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Hydrogeochemical Assessment of Mbanabor Area, Anambra Basin, Southeastern Nigeria

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Abstract
Surface and groundwater resources evaluation of Mbanabor was done to assess the quality for human consumption and agricultural purposes. This was achieved through physicochemical and bacteriological analysis of twenty one (21) water samples from both surface and groundwater sources in the area. The result reveals that the concentration of Ca^{2+}(mg/l), Mg^{2+}(mg/l), Na^{+}(mg/l), K^{+}(mg/l), Fe^{2+}(mg/l), Pb^{2+}(mg/l), Cd^{2+}(mg/l), Zn^{2+}(mg/l), and Cu^{+}(mg/l), range between: 0.12 – 27.21, 0.05 – 3, 3.23 – 7.06, 0.1 – 7.31, 0.05 – 3.62, 0.002 – 0.28, 0 – 0.02, 0.04 – 2.5 and 0.001 – 3.0 respectively. The range of SO_4^{2-} (mg/l), NO_3^- (mg/l), and HCO_3^- (mg/l), are between: 1.0 – 13.1, 0.27 – 49.0 and 8.00 – 20.5 respectively. The average of pH (mg/l), colour (Hz), temperature (^{0}C), conductivity (us/cm), turbidity (NTU), TDS (mg/l), TSS (mg/l), BOD (mg/l), DO (mg/l) and hardness (mg/l), are: 6.19, 61.43, 24.7, 63.57, 4.48, 21.44, 5.05, 0.69, 4.64 and 6.4 respectively. Classification of the water samples shows the predominance of Ca(Mg)Cl(SO_4) and Na(K)Cl(SO_4) water types that are largely soft. The values of the Sodium Adsorption Ratio (SAR) range between 0.24 – 2.86 indicating prevalence of good water for agricultural uses. The surface water sources are predominantly infected with microbial contamination, indicating significant input of organic (Faecal) wastes in the flow system. Water resources development programmes in the area requires elaborate qualitative assessment, to ensure that any necessary pre-use treatment is effected.
Keywords: Water Quality, Water Classification, Hydrogeochemistry, Sodium Adsorption Ratio.

INTRODUCTION

Gyan-Boakye, (1999) stated that the health of a given community is reflected to a large extent, in the community's available water resources. Mbanabor is located in the northern part of Awgu Local Government Area of Enugu State, Nigeria. It is one of the new rural development centers in the state with rapid growth in population, urbanization and industrialization. Due to the increasing demand for groundwater, many hand-dug wells and boreholes are being sunk into the shallow aquifer units. Akudinobi and Okolo (2013) observed that high vulnerability to pollution from surface sources prevails in shallow and unconfined aquifers. The various pollutants/contaminants on the ground surface or atmosphere can be transferred through the soil zone into the groundwater flow system (via the hydrologic cycle) thus degrading such water. Regular evaluation of groundwater quality is therefore of fundamental importance. Many urban and rural dwellers depend entirely on groundwater for their daily water needs (Aganigbo et al., 2016). The desirability of water resources evaluation becomes most evident when it is recalled that the resource is heavily impacted by both natural and anthropogenic pollution incidences (Akakuru et al., 2013). The United States Environmental Protection Agency (1977) reported that almost every known instance of aquifer contamination has been discovered after a water supply well has been affected. The factors of pollution include urbanization, population explosion, industrialization, agriculture, which are all inherent in the study area. Septic systems, pit latrines; surface waste disposal sites, garbage dumps; automobile workshops, petrol stations, hospital washings and agricultural activities (application of pesticides, insecticides, fungicides, plants and animal wastes) are common in the area. With the increasing population, the need exists for continual and sustainable efforts towards qualitative evaluation of the water resources in the area, as an inevitable tool for sustainable development. This work aims at establishing the quality status of the available water supply sources in the study area.

Location, Extent, and Accessibility

The study area lies between latitudes $6^0 10^1$N and $6^0 15^1$N, and longitudes $7^0 25^1$E and $7^0 30^1$E, covering an area of about 324km^2. It comprises Ihe, Agbogugu, Isu-Awaa, Agbudu, Owelli, Amaowelli, and Ogugu towns. It is accessible by Enugu to Portharcourt express way. Accessibility is also possible through the old Enugu-Portharcourt road, Enugu State, Nigeria. There are also minor link roads and footpaths, connecting the various towns and villages (Fig. 1).

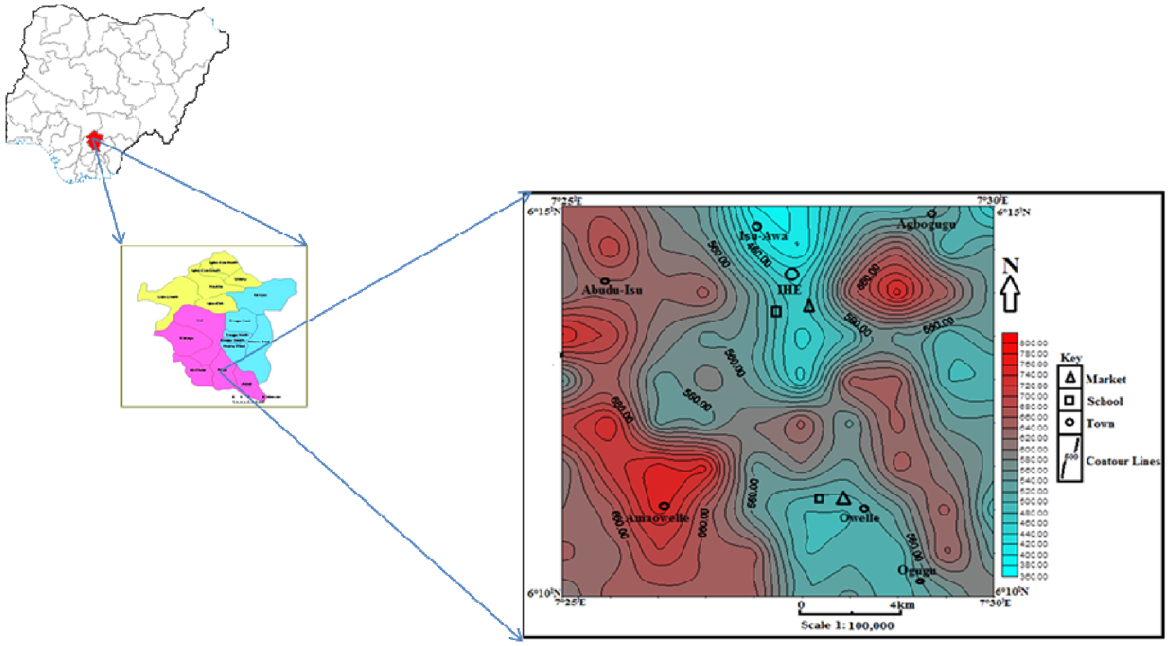

Fig. 1: Location of the study area in Enugu State, Nigeria.

