10°00'N to 10°15'N and Longitude 6°15'E to 6°33'E on the South-eastern part of Tegina sheet 142 and South-western part of Alawa sheet 143. The study area is prominent for Gold and Manganese mining. It is accessible through Minna-Birni Gwari road and Lagos- Kaduna highway through Kagara (Figure 1). Footpaths leading to the various villages and hamlets eases access to different parts of the study area.

The climate of the area lies within the tropical climate and its associated with high temperature (31.2°C-36.9°C) and marked with cloudless sky for most of the year with wet and dry season (NIMET, 2010). The dry season last for about six to seven months, from November to April with very low humidity accompanied by the North-East trade wind which is usually the harmattan periods. Relative humidity is low in the early March at around 40% and increase to over 94% around September. Wet season last for about five to six months usually begins from April to November (Elias, 2015). Highest mean monthly rainfall is September with almost 300mm. The vegetation of the area falls within the Guinea Savannah belt which comprises of different species of shrubs and also forest like along the stream channels (Kogbe, 1989; Ajibade, 1982). Generally, the climate, soil and hydrology of the area permits the cultivation of most of Nigeria's staple crops (yam, rice, guinea corn, millet, cowpea and groundnut) and still allow sufficient opportunity for grazing, fresh water, fishing and other forestry development (Ayinde, Ojehon & Daramola, 2015).

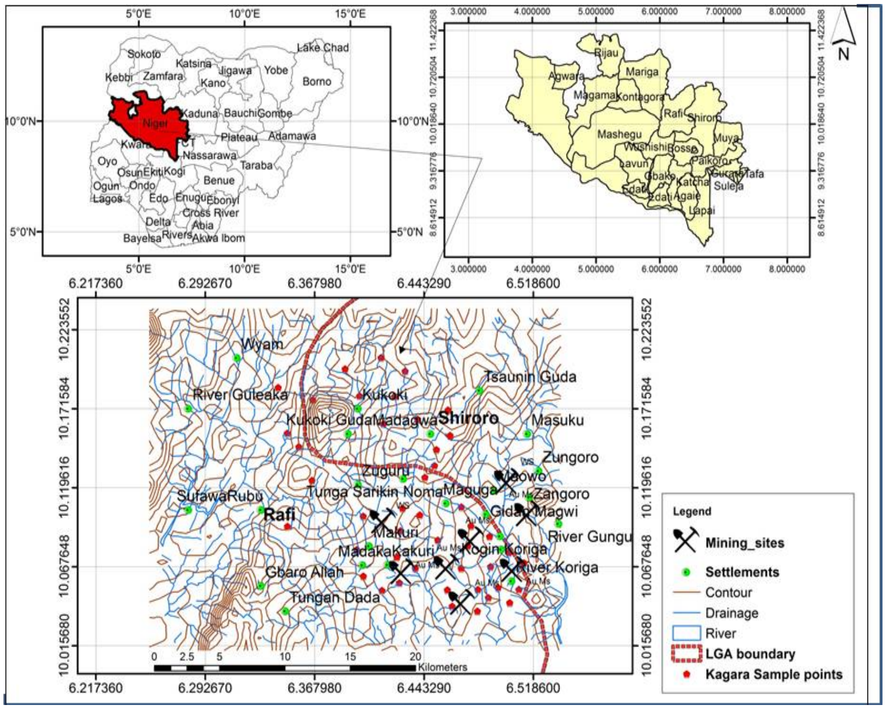

Figure 1: The study area showing mining site and sampling points

2.1. Topography and Drainage

The topography of the study area is gentle with major hill at Madaka which is granitic in nature while some portions of the area are rugged (Figure 2). Rivers in the study area are elevation and fractured controlled as they flow southward and mainly drained by river Shuwa, Koro, Boro, Ankawa, Gungu and Bikoro. Most of these rivers are seasonal; they flow during wet season and dry up during dry season.

