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Groundwater Quality Assessment for Domestic and Irrigation Purposes in Yola, Adamawa State Northeastern Nigeria

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Abstract: - To assess groundwater quality for domestic and irrigation purposes in Yola Adamawa State during the peak of dry season, groundwater samples were collected for analysis from fifteen boreholes and five hands dug wells that cover twenty wards of the City. The area investigated falls within longitude 12° 26' E and Latitude 9° 16' N. The groundwater samples collected were analyzed using Atomic Absorption Spectrophotometer (AAS), multi – analyte photometer and flame photometer while interpretation of the results was done by Comparison with the World Health Organization (WHO) and the Nigerian Standard for Drinking Water Quality (NSDWQ) guidelines for portable water. The pH values ranged from acidic to slightly alkaline 5.5 – 7.4, turbidity recorded 0 – 40NTU with four samples above the limit of 5NTU.
TDS and EC recorded values ranged between 17 – 1200mg/l, 129 - 1600µs/cm with two samples each above stipulated limit. The concentrations of the cat ions (Ca, Mg, Na, and K) are all found below the guideline of WHO and NSDWQ. Sulphate and bicarbonate recorded value range of 2 – 94.1mg/l and 11 – 630mg/l, which are also below the value of 100mg/l and 1000mg/l set by NSDWQ and WHO standards; however the recorded value of nitrate exceeded the specified limit of 50mg/l in seven water samples. Five water samples are classified as hard water based on the limit of 150mg/l and 500mg/l total hardness classification by the limit under consideration. The concentrations of heavy metals cadmium, lead, chromium, copper, manganese and iron were all found to exceed the WHO and NSDWQ standards. Iron concentration exceeded 0.3mg/l in seventeen water sample, manganese concentration exceeded 0.2mg/l and 0.05mg/l in twelve water samples, lead exceeded the limit of 0.01mg/l in seven water samples, also, chromium and cadmium exceeded limits of 0.05mg/l and 0.003mg/l in four and six water samples, copper exceeded set limit in only one sample while Nickel concentration exceeds in two water samples; others are beyond detection level. In all, concentration of heavy metals in groundwater is in the order Mn >Fe > Pb > Cd > Cr > Cu > Ni. The implication of the elevated levels of heavy metals in some samples of groundwater is a serious cause for concern to public health. Most of the groundwater samples are good and can be used for irrigation with adequate soil management.

Keywords: - *Groundwater, heavy metal, physicochemical parameters, water quality.*

I. INTRODUCTION

Groundwater is globally important for human consumption and changes in quality with subsequent contamination can definitely, affect human health. Water is essential natural resources for the sustainability of life on earth. Humans may survive for several weeks without food, but barely few days without water because constant supply of water is needed to replenish the fluid lost through normal physiological activities, such as respiration, perspiration, urination, (Chinedu *et al*., 2011).

Due to rapid growth in population, urbanization, industrialization and the extensive use of chemical fertilizers for urban and peri- urban Agriculture are some of the factors that have direct effects on the quantity and quality of groundwater resources especially in arid and semi – arid region of northern Nigeria. Globally, the quantity and quality of groundwater reserves is diminishing on daily basis. Therefore, any study that can aid in identifying new sources of threats to groundwater is desirous not only around the study area but everywhere

(Abdullahi *et al*., 2010a). There is no life without water, therefore it is essential to safeguard the future of our water resources by studying past and present both quantitatively and qualitatively.

Water pollution is defined as contamination of water or alteration of the physical, chemical or biological properties of natural water. Water is said to be polluted when it changes its quality or composition either naturally or as a result of human activities, thus becoming unsuitable for domestic, agricultural, industrial, recreational uses and for the survival of wildlife. A water pollutant can be defined as an agent affecting aesthetic, physical, chemical and biological quality and wholesomeness of water.

Anthropogenic practices like mining and disposal of untreated waste effluents from slaughter houses, mechanical workshops, and hospitals containing toxic heavy metals are some of the causes of groundwater pollution because these heavy metals finally infiltrate into the soil and could reach the groundwater table and hence the water become polluted (Laar *et al*., 2011).