Materials and Methods

Fieldwork involving surface geological mapping and water sample collection was done. Twenty one (21) water samples (comprising six from surface sources and fifteen from wells) were collected for hydrochemical and microbial tests. Two samples were collected at each location, one for cation test and the other for anion and microbial tests. Each sample for cation test was filtered on collection, stabilized with two drops of dilute nitric acid (HNO_3), and stored in a two-litres volumetric plastic containers with tightly fitting covers, while samples for anion and microbial tests were preserved without any additives. The containers were first washed with de-ionized water, and then rinsed several times with the sample water before collection in order to avoid any contamination. All water samples were transported in a family flask, and later stored in a refrigerator prior to analysis. pH, temperature, conductivity, and turbidity were measured in-situ due to their unstable nature, using Myron LpDs Meter. Nitrate, sulphate and some major cations were analyzed with DR 210 spectrophotometer, while heavy metals were analyzed using UNICAM 919 spectrophotometer. Total faecal coliform (TFC) test was done using Membrane filtration technique, with sodium lauryl sulphate broth as the medium.

Results and Discussion

The water samples collected were analyzed for physical, chemical, and microbial constituents and the analytical results presented in Tables 1a and 1b. Comparative consideration of these results with the World Health Organization (WHO) water quality guidelines (2014) was done. The result revealed that chloride concentration ranges from 1.4 - 48.7mg/l, while sulphate and nitrate values range between 1.0 – 13.1mg/l, and 0.27 – 49.0mg/l, respectively. The chloride, sulphate and nitrate concentration levels in the study area fall below the WHO (2014) recommended highest permissible limit for drinking water. Too much sulphate may have laxative effects (Chapman, 1992).

Generally, nitrate content shows very low values, with concentration level below WHO (2014) recommended permissible limit. Nitrate value over 50mg/l is dangerous to babies as it could lead to the problem of infantile cyanosis or blue blood, which could result to death (Chapman, 1992).

The bicarbonate shows concentration values between 8.00 – 20.5mg/l. The most important effect of bicarbonate ingestion is the change in acid-base balance as well as blood pH and bicarbonate concentration in biological fluids. Water with over 600mg/l of bicarbonate may affect acid-base balance.

The appearance and colour of the samples ranges from 1 – 13 in the groundwater samples and from 60 – 444 in the surface water samples. Majority of the samples are odourless, though some objectionable odour was observed in some surface water samples. pH values range from 5.2 – 6.8. According to the World Health Organizsation (2014), health effects are most pronounced in pH extremes. Drinking water with an elevated pH (above 11) can cause skin, eye, and mucous membrane irritation, while pH values below 4 can have corrosive effects on metals. Extreme pH levels can worsen existing skin condition (WHO, 2014).

Conductivity values range from 19 – 110uș/cm, with an average of 63.57uș/cm. Conductivity is a measure of the total dissolved ionic constituents in water, and it varies with temperature. Total Dissolved Solids

(TDS) values range from 9.1 – 42mg/l, with an average of 21.44mg/l. The TDS values in the water samples are far below the WHO permissible limits. TDS is the quantitative measure of the sum total of organic and inorganic solutes in water.

Total Hardness values ranges from 0.26 – 27.26mg/l, with an average of 6.4mg/l. Hardness causes scale formation in boilers, but can also protect pipes against corrosion. The results of hardness test in the water samples analyzed indicated prevalence of predominantly soft water (based on Sawyer and McCarty [1967] hardness classification standards).

Table 1a: Result of the physicochemical and bacteriological analysis of water samples in the study area.

Sample Number / Parameter	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	WHO (2014)
Ca^{2+} (mg/l)	10.52	11.01	7.13	14.81	0.09	25.62	27.21	4.23	3.4	5.39	75
Mg^{2+} (mg/l)	0.2	0.1	0.4	0.6	0.1	0.19	0.05	0.081	1.7	0.56	0.2
Na^{+} (mg/l)	7.06	3.91	5.43	4.2	4.36	5.36	4.47	3.85	3.91	3.4	200
K^{+} (mg/l)	0.6	1.7	0.67	0.33	0.34	0.4	0.1	3.9	0.6	1.7	
Cl^{-} (mg/l)	15.9	13.01	17	48.7	16.2	12.6	1.82	12.6	9.1	1.82	250
$S0_4^{2-}$(mg/l)	1.8	5.1	4.2	6.01	5.4	4.3	5.2	2.1	5.4	12.1	500
$N0_3^{-}$ (mg/l)	8.21	13.3	10.5	7.1	3.20	0.91	0.35	8.01	9.12	8.23	50
HCO_3^{-} (mg/l)	9.54	18.49	18.49	17.4	12.5	9.54	8.00	9.81	12.5	17.5	
Fe^{2+}(mg/l)	0.83	0.25	0.78	0.43	0.25	0.4	0.54	0.48	0.29	0.3	0.3
Pb^{2+}(mg/l)	0.01	0.08	0.002	0.009	0.01	0.002	0.01	0.009	0.009	0.01	0.01
Hg^{2+}(mg/l)	0.12	0.03	0.14	0.001	0.003	0.001	0.01	0.11	0.002	0.001	0.001
Cd^{2+}(mg/l)	0.003	0.005	0.002	0.001	0.007	0.001	0.002	0.001	0.001	0.00	0.003
Zn^{2+}(mg/l)	0.69	0.6	0.8	1.97	1.91	2.1	2.5	1.95	2.5	2	3
Cu^{2+}(mg/l)	0.57	0.06	0.25	0.2	0.37	0.48	0.07	0.44	0.06	1.25	1
pH (mg/l)	6.1	5.2	5.7	5.5	5.7	5.9	6.5	5.9	6.2	6.3	9.2
Colour (TCU)	13	11	7	12	13	12	9	5	6	3	15
Temperature(^{0}c)	23	23	27.8	26	27	24	23	24	23	25	
Conductivity(us/cm)	70	71	60	55	50	60	50	55	19	38	
Turbidity (NTU)	2	5	3	4	2	3	6	5	4	2	5
T DS(mg/l)	17.1	35.1	12.4	14.3	37.8	42	36	17.1	14.3	12.4	
TSS (mg/l)	0	0	0	0	0	1	2	4	0	5	
BOD(mg/l)	0.1	0.2	0.7	0.2	0.2	0.4	0.1	0.3	0.4	0.2	
D O(mg/l)	3.1	4.1	4.8	3.8	4.1	4.3	4.1	4.4	4.0	3.1	
Total fecal coliform (cfu/ml)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
Total microbial load (cfu/ml)	0.2	0.1	0.001	0.2	1.5	0.5	0.2	0.1	0.01	0.001	

W = Well, WHO = World Health Organization.