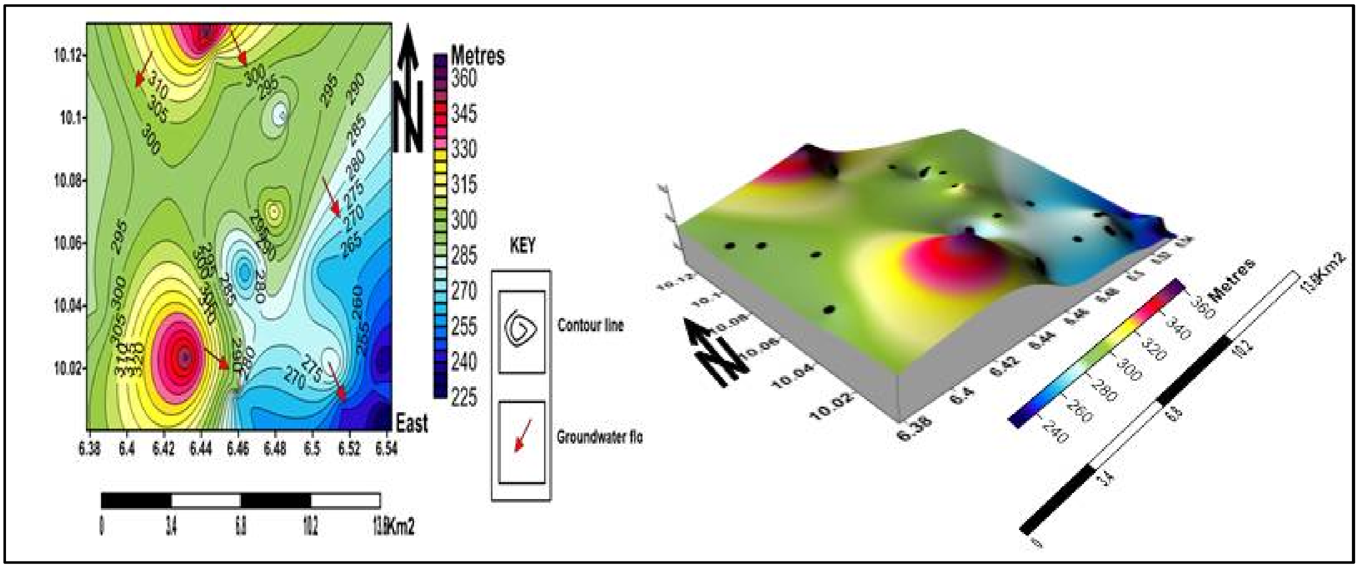

Figure 2: Ground water flow direction and digital elevation model of the study area

3. Materials and Methods

A total of twenty eight (28) water samples were collected from different sampling points in the study area and the geographical coordinates of each point determined with hand held Global Positioning System (GPS) (Germin e-trex). Water samples were collected randomly base on the available water types. Methanol (5% distilled water) was used to wash a pre-cleaned plastic bottles and later washed with water from sampling point up to four times before final collection and acidified with concentrated (HNO_3), after which the plastic bottles was numerically labeled. The samples were stored inside cooler and transported to the ALS geochemistry laboratory in Czech Republic laboratory for analysis. Field parameter such as pH was measured with digital pH meter (pen type) model 8685, Electrical Conductivity (EC) and Total Dissolved Solids (TDS) and temperature (T) was determined using water quality meter (pen type) model AZ8361. These parameters were measured in-situ.

Water type	Number
Surface	9
Hand dug well	9
Borehole	10

Table 1: Summary of collected water samples

3.1. Water Quality Index (WQI)

Water quality index is defined as a method of rating that gives the composite influence of individual water quality parameters on the overall quality of water for human consumption. It is an effective method for assessing water quality suitability in an area in other to communicate information on overall water quality. Water quality was measured by using the following equation for WQI as used by Amadi *et al.,* (2016) with respect to Nigerian Standard for Drinking Water Quality (NSDWQ, 2007). In other to know water quality rating and status of the study area, the quality rating developed by Krishnan *et al*., 1995 was used in Table 1. Overall water Quality Index was calculated by aggregating quality rating with the unit weight as shown below

Overall WQI = $\frac{\sum qiWi}{\sum Wi}$

Where q_i is quality rating scale for each parameter

$q_i = (C_i/S_i)*100$

C_i is **mean concentration** of parameters

S_i is Nigerian Standard for Drinking Water Quality (NSDWQ, 2007)