Groundwater pollution has become a major subject of public concern the world over. Musa, *et al* (2004) in their study of lead concentration in well and borehole water in Zaria, found out that the lead concentration ranged from 0.000786 to 0.0595mg/l with 91% of the samples above the 0.01mg/l WHO drinking water guideline level. Adekunle *et al*;(2007) in their study on the assessment of groundwater quality in a typical rural settlement in the southwest Nigeria, noted elevated level of nitrate, cadmium and lead which was a course for serious concern. Abdullahi *et al* (2010b) in their investigation of groundwater quality around Gubrunde and environs, northeastern Nigeria found out that samples had nitrate that ranged from 53mg/l to 106mg/l which exceeded WHO standard of 50mg/l which has the tendency of causing asphyxia to infant less than three months old. Longe E.O and Balogun M.R,(2010), in their study on Groundwater quality assessment near a municipal land fill in Lagos found out that concentration of nitrate in leachate is 62.8mg/l, while in groundwater levels ranged between 20.4mg/l and 60.5mg/l exceeding the WHO stipulated tolerance level of 10mg/l, Chromium ranged between 0.02mg/l to 0.71mg/l which is above the highest permissible level allowed by Nigerian Standard for Drinking Water Quality and the WHO permissible limits (NSDWQ,2007; WHO, 2004). Saleem *et al* (2012) in their study of physico – chemical quality of groundwater quality in Gulbarga City in South India concluded that groundwater was very hard and saline and the presence of high chlorides and nitrates concentrations indicated potential influence of sewage pollution owing to poor drainage and solid waste disposal system in the City. Fluoride values were high in few samples and concluded that the water is not fit for drinking purpose.

Tmava *et al*; (2013) in their study on the assessment of Groundwater in the mining areas in Stan Terg, Kosovo discovered that Zinc, manganese, lead and iron were the dominant element in groundwater and they are of the order Zn>Mn>Pb>Fe>Cu>Ni.

Inadequate solid waste management is a major environmental problem in Yola metropolis; the contributing factors ranged from technical problem to financial and institutional constraints. The challenge of indiscriminate refuse disposal (solid waste) is enormous and has become very serious problem. Unfortunately, most of the refuse is permanently disposed at groundwater recharge points, open space or burrow pits, pit latrines, septic tanks for human wastes. Liquid wastes are admitted through the major drainage networks and finally emptied into river with the negative impact on groundwater, surface water and the environment and hence the need to assess the groundwater quality in other to avert contamination risk that it may pose to public health.

II. MATERIALS ANDMETHODS

2.1 Study Area

Adamawa state is located in northeastern part of Nigeria with a population of 3,737,223 people and land mass of 36,917km^2. Yola (jimeta) the Adamawa state capital is located between longitude 12^o 26' E and Latitude 9^o 16' N (http://www.en.wikipedia.org/wiki/jimeta) along the banks of River Benue (Adebayo, 1999). The state is in the Sahel region of Nigeria generally Semiarid with low rainfall, low humidity and high temperature. The area experiences two distinct wet and dry seasons, the wet season starts from April to October while the dry season starts from November to April. Mean daily temperature fluctuates with season from 25^o C to 40^{o}C and the mean annual rainfall received is between (250 – 1000mm). The climate is characterized by high evapotranspiration especially during dry season (Adebayo, 1999). Yola the state capital being an urban centre has an estimated population of about 200,000 people. There is high water demand for domestic as well as industrial and agricultural purposes. Jimeta metropolis consist of the following areas/wards; Karewa, Federal Secretariat, GMMC, FCE Yola, Police Barracks, Maskare, Malamre A, Malamre B, Karewa Extension, Legislative Quarters, Nassarawo, Luggere, Demsawo, Damilu, Jambutu, Old GRA, Bye – pass, Nepa ward, Old Abattoir, and Anguwan Tana.

2.2 Groundwater Sampling

Representative samples of groundwater was collected from 15 boreholes and 5 hands dug wells from 20 locations in march, 2013 based on distribution of bore holes and wells that represent groundwater and permission from owners prior to sampling. The water was collected in 1 litre plastic containers and prior to collection as part of quality control measures all the bottles were washed with non – ionic detergent and rinsed with de – ionized water prior to usage. The sampling bottles were rinsed three times with both borehole and well waters at the point of collection. Each bottle was labeled according to sampling location to avoid mixing error and was carefully preserved at 4^{o}C and transported directly the laboratory for analysis.