Table 1b: Result of the physicochemical and bacteriological analysis of water samples in the study area (continued).

Sample Number / Parameters	W11	W12	W13	W14	W15	SW1	SW2	SW3	SW4	SW5	SW6	WHO (2014)
Ca^{2+} (mg/l)	0.7	2.5	0.8	0.32	6.40	0.12	1.18	0.29	0.16	1.21	0.18	75
Mg^{2+} (mg/l)	0.61	0.07	0.05	0.1	0.081	0.22	0.56	1.02	0.1	0.6	3	0.2
Na^{+} (mg/l)	4.2	5.49	6.2	5.6	5.31	3.85	3.23	7.06	5.91	3.4	4.2	200
K^{+} (mg/l)	3.1	0.7	0.4	0.2	0.56	0.7	3.4	1.7	7.31	3.9	3.4	
Cl^{-} (mg/l)	1.47	1.4	18.28	18.3	15.9	16.5	13.0	20.2	14.8	19.4	16.5	250
$S0_4^{2-}$(mg/l)	5.4	5.2	4	5.2	2.0	12	13.1	10.2	2.3	2.3	1.0	500
$N0_3^{-}$ (mg/l)	6.4	4.6	12.1	3.2	3.9	49.0	12.1	10.0	5.2	0.27	4.1	50
HCO_3^{-} (mg/l)	16.8	18.49	17.2	19.3	18.9	15.3	18.1	20.2	18.6	15.3	20.5	
Fe^{2+}(mg/l)	0.78	0.25	0.83	0.5	0.69	0.25	0.05	1.6	3.62	1.26	0.4	0.3
Pb^{2+}(mg/l)	0.02	0.008	0.02	0.01	0.05	0.08	0.01	0.18	0.12	0.28	0.01	0.01
Hg^{2+}(mg/l)	0.001	0.008	0.003	0.004	0.001	0.001	0.008	0.003	0.001	0.12	0.001	0.001
Cd^{2+}(mg/l)	0.001	0.001	0.00	0.002	0.002	0.001	0.001	0.001	0.02	0.001	0.003	0.003
Zn^{2+}(mg/l)	0.04	0.5	0.4	0.8	0.68	0.04	2.1	0.07	0.33	0.75	0.5	3
Cu^{2+}(mg/l)	0.45	0.3	0.001	0.2	0.42	0.45	0.57	3.0	0.8	1.25	0.2	1
pH (mg/l)	5.9	6.2	6.8	6.6	6.7	6.5	6.3	6.6	6.8	6.5	6.2	9.2
Colour (TCU)	2	1	2	2	1	119	125	320	444	125	60	15
Temperature(^{0}c)	23	23	28.1	24	25	26	24	27	24	25	24	
Conductivity(us/cm)	73	68	55	61	70	90	110	80	72	73	55	
Turbidity (NTU)	1	3	4	3	2	1	10	8	15	5	6	5
T DS(mg/l)	35.5	36	14.3	12.4	9.1	17.8	28.2	19.3	12.2	12.0	14.95	
TSS (mg/l)	8	4	3	0	0	12	13	12	15	12	15	
BOD(mg/l)	0.3	0.4	0.6	0.1	0.1	1.6	1.5	2	1.7	1.5	1.9	
D O(mg/l)	3.1	4.1	4.4	4.0	3.9	5.3	7.1	6.1	5.1	7.3	7.2	
Total fecal coliform (cfu/ml)	ND	ND	ND	ND	ND	ND	10	9	8	6	8	
Total microbial load (cfu/ml)	0.1	0.2	0.002	0.1	0.007	15	25	35	26	18	17	

W = Well, SW = Surface Water, WHO = World Health Organization.

Water Classification

The chemical composition of water varies considerably. From the Piper Trilinear diagrams (Table 2 and Figs. 2a and 2b), the dominant water type is $Ca(Mg)Cl(SO_4)$ and $Na(K)Cl(SO_4)$, typical of gypsum and deep ancient groundwater (Back and Hanshaw, 1965). Reyment (1965) reported efflorescence of gypsum and Alum on the surface of the Enugu Shale, which may have been a factor in the chemical character of the water. Onyekuru et al., (2010) opined that the aquifer units of the Southern Anambra basin are characterized by two distinct ionic regimes: Ca-HCO_3 and Na-SO_4. The later is associated with the deeper groundwater flow system within the Mamu Formation while the former occurs in the upper shallow flow system within the Ajali Sandstone.

Table 2: Water analysis data (%meq/l) for the plotting of Piper Trilinear diagram in the study area.