Relative Weight (W) calculated by a value inversely proportional to standard value (S_i) of each respective parameter that is

$W = 1/S_i$

WQI Value	**Water quality**
<50	Excellent
50-100	Good Water
100-200	Poor water
200-300	Very poor water
>300	Unsuitable for drinking

Table 2: Water Quality Index and Status of water quality (Krishnan et al., 1995)

3.2. Metal Pollution Index (MPI)

This rating method show composite influence of individual metallic parameters on the overall water quality. It used to know suitability of water for drinking purpose. It represents the total ratio between parameters and their corresponding national standard value. The higher the concentration of a metal compared to its respective maximum allowable concentration value, the worse the water quality.MPI has been classified into 5 classes by Krishnan *et al*., 1995, the water quality is rated very lightly polluted, Lightly polluted, moderately polluted, highly polluted and very highly polluted when the value of the index lies between < 0.01, 0.01–1, 1–5, 5–10 and >10, respectively (Table 3). According to (Krishnan *et al*., 1995), the MPIis calculated by using the following formula:

MPI= $\sum_{i=1}^{n}\left[\frac{C_i}{MAC}\right]$

Where:

C_i is **mean concentration**

MAC is maximum allowable concentration.

Values	**MPI Rating**
<0.01	Very lightly Polluted
0.01-1.0	Lightly Polluted
1.0-5.0	Moderately polluted
5.0-10.0	Highly polluted
>10.0	Very highly polluted

Table 3: Metal Pollution index rating (Krishnan et al., 1995)

4. Results and Discussion

4.1. Water Quality Index

Results of computed WQI are summarized in Table 4-6.

Parameters	**Units**	**Mean (*Ci*)**	**NSDWQ (*Si*)**	***Ci/Si***	***qi***	***Wi***	***qi.wi***
TDS	mg/l	151.8	500	0.30	30.38	0.002	0.06
Conductivity	µS/cm	304.89	1000	0.30	30.49	0.001	0.03
pH	-	7.72	6.5-8.5	1.03	102.93	0.133	13.69
Lead	mg/l	1.41	0.01	141	14100	100	1410000
Iron	mg/l	0.3	0.3	1	100	3.33	333
Manganese	mg/l	3.64	0.2	18.22	1882	5	9110
Carbonate	mg/l	29.01	250	0.12	11.60	0.004	0.05
Sulfate	mg/l	38.02	100	0.38	38.02	0.01	0.38
Chloride	mg/l	21.67	250	0.09	8.67	0.004	0.03
Potassium	mg/l	5.01	100	0.05	5.01	0.01	0.05
Sodium	mg/l	13.84	200	0.07	6.92	0.005	0.03
Calcium	mg/l	29.54	200	0.15	14.77	0.005	0.07
Magnesium	mg/l	15.73	200	0.08	7.865	0.005	0.04
						108.509	**1419457.4429**

Table 4: Computed WQI value for surface water

Parameters	**Units**	**Mean (*Ci*)**	**NSDWQ (*Si*)**	***Ci/Si***	***qi***	***Wi***	***qi.wi***
TDS	mg/l	284.56	500	0.57	56.91	0.002	0.11
Conductivity	µS/cm	565.33	1000	0.57	56.53	0.001	0.06
pH	-	7.16	6.5-8.5	0.95	95.47	0.133	12.69
Lead	mg/l	4.07	0.01	407	10700	100	4070000
Iron	mg/l	0.54	0.3	1.8	180	3.33	599.4
Manganese	mg/l	0.29	0.2	1.45	145	5	725
Carbonate	mg/l	21.15	250	0.08	8.46	0.004	0.03
Sulfate	mg/l	47.06	100	0.47	47.06	0.01	0.47
Chloride	mg/l	41.95	250	0.17	16.78	0.004	0.067
Potassium	mg/l	4.88	100	0.05	4.88	0.01	0.05
Sodium	mg/l	18.73	200	0.09	9.37	0.005	0.05
Calcium	mg/l	38.19	200	0.19	19.09	0.005	0,09
Magnesium	mg/l	19.11	200	0.09	9.56	0.005	0.05
						108.509	**4071338.067**