2.3 Sample Preparation and analysis

After each sample was collected, standard methods and procedures was adopted (APHA, 1992) to conduct the analysis. An in- situ measurement was made for conductivity, pH, TDS and temperature using Sension Platinum Series portable pH and conductivity meter (HACH made). Turbidity was determined using a standardized Hanna H198703 Turbidimeter. The samples were poured into the measuring bottle and the surface or the bottle was wiped with silicon oil. The bottle was then inserted into the turbidimeter and the reading was obtained. Total hardness was obtained by calculation. The water samples for anion analysis were filtered using a hand operated vacuum pump equipped with a 0.45µm cellulose acetate filter membrane. Chloride determination was undertaken using the argentometric titration. Bicarbonate (HCO_3^-) was carried out using acid titration, with methyl orange as indicator. Nitrate (NO_3^-), Sulphate (SO_4^{2-}) were determined using V2000 multi – analyte photometer, Na and K were carried out with a CORNING FLAMEPHOTOMETER 410 after calibrating it with analyte standard while the remaining Trace and heavy metals were carried out with a Varian model AA240FS Fast Sequential Atomic Absorption Spectrometer.

III. RESULTS AND DISCUSSION

3.1 Groundwater Quality:

The results of boreholes and wells which represent groundwater quality is presented in tables 1, 3, 4 and 5. The physicochemical quality parameters are in table 1, while the descriptive statistics of the same parameters is in (Table 3). The trace and Heavy metals concentrations and their descriptive statistics are presented in tables 3 and 4. The TDS value in groundwater ranged between 17mg/l to 1200mg/l, while in borehole water is in the range of 17mg/l to 220mg/l, the values in well water is between 240mg/l to 1100mg/l (Table 1). The TDS values in the borehole water are all below the maximum permitted level of 500mg/l set by the World Health Organization (WHO) and the Nigerian Standard for Drinking Water Quality (NSDWQ), while values in the wells WW3 and WW4 located in the Old Abattoir and Anguwan Tana exceeded the set limit. This could be inferred that open exposure of such wells without surface cover are subject to contamination from solid and liquid contaminants and hence responsible for the high TDS values. High value of TDS influences the taste, hardness, and corrosiveness property of water (Saleem *et al*; 2012, Subhadra Devi *et al*; 2003). Temperature recorded the minimum of 29.1^{o}C and the maximum of 33^{o}C with a mean value of 30.8^{o}C and standard deviation of 1.287(Table 3).

The groundwater samples are generally acidic to slightly alkaline with a minimum of 5.50 and a maximum of 7.40 and a mean of 6.60 which is below the World Health Organization (WHO) and the Nigerian Standard for Drinking Water Quality (NSDWQ) guidelines for portable water. Past studies had equally revealed the acidic nature in northeastern and western part of Nigeria (Adullahi et al; 2010a, b, Musa *et al*; 2004, Longe and Kehinde 2005; Longe and Enekwechi, 2007; Yusuf, 2007, Chinedu, *et al*; 2011). The pH of boreholes and well water were within the normal range of (6.0 – 9.0) acceptable for normal consumption except at BH5, BH10 and BH11with pH 5.50, 5.53 and5.5, the samples are from Police Barracks, Legislative Quarters and Nasarawo areas. Consumption of such acidic water could have adverse effect on the digestive and lymphatic system of humans. Turbidity values groundwater ranged from (0 - 40NTU) with the mean of 6.47NTU and standard deviation of 11.190(Table 3). From the Nigerian Standard for Drinking Water (NSDWQ), acceptable standard is 5TNU; this indicates that all groundwater taken from boreholes are within the acceptable limits while groundwater from wells labeled as WW1(12NTU),WW2 (14NTU),WW3(30NTU) and WW4(40NTU) had values above limit of 5NTU.