Parameter / Well No.	Ca^{+2} (%meq/L)	Mg^{+2} (%meq/L)	Na^{+} (%meg/L)	K^{+} (%meq/L)	Na^{+}+K^{+} (%meq/L)	HCO_3^{-} (%meq/L)	SO_4^{-} (%meq/L)	Cl^{-} (%meq/L)
W1	60.77	1.91	35.55	1.78	37.33	24.34	5.84	69.83
W2	71.24	1.10	22.06	5.64	27.69	39.04	13.68	47.28
W3	55.41	5.13	36.79	2.67	39.46	32.71	9.44	57.85
W4	75.45	5.04	18.65	0.86	19.51	15.98	7.01	77.00
W5	17.86	3.27	75.42	3.46	78.87	26.46	14.52	59.02
W6	83.15	1.02	15.17	0.67	15.83	26.00	14.89	59.11
W7	87.05	0.26	12.52	0.16	12.69	45.10	37.24	17.66
W8	43.52	1.37	34.54	20.57	55.11	28.71	7.81	63.48
W9	34.28	28.26	34.37	3.09	37.47	35.69	19.59	44.72
W10	53.11	9.09	29.21	8.58	37.79	48.61	42.69	8.70
W11	10.06	14.46	52.64	22.84	75.48	64.15	26.19	9.66
W12	32.22	1.49	61.67	4.62	66.29	67.22	24.02	8.76
W13	12.32	1.27	83.25	3.16	86.41	32.00	9.45	58.54
W14	5.85	3.01	89.26	1.87	91.14	33.62	11.50	54.87
W15	55.89	1.17	40.43	2.51	42.94	38.72	5.21	56.07
SW1	2.86	8.64	79.96	8.55	88.50	25.96	25.86	48.18
SW2	17.72	13.86	42.27	26.16	68.43	31.69	29.14	39.18
SW3	3.22	18.69	68.41	9.68	78.09	29.74	19.08	51.19
SW4	1.74	1.79	55.86	40.62	96.48	39.58	6.22	54.20
SW5	16.89	13.81	41.39	27.91	69.29	29.64	5.66	64.69
SW6	1.71	46.97	34.77	16.55	51.32	40.86	2.53	56.61

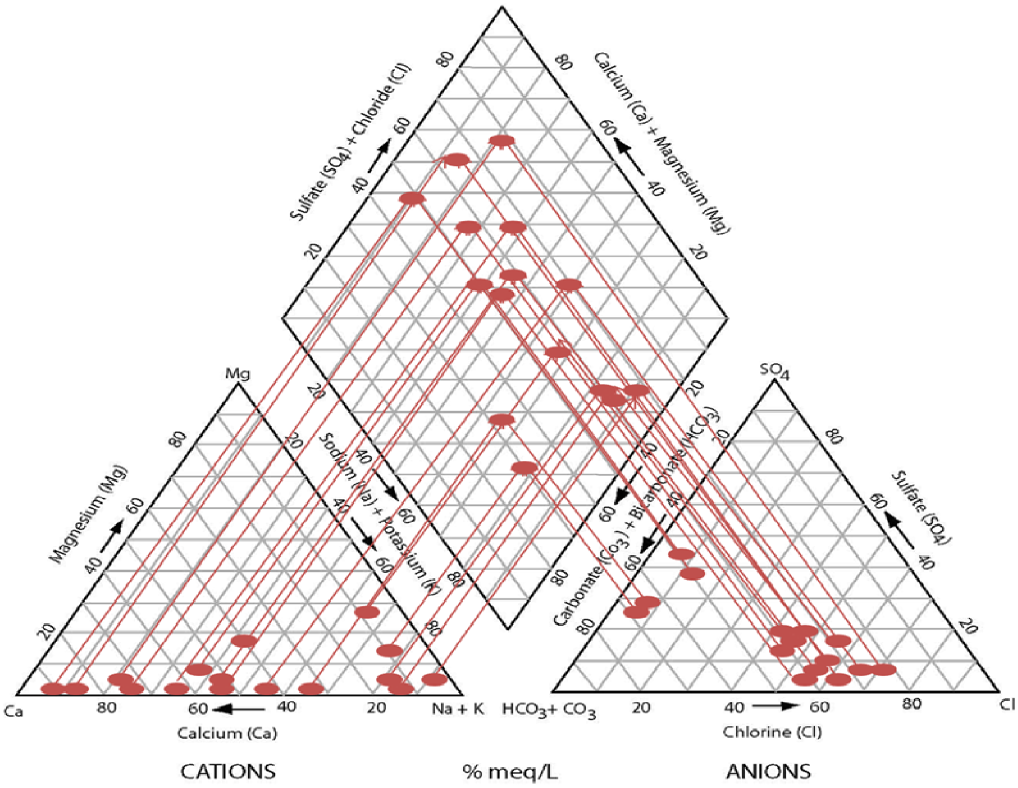

Fig. 2a: Piper Trilinear diagram showing the water types of the groundwater sources in the study area. The plot corresponds to water type N and P (Back and Hanshaw, 1965).
Where N = Ca(Mg)Cl(SO_4)
P = Na(K)Cl(SO_4)