Table 5: Computed WQI value for hand dug well water

Parameters	**Units**	**Mean (*Ci*)**	**NSDWQ (*Si*)**	***Ci/Si***	***Qi***	***Wi***	***qi.wi***
TDS	mg/l	288.5	500	0.58	57.7	0.002	0.12
Conductivity	µS/cm	574	1000	0.57	57.4	0.001	0.06
pH	-	7.18	6.5-8.5	0.96	95.73	0.133	12.73
Lead	mg/l	0	0.01	0	0	100	0
Iron	mg/l	0.06	0.3	0.2	20	3.33	66.67
Manganese	mg/l	0.04	0.2	0.2	20	5	100
Carbonate	mg/l	18.02	250	0.07	7.21	0.004	0.03
Sulfate	mg/l	40.26	100	0.4	40.26	0.01	0.40
Chloride	mg/l	60.28	250	0.24	24.11	0.004	0.09
Potassium	mg/l	4.96	100	0.05	4.96	0.01	0.05
Sodium	mg/l	20.91	200	0.10	10.46	0.005	0.05
Calcium	mg/l	49.51	200	0.25	24.76	0.005	0.12
Magnesium	mg/l	22.99	200	0.11	11.50	0.005	0.06
						8.509	**180.37**

Table 6: Computed WQI value for borehole water

The overall water quality index using the formula:

$$WQI = \frac{\sum qiWi}{\sum Wi}$$

shows that WQI for surface water is 13081.47 (Table 4), hand dug well water is 3750.7 (Table 5) andborehole water is 21.19 (Table 6).

The WQI result for the surface and hand dug well water base on the Krishnan *et al.*, 1995 quality rating status in Table 1, reflected that water quality in the area is unsuitable for drinking except borehole water with quality ratings of excellent. From the computed parameters, it can be observed that Pb, Mn and Fe exceeded maximum permissible limits in surface and hand dug well water which may be responsible for poor water quality.

4.2. Metal Pollution Index

Table 7-9 shows the result of calculated MPI for selected heavy metal in Surface, hand dug well and borehole water with their respective spatial distribution in Figure 3-5.

ID	**Fe**	**MPI**	**Pb**	**MPI**	**Mn**	**MPI**
MAG 01	0.007	VLP	0.1	LP	41.65	VHP
MAG 04	0.052	LP	0.1	LP	8.2	HP
MAG 06	0.04	LP	0.1	LP	0.063	VLP
MAG 07	0.5	LP	4.56	MP	18.55	VHP
KAW 01	2.4	MP	0.99	LP	18.45	VHP
KAW 02	0.65	LP	5.35	VLP	53	VHP
ANK 01	0.3	LP	0.1	LP	0.79	LP

Table 7: Calculated MPI for surface water

VHP= Very Highly Polluted, HP= Highly Polluted, MP= Moderately Polluted, LP= Lightly Polluted, VLP= Very Lightly Polluted.