The electrical conductivity (EC) of groundwater ranged from 129µs/cm to 1600µs/cm and a mean of 667.86µs/cm and a standard deviation of 393.419 (Table 3), which consists of samples from sixteen boreholes and four hands dug wells. The lowest EC value was recorded in borehole BH2 (129µs/cm) and the highest in BH16 (1000µs/cm), the wells, recorded (678µs/cm) in WW1 as the lowest, while WW4 recorded a value of (1600µs/cm) as the highest value. The EC value in WW3 and WW4 from Old Abattoir and Anguwan Tana exceeded the maximum permitted value of 1000µs/cm by NSDWQ and WHO guideline for portable water. The electrical conductivity in water samples is an indication of dissolved ions. Thus the higher the EC, the higher the levels of dissolved ions in the sample.

Calcium and Magnesium had concentration of 1.30mg/l and 1.9mg/l as minimum and 190mg/l, 115mg/l as maximum with mean and standard deviation of 80.36mg/l, 40.08mg/l and 50.169 and 37.964 respectively. Also Sodium had a concentration of 9mg/l, 56mg/l as minimum and maximum with standard deviation of 16.222. Potassium recorded a mean value of 3.472mg/l and a maximum and minimum value of 6mg/l and 0.08mg/l all the values are within the maximum permitted limit set out by WHO(2004) and the Nigerian Standard for Drinking Water Quality (NSDWQ) guideline for portable water.

Fluoride concentrations in boreholes and well water samples were recorded as 0.014mg/l as minimum and 0.3mg/l as maximum with mean and standard deviation of 0.106mg/l and 0.098mg/l. This value is also below the save guideline of WHO and NSDWQ of 1.5mg/l. This means therefore that the boreholes and hand dug wells groundwater is safe for drinking. Chloride also had a recorded concentration of 4mg/l, 28mg/l, 13.10mg/l and 1.330 as minimum, maximum and standard deviation. Fluoride value also fall within safe and permissible limit of 1.5mg/l and thus the groundwater is safe for drinking and domestic purposes.

The concentrations of dissolved oxygen in wells and boreholes water samples were in the range of 3.1mg/l to 8.90mg/l with a mean value and standard deviation of 6.234mg/l and 0.562. The highest value of dissolved oxygen was in borehole water sample labeled as BH12 (8.90mg/l) and the lowest is in BH15 (3.7mg/l). In the wells, WW1 had dissolved oxygen value of 6.6mg/l and WW2 had 4.9mg/l. The lowest dissolved oxygen values in well water was in WW3 (3.2mg/l) and WW4 (3.1mg/l). Threshold for dissolved oxygen (DO) is 5.0mg/l for drinking water and should be more 5mg/l for agricultural purposes. The results revealed that borehole water and well water quality with respect to DO are good for drinking purposes, except that the low level of oxygen in WW3 and WW4 is not suitable for agricultural and fisheries project but high enough not to cause anaerobic conditions in drinking water. Very low DO may result in anaerobic conditions that cause bad odors.

The concentration of nitrate (NO_3^-) in groundwater generally is 8.85mg/l, 66.0mg/l and34.992mg/l as the minimum, maximum, and 23.088 as standard deviation. This minimum value of nitrate was recorded in borehole BH1while the maximum was in WW4 well water. In all, boreholes BH7,BH11 and well water WW1,WW2,WW3 and WW4 had nitrate concentration that exceeded the maximum permitted level of 50mg/l as defined by WHO (2004) and the Nigerian Standard for Drinking Water Quality (NSDWQ) guideline for portable water. All the 19 groundwater samples out of 20 had nitrate values above the stipulated tolerance level of 10mg/l for portable water. The high level of nitrate in groundwater used for human consumption is a serious source of concern to public health. Problems associated with high nitrate concentration in groundwater have become increasingly prevalent in the recent years. Natural levels of nitrate in groundwater may have been enhanced by anthropogenic, municipal, industrial and agricultural wastewaters from waste disposal sites. High nitrate concentrations have detrimental effect on infants less than six month of age. Nitrate reduces nitrite which can oxidize haemoglobin to methaemoglobin, thereby inhibiting the transport and availability of oxygen around the body or simply causes Cyanosis and asphyxia (blue – baby syndrome) (WHO, 1985, Alsabahi *et al*; 2009; Adullahi *et al*; 2010, Longe and Balogun; 2010).