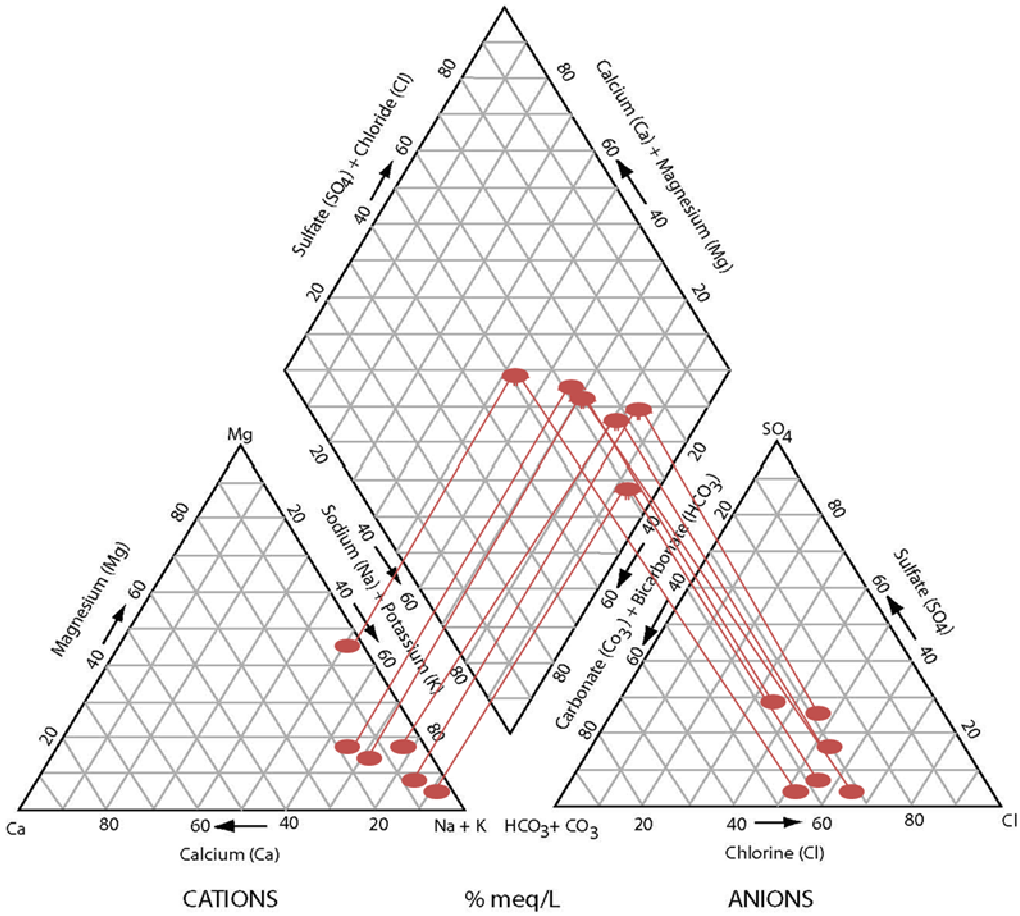

Fig. 2b: Piper Trilinear diagram showing the water type of the surface water sources in the study area. The plot corresponds to water type P (Back and Hanshaw, 1965).
Where P = Na(K)Cl(SO_4)

Sodium Adsorption Ratio (SAR)

Sodium Adsorption Ratio was evaluated for the study area using the relevant chemical parameters analyzed (Table 3 and Fig. 3). It was observed that hundred percent (100%) of the water samples fall below 2.855meq/l, indicating predominance of excellent water for irrigation purposes (Offodile, 2002).

Table 3: Water analysis data (meq/l) for the plotting of SAR (Using Richards, 1954).

Parameter / Sample No.	Na^{+} (meq/l)	Ca^{+2} (meq/l)	Mg^{+2} (meq/l)	SAR (meq/l)
W1	0.31	0.53	0.02	0.59
W2	0.17	0.55	0.01	0.32
W3	0.24	0.36	0.03	0.39
W4	0.18	0.74	0.05	0.29
W5	0.19	0.05	0.01	1.16
W6	0.23	1.28	0.02	0.29
W7	0.19	1.36	0.00	0.24
W8	0.17	0.21	0.01	0.51
W9	0.17	0.17	0.14	0.43
W10	0.15	0.27	0.05	0.37
W11	0.18	0.04	0.05	0.89
W12	0.24	0.13	0.01	0.93
W13	0.27	0.04	0.00	1.82
W14	0.24	0.02	0.01	2.21
W15	0.23	0.32	0.01	0.57
SW1	0.17	0.01	0.02	1.53
SW2	0.14	0.06	0.05	0.61
SW3	0.31	0.01	0.08	1.38
SW4	0.26	0.01	0.01	2.86
SW5	0.15	0.06	0.05	0.63
SW6	0.18	0.01	0.25	0.51

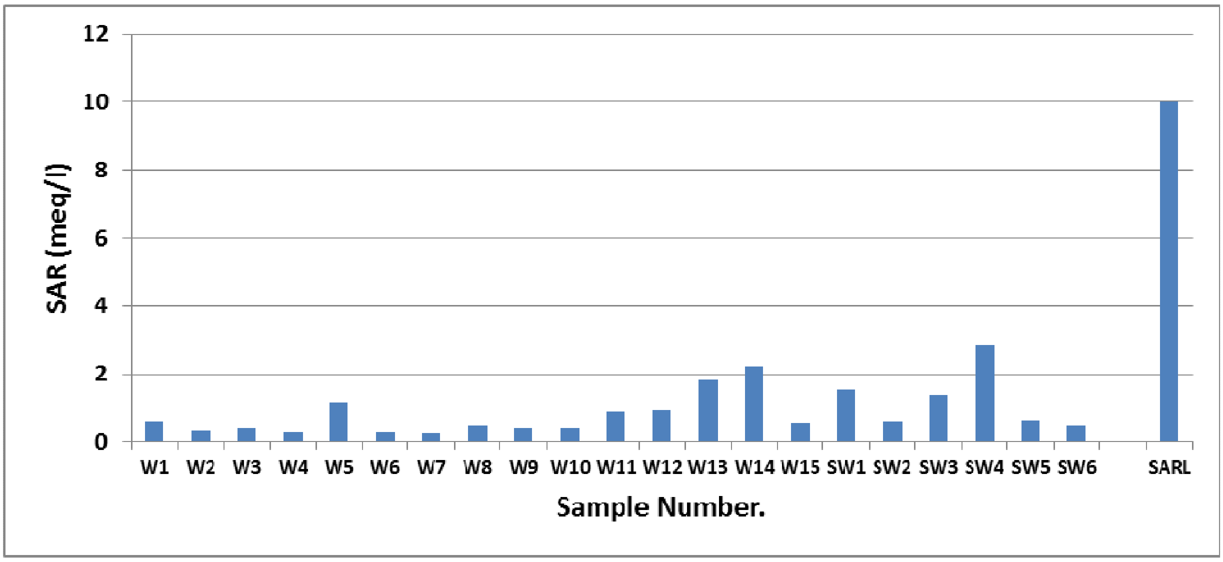

Fig. 3: Bar-chart showing sodium adsorption ratio (SAR) values in the water samples analyzed. W = Well, SW = Surface Water, SARL = Sodium Adsorption Ratio Limit.

Table 4: The recommended irrigation water classification based on sodium adsorption ratio (Offodile, 2002).

	SAR	Water Class
Less than	<10	Excellent, No Problem
	>10 – 18	Good (Medium), Increasing Problem
About	>18 – 26	Poor (High), Severe Problem

It is important to note that hundred percent (100%) of the water samples fall below 2.855meq/l, indicating predominance of excellent water for irrigation purposes.

Water Hardness

Total Hardness values ranges from 0.26 – 27.26mg/l, with an average of 6.4mg/l (Table 5). Hardness causes scale formation in boilers, but can also protect pipes against corrosion. The results of hardness test in the samples analyzed indicated prevalence of predominantly soft water (based on Sawyer and McCarty [1967] hardness classification standards, [Table 6]).

Table 5: Water hardness result (mg/l).