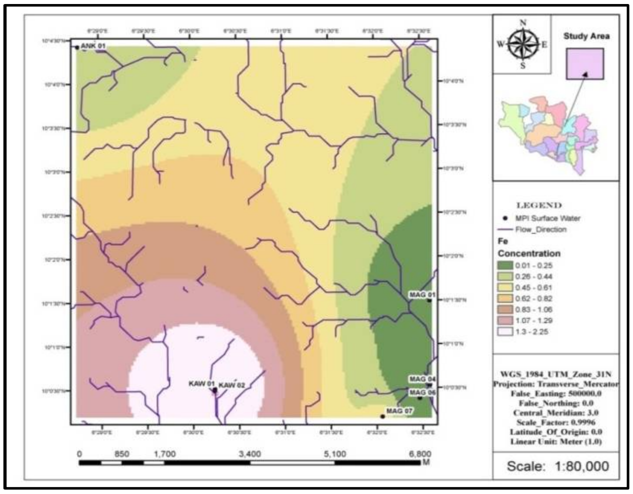

Figure 3 (a): Surface water MPI Spatial distribution for Fe

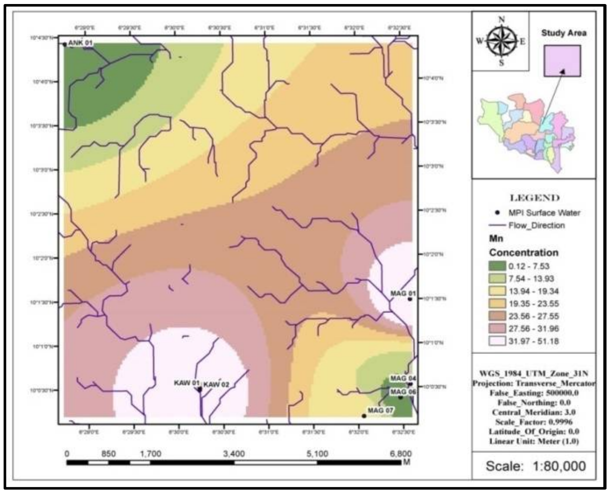

Figure 3 (b): Surface water MPI Spatial distribution for Mn

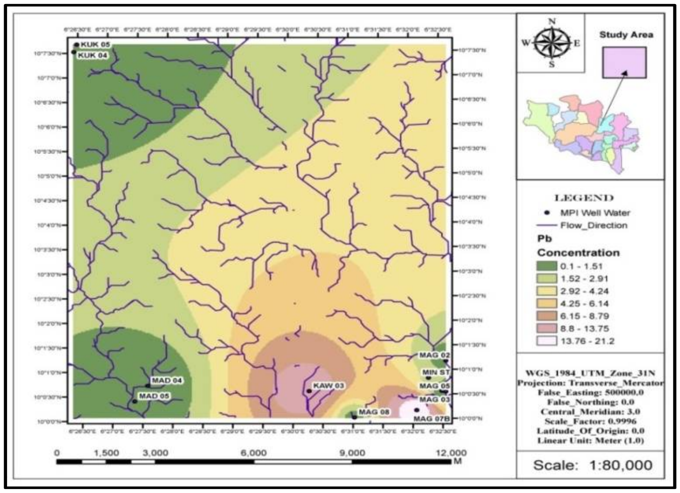

Figure 3(c): Surface water MPI Spatial distribution for Pb

SAMPLE	Fe	MPI	Pb	MPI	Mn	MPI
MAG 02	**8.90**	HP	0.11	LP	0.20	LP
MAG 03	**1.90**	MP	0.10	LP	**8.70**	MP
MAG 07B	**4.00**	MP	**21.20**	VHP	**17.70**	VHP
MAG 08	0.05	LP	0.82	LP	0.10	LP
KUK 04	0.08	LP	0.10	LP	0.003	VLP
KUK 05	0.03	LP	0.10	LP	0.003	VLP
MAD 04	0.20	LP	0.10	LP	0.20	LP
KAW 03	**4.70**	MP	**12.20**	VHP	**3.70**	MP
MIN ST	0.00	VLP	**2.80**	VHP	**5.60**	HP

Table 8: Calculated MPI for hand dug well water

VHP= Very Highly Polluted, HP= Highly Polluted, MP= Moderately Polluted, LP= Lightly Polluted, VLP= Very Lightly Polluted, ND= Not Determined.

SAMPLE	Fe	MPI	Pb	MPI	Mn	MPI
KUK 01	0.20	LP	0.10	LP	0.04	VLP
KUK 02	0.10	VLP	0.10	LP	0.25	LP
KUK 03	0.30	LP	0.10	LP	0.01	VLP
MAD 01	0.50	LP	0.10	LP	0.09	VLP
MAD 02	0.50	LP	0.10	LP	0.76	LP
MAD 03	0.03	VLP	0.10	LP	0.51	LP
KAW 04	0.10	VLP	0.15	LP	0.01	VLP
ANK 02	0.40	LP	0.10	LP	0.12	LP
KAM MA	0.03	VLP	0.10	LP	0.02	VLP
SHK	0.05	VLP	0.10	LP	0.02	VLP

Table 9: Calculated MPI for borehole water

VHP= Very Highly Polluted, HP= Highly Polluted, MP= Moderately Polluted, LP= Lightly Polluted, VLP= Very Lightly Polluted, ND= Not Determined.