The observed level of sulphate (SO_4^{2-}) in groundwater samples were 0.04mg/l minimum, 94.1mg/l maximum, while the mean of 34.99mg/l and standard deviation of 27.90 was observed. All the values observed for well and borehole are within the maximum permitted level stipulated by WHO and NSDWQ. The bicarbonate (HCO_3^-) observed water quality parameter indicated that the maximum of 630mg/l and minimum of 11.0 mg/l and a mean of 176.71mg/l with standard deviation of 184.35 were observed and all are below the limit of 1000mg/l by the World Health Organization Standard. The bicarbonate concentration tested in boreholes and wells can be said to be free and safe for use as house hold level.

Total Hardness (TH), the value of total hardness of groundwater samples measured as the sum of calcium and magnesium concentration express in terms of mg/l of calcium carbonate had a minimum value of 115mg/l and maximum of 630mg/l. Calcium and magnesium form an insoluble residue with soap. The degree of hardness is commonly based on the classification listed in Table 5 (Sawyer and McCarty, 1967).

Based on the classification above, 13 groundwater samples labeled as BH1, BH4, BH5,BH6,BH8, BH9,BH10,BH11,BH12,BH14,BH15,BH16 and WW4 are soft water because their values are below 75mg/l, BH13 and BH2 are within the class of moderately hard water. The concentrations of water samples WW3, with value of 200mg/l fall within the class of hard water, while samples, WW2, WW1, BH3 and BH7 are classified as very hard water. In all, 65% of the water samples are classified as soft water, 10% as moderately soft, 5% as hard water and 20% as very hard water, most of the groundwater samples are found to be below the Nigerian Standard for Drinking Water Quality (NSDWQ) guideline for portable drinking water except samples from Old Abattoir (WW3), Damilu (WW2), Demsawo (WW1), Malamre A (BH7) and GMMC (BH3) that are classified as hard to very hard. Hardness in groundwater is often cause by calcium and magnesium present in soils or rock that dissolves in the water to cause hardness. Hardness in groundwater is normally considered as an aesthetic water quality factor, it does not pose a health risk but higher concentration in water however creates consumer problems that ranged from wastage of soap and interferes with every cleaning task from laundry to household washing.

3.2 Heavy Metals in Groundwater Samples:

Measured values of heavy metals in boreholes and wells water samples and their descriptive statistics are presented in Table 4 and 5. The values of copper in all boreholes and wells water are all below the WHO standard of 2mg/l, while BH7 recorded 1.3mg/l above the NSDWQ permissible level of copper in the water sample (1mg/l). Cadmium concentration exceeded the WHO and NSDWQ in all wells and some boreholes in six locations. Elevated level of lead concentrations was also recorded in BH12 (0.1mg/l), BH13 (0.4mg/l), BH15 (0.6mg/l), WW3 (0.6mg/l) and WW4 (0.5mg/l) which is above 0.01mg/l set standard, others samples are beyond detection level. Chromium concentrations are detected in only 2 boreholes and 2 wells but also above the recommended standard World Health Organization (WHO) and NSDWQ value of 0.05mg/l (figure 1); others fell beyond the limit of detection. Heavy metal such as lead, cadmium, and copper in groundwater have been reported at excessive levels in groundwater due to land fill operations (Lee *et al*; 1986; Ogundiran and Afolabi, 2008, Longe and Balogun, 2010) These elevated level of copper, cadmium and chromium in groundwater has the potential of causing gastrointestinal disorder, while cadmium is toxic to the kidney, chromium remains on the top list of causing cancer and cancer related disorder.

Manganese concentrations are also found in appreciable quantity in all the tested groundwater samples except from 2 locations that are beyond detection limit. Most of the obtained values are above stipulated level of 0.2mg/l by NSDWQ and 0.05mg/l by the World Health Organization(WHO) standard. Nickel was also found in trace quantities in few of the samples, while most of the samples are beyond detection level.

The World Health Organization WHO and NSDWQ permissible level of iron (0.3mg/l) had been exceeded in all samples from boreholes and wells. The value of iron ranged from 0.6mg/l to 2.10mg/l with a mean of 1.11mg/l and standard deviation of 0.437. High iron level noticed in wells and boreholes is a characteristic of groundwater due to anthropogenic activities and local geology. Excessive dissolved iron and manganese concentrations result in taste and precipitation problems. In general, the concentration of heavy metals in groundwater is in the order Mn > Fe > Pb >Cd >Cr >Cu >Ni.