Parameter / Sample Number	Ca^{+2} (mg/l)	Mg^{+2} (mg/l)	$Ca^{+2} + Mg^{+2}$ (mg/l)
W1	10.52	0.2	10.72
W2	11.01	0.1	11.11
W3	7.13	0.4	7.53
W4	14.81	0.6	15.41
W5	0.9	0.1	1
W6	25.62	0.19	25.81
W7	27.21	0.05	27.26
W8	4.23	0.081	4.311
W9	3.4	1.7	5.1
W10	5.39	0.56	5.95
W11	0.7	0.61	1.31
W12	2.5	0.07	2.57
W13	0.8	0.05	0.85
W14	0.32	0.1	0.42
W15	6.40	0.081	6.48
SW1	0.12	0.2	0.34
SW2	1.18	0.56	1.74
SW3	0.29	1.02	1.31
SW4	0.16	0.1	0.26
SW5	1.21	0.6	1.81
SW6	0.18	3	3.18

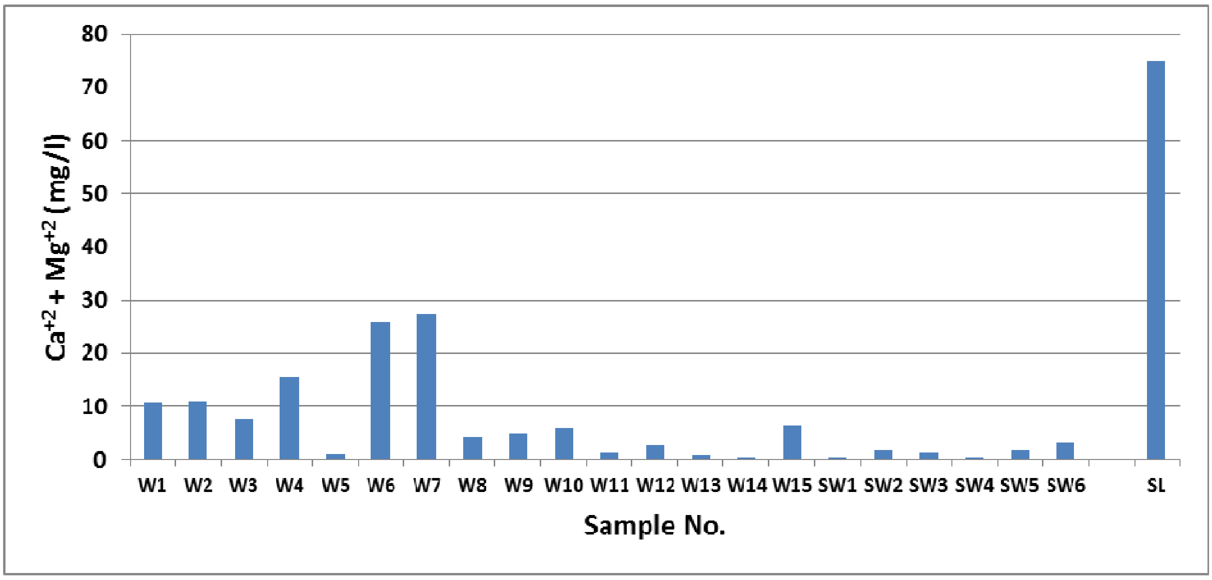

Fig. 4: Water hardness (mg/l) classification of the samples analyzed.
W = Well, SW = Surface Water, SL = Soft Limit.

Table 6: Hardness classification (Sawyer and McCarty, 1967).

Hardness ($Ca^{+2} + Mg^{+2}$)mg/l	Water Classification	% Result of this Study
0 – 75	Soft	100
>75 – 150	Moderately Hard	-
>150 – 300	Hard	-
>300	Very Hard	-

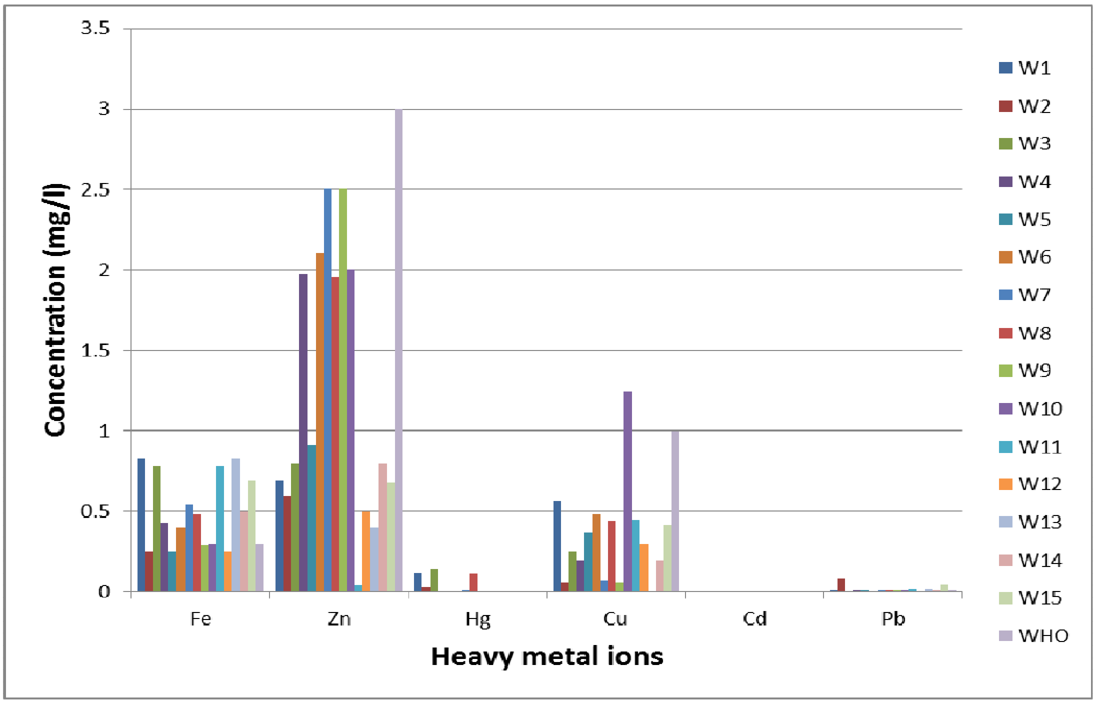

Fig. 5a: Bar chart showing heavy metal concentration in the groundwater samples analyzed.
W = Well, WHO = World health Organization.