Three selected heavy metals (Fe, Mn and Pb) were used to assess metal pollution in the area base on their computed WQI with high values. MPI assessment of these heavy metals in Table 7 (surface water), shows that pollution is in the order of Mn > Pb > Fe. In Table 8, pollution is in the order of Pb> Mn >Fe but MPI assessment in Table 9 (borehole water) indicated extremely low pollution. The result of MPI for sampled water types show similar trend as observed in WQIhigh concentration of these metals in the area. Observed spatial MPI distribution of these metals shows that the concentration tends to increase towards the mining areas in the southwestern end of the study area.

Health issues related with ingestion of Pb in children include brain damage, behavioral problems, anaemia, liver and kidney damage and hearing loss (Gohar & Mohammadi, 2010; Rajaganapathy *et al*., 2011) but in adults lead increases blood pressure, vision and hearing impairment, damages reproductive organ, damage central nervous system, causes poor muscle coordination and nerve damage, damages nerve to the sense organs, and retards fetal

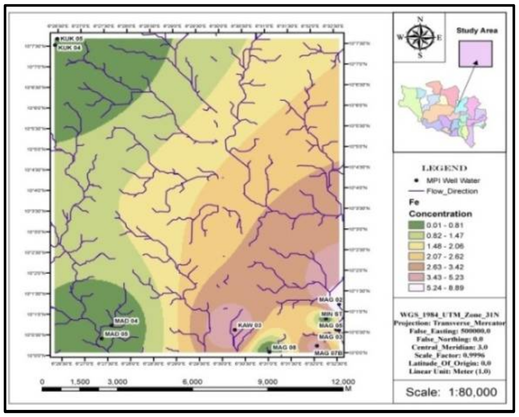

Figure 4 (a): Hand dug Well MPI Spatial distribution for Fe

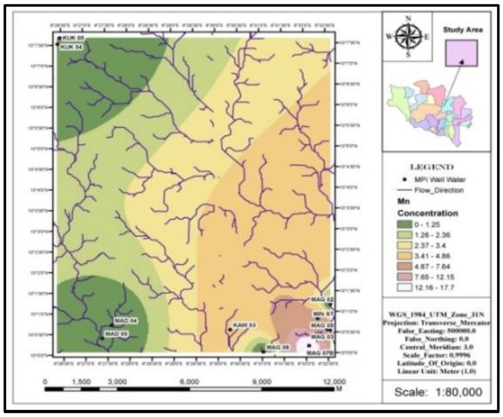

Figure 4 (b): Hand dug Well MPI Spatial distribution for Mn

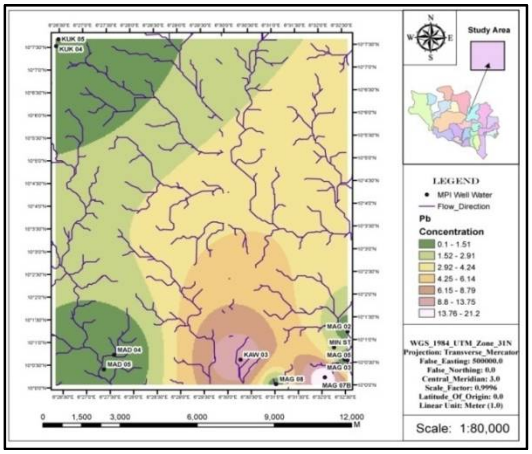

Figure 4 (c): Hand dug Well MPI Spatial distribution for Pb

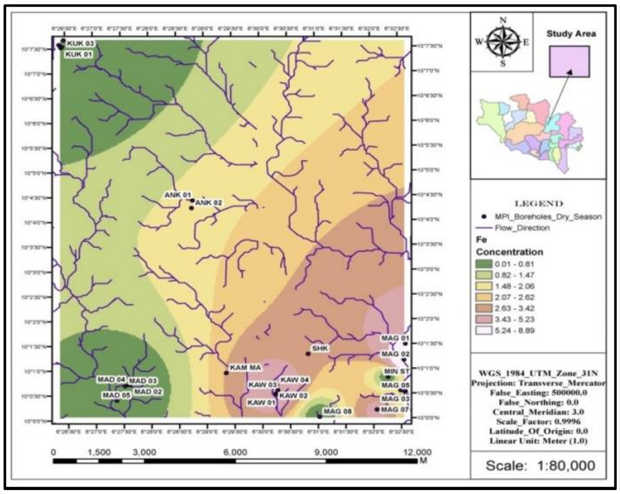

Figure 5 (a): Borehole MPI Spatial distribution for Fe

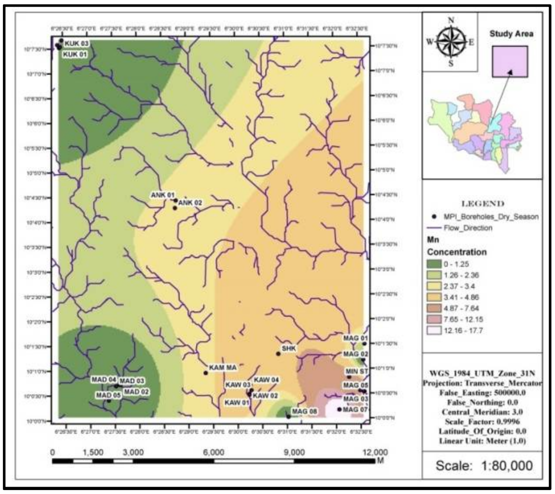

Figure 5 (b): Borehole MPI Spatial distribution for Mn

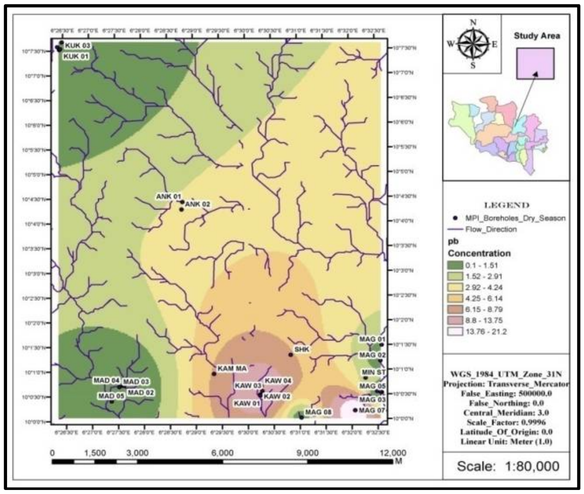

Figure 5 (c): Borehole MPI Spatial distribution for Pb