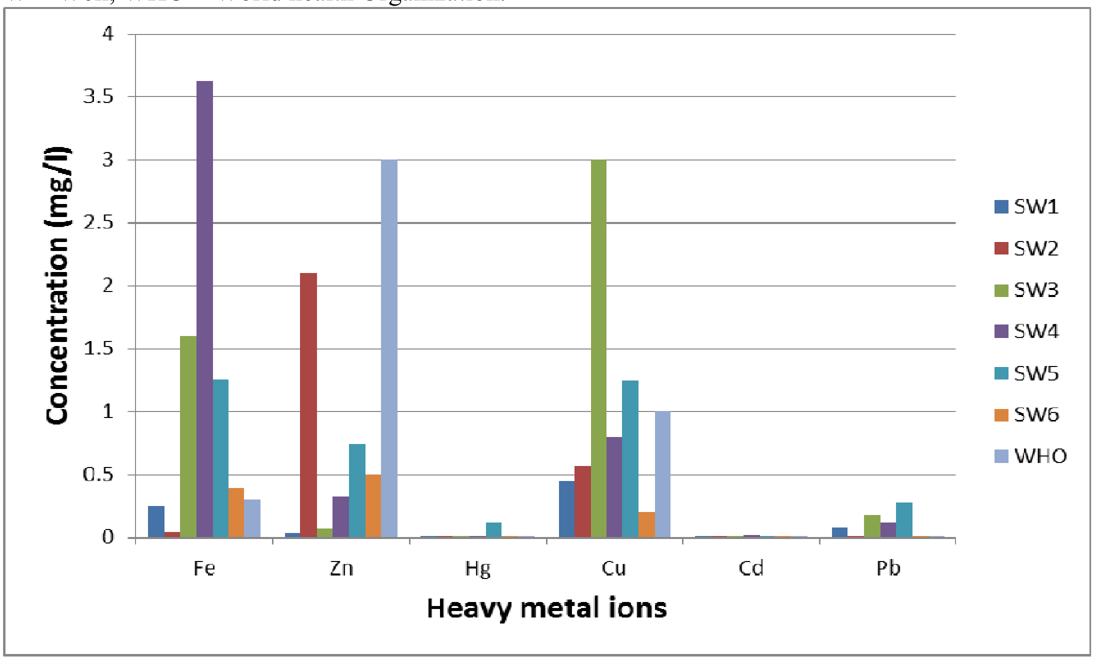

Fig 5b: Bar chart showing heavy metal concentration in the surface water samples analyzed.
SW = Surface Water, WHO = World Health Organization.

Summary of Bacteriological Constituents and their Significance.

The analysis was done to determine the presence of fecal coliform, especially the E-coli and the total microbial load which represent the total number of bacteria and fungi in the water samples. Figs. 6 and 7 show the concentration of fecal coliform and the total microbial load respectively.

Results of the bacteriological analysis of the water samples show that the surface water sources are contaminated with fecal coliform.

The presence of fecal coliform is an indicator of microbial contamination, which is an indicator of pathogenic organisms that may be present.

The values of total microbial load and total coliform in the surface water sources indicate poor quality for domestic water supplies. The source could be attributed to the introduction of human feces and animal waste into the surface water system, refuse dumps at gully sites and river channels.

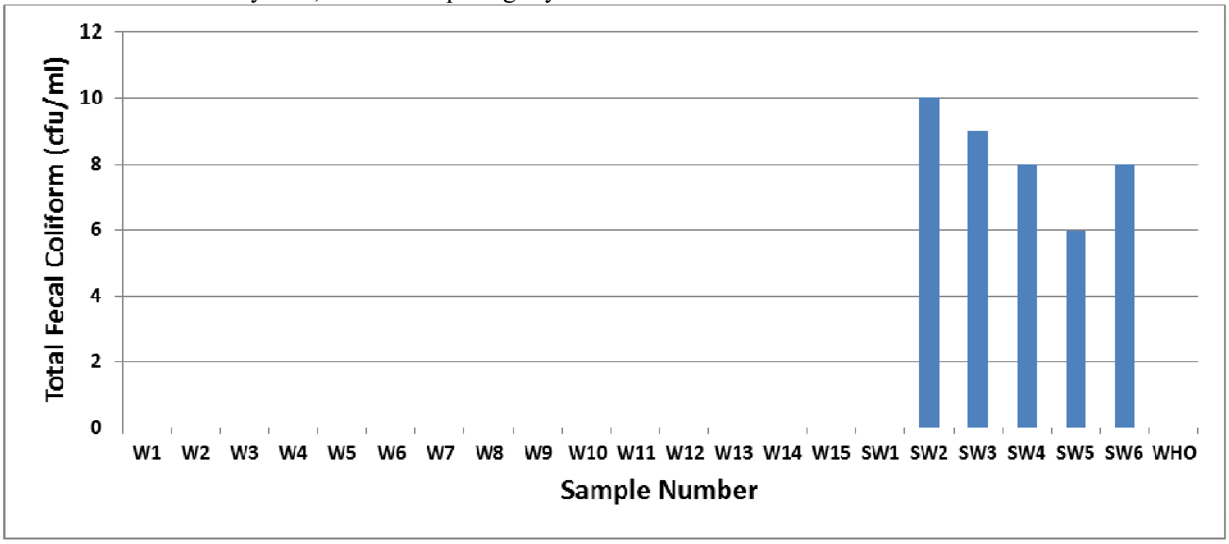

Fig. 6: Bar-chart showing the Fecal Coliform in the water samples analyzed.
W = Well, SW = Surface Water, WHO = World Health Organization.