development (Surendran and El-Fawal, 2008). In this study, concentration of Pb in the surface and hand dug wells around Au and Mn mining site are dangerous for human health, aquatic life and animal health.Prolonged inhalation and ingestion of Mn particulates in mining results in its accumulation in selected brain regions that causes damage to central nervous system and manganism that is extrapyramidal motor disorder (Keen *et al*, 2000; Takeda, 2003 & Dobson, 2004). Prolonged exposure to Mn also causes Parkinson's disease (Gorell *et al*, 1999). Although, Fe is essential part of hemoglobin and helps in formation of red blood cells in the body but excessive of it may result to conjunctivitis, choroiditis, and retinitis. Excessive inhalation of high concentrations of iron oxide fumes or dusts can cause pneumoconiosis and risk of lung cancer.

5. Conclusion

The result of WQI and MPI as applied to water around the study area revealed pollution of Pb, Mn and Fe. The revealed parameters exceeded the maximum permissible limit for drinking water quality and the excessive concentration is attributed to mining activities in the area which rendered surface and hand dug well water unsuitable for drinking. Lithologic dissolution, weathering, water rock interaction, leaching and surface run off aided high concentration within the vicinity of mines. MPI spatial distribution of Pb, Mn and Fe also revealed high concentration within the mine vicinities, there is likelihood of contamination of borehole water with time. Those living down the mines may likely be affected because of the direction of flow. It is therefore advisable to relocate those living within the vicinity of mines, change the source of their water and the affected wells should be abandoned.

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