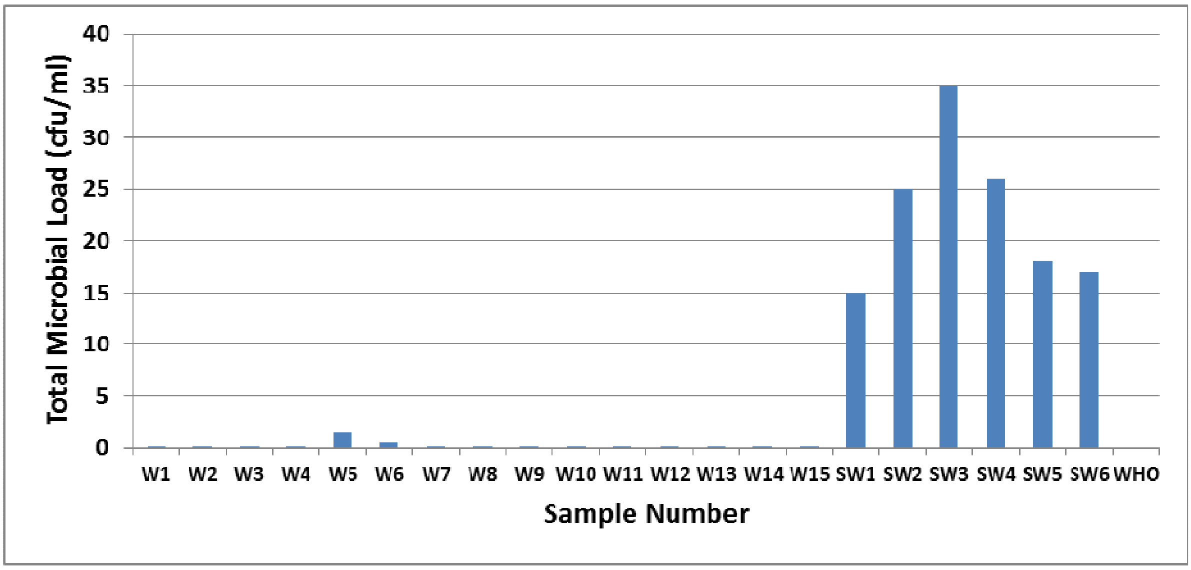

Fig. 7: Bar-chart showing microbial constituents in the water samples analyzed.
W = Well, SW = Surface Water, WHO = World Health Organization.

Table 7: Summary of the physicochemical and bacteriological analysis of water samples.

Parameter	Range	Mean	Standard deviation	WHO Standard (2014)
Ca^{+2} (mg/l)	0.12-27.21	5.9	7.99	75
Mg^{+2} (mg/l)	0.05 - 3	0.49	0.7	0.2
Na^{+} (mg/l)	3.23 - 7.06	4.78	1.15	200
K^{+} (mg/l)	0.1- 7.31	1.7	1.83	
Cl^{-} (mg/l)	1.4 - 48.7	14.59	9.98	250
SO_4^{-2} (mg/l)	1.0-13.1	5.44	3.53	500
NO_3^{-} (mg/l)	0.27-49.0	8.56	10.04	50
HCO_3^{-}(mg/l)	8.00-20.5	15.83	3.89	
Fe^{+2} (mg/l)	0.05-3.62	0.7	0.76	0.3
Pb^{+2} (mg/l)	0.002-0.28	0.045	0.07	0.01
Hg^{+2} (mg/l)	0.001-0.14	0.027	0.05	0.001
Cd^{+2} (mg/l)	0-0.02	0.003	0.01	0.003
Zn^{+2} (mg/l)	0.04-2.5	1.05	0.84	3
Cu^{+2} (mg/l)	0.001-3.0	0.54	0.66	1
pH (mg/l)	5.2-6.8	6.19	0.44	9.2
Colour (Hz)	-1-444	61.43	116.25	15
Temperature (^{0}C)	23-28.1	24.7	1.67	
Conductivity (uş/cm)	19-110	63.57	18.53	
Turbidity (mg/l)	1-15	4.48	3.29	5
TDS (mg/l)	9.1-42	21.44	10.88	
TSS (mg/l)	0-15	5.05	5.71	
BOD (mg/l)	0.1-2	0.69	0.68	
DO (mg/l)	3.1-7.3	4.64	1.29	
Fecal Coliform (cfu/ml)	0-10	1.95	3.64	
Total Microbial Load (cfu/ml)	0.001-35	6.63	11.05	
Hardness (mg/l)	0.26-27.26	6.4	7.85	500

Summary

The qualitative evaluation of groundwater resources of Mbanabor area was done using data on water sample analysis and the result was compared with WHO (2014) standards for drinking water. Some important water quality problems identified in parts of the study area are high concentrations of iron (Fe^{+2}), lead (Pb^{+2}), mercury (Hg^{+2}), cupper (Cu^{+2}), and cadmium (Cd^{+2}), which may have adverse pathogenic consequences. These pollutants and contaminants are predominantly sourced from residues linked to anthropogenic activities, and from the geology of the area. Bacteriological analysis of groundwater in the study area show satisfactory result, showing appreciable microbial filtration during recharge. Whereas the results of microbial tests on samples from surface water sources are predominantly objectionable. The source could be attributed to the introduction of human feces and animal waste, and refuse dumps into the surface water system. This shall be of great concern to various agencies and arms of government linked with water supply to the population since the surface water sources constitute a common and affordable source of water supply to the less privileged group.

Results of hydrochemical analysis of water samples show the predominance of $Ca(Mg)Cl(SO_4)$ and $Na(K)Cl(SO_4)$ water types that are largely soft. Based on the chemistry, the water is considered acceptable for many household uses except for drinking purposes where pre-use treatment is required. The values of sodium adsorption ratio (SAR) indicate prevalence of good water for agriculture.

Conclusion

Prolific aquifers exist in Mbanabor, and abundant surface water resources are also in existence. However, water quality devaluation constitutes a major environmental and socio-economic problem in the area. Well records indicate the prevalence of shallow groundwater sources for the hand-dug wells, with elevated vulnerability to pollution and contamination from surface sources. Comparative consideration of the water analysis result with the World Health Organization (WHO) water quality guidelines (2014) was done to assess the quality status of the public water supply sources, which revealed that predominance of public water supply sources (surface water and groundwater) with objectionable quality is evident. Some important water quality problems identified in parts of the study area are high concentrations of iron (Fe^{+2}), lead (Pb^{+2}), mercury (Hg^{+2}), cupper (Cu^{+2}), and cadmium (Cd^{+2}), which may have adverse pathogenic consequences. The base-metal ionic pollutants and contaminants are predominantly sourced from residues linked to anthropogenic activities, and the geology of the area. Based on the chemistry, the water is considered acceptable for many household uses except for drinking purposes where pre-use treatment is required. The need therefore exists for an urgent organized intervention programmes in the area of environmental protection through improved waste management, enhanced public enlightenment efforts, legislation and economic empowerment of the people.

Recommendation

1. There is need for regular appraisal of the available water resources by water managers and planners to ascertain the quality of the resource.
2. Pre-use treatment programmes should be incorporated in cases of water resources development of the area.
3. Adequate legislative measures should be in place to ensure that environmental standards are observed while embarking on various private, commercial and industrial activities in the area.
4. Public enlightenment efforts need to be enhanced in the entire area, to improve on personal and public hygienic lives of the people. Efforts in this direction can reduce the problems of microbial pollution/contamination in public water supply sources.

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