IV. SUITABILITY OF GROUNDWATER FOR IRRIGATION PURPOSES

The suitability of tested groundwater samples for irrigation purposes was assessed on the basis of TDS, Salinity or EC and Sodium adsorption ratio values.

4.1 Total Dissolved Solid (TDS):

Any increase in the amount of dissolved solids in irrigation water affects the efficiency, growth and yield of plants. Long time irrigation under average conditions, the total dissolved solid in irrigation water should not exceed 2000mg/l, higher salt content of irrigation water leads to salinization problems which result in high osmotic pressure in soils and water absorption via roots system becomes difficult. Classification of water according to TDS values (Wilcox, 1955) is given in Table 6.

The highest TDS value recorded in examined groundwater samples is 1200mg/l, while the lowest is 17mg/l, based on the categorization, most of the water samples are in the class of best quality water and is good for irrigation except WW3 and WW4 that fall into the class of water involving hazard.

4.2 Based on salinity hazard:

Groundwater samples can be classified into four categories (Table 7) Salinity hazard allowed the classification of groundwater into four categories C1 class with EC (100 -250µs/cm) as excellent water, C2 class with EC (250 - 750µs/cm) as good water, C3 class with EC (750 – 2250µs/cm) as doubtful water and C3 class with EC (> 2250µs/cm) as unsuitable water. Based on these, the groundwater's have 4 samples as excellent water, 11 samples as good water and 5 samples as doubtful water. The groundwater can adequately be used for irrigation with management practice.

V. CONCLUSION

The results of analysis and evaluation of groundwater from twenty locations in Yola metropolitan capital of Adamawa state for domestic and irrigation purpose revealed that the groundwater quality have been impacted by trace and heavy metals. The levels of nitrate, copper, cadmium, chromium, manganese and iron in some water samples in boreholes and wells are above the World Health Organization (WHO) and the Nigerian Standard for Drinking Water Quality (NSDWQ) guideline for portable water. Such elevated levels of nitrate, copper, Cadmium, Chromium manganese and iron in groundwater used for drinking is a serious cause for concern. The negative impact of these heavy metals which ranges from causing blue baby syndrome in infants less than three months, gastrointestinal disorder, cancer, kidney damage and neurological disorder may come up with time if remedial measures are not taken in good time. Some of the ground water samples can safely be used for drinking and irrigation purposes as their parameters are within the stipulated standards. It is recommended

that groundwater quality assessment be carry out in both wet and dry season to better understand the dynamic changes in water quality that may occur with time.
Source: Laboratory analytical data, 2012

Samples	TDS (mg/l)	Temp °C	pH	TUB (NTU)	EC (µs/cm)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	O_2 (mg/l)	Cl (mg/l)	F (mg/l)	NO_3^- (mg/l)	SO_4^{2-} (mg/l)	HCO_3^- (mg/l)	TH (mg/l)
BHI	35.0	31.2	6.0	0	230	29.0	6.9	12.0	5.4	6.5	9.0	0.10	8.85	13.0	30.0	30.0
BH2	22.0	31.0	7.4	0	129	103.0	25.8	16.0	3.9	6.3	6.0	0.16	11.0	9.0	85.0	85.0
BH3	70.0	30.0	7.2	0	235	190.0	115	14.0	5.0	5.6	9.0	0.24	26.5	10.0	403.0	403.0
BH4	18.0	30.1	6.5	0	234	83.0	19.7	13.0	0.08	6.6	10.0	0.01	17.7	0.60	67.0	67.0
BH5	110.0	33.0	5.5	0	390	47.0	114	12.0	3.0	7.8	20.0	0.03	17.6	4.0	64.0	64.0
BH6	17.0	32.5	6.0	0	470	162.0	39.4	9.0	5.0	8.4	17.0	0.20	46.6	4.0	62.0	62.0
BH7	40.0	29.1	7.0	0	490	1.30	1.9	9.0	2.1	7.5	20.0	0.26	62.5	9.4	400.0	400.0
BH8	19.0	33.0	6.7	0	420	81.0	19.7	17.0	0.08	6.5	10.0	0.01	17.6	0.04	66.0	66.0
BH9	190.0	30.7	7.1	0	430	140.0	34	23.0	6.0	7.7	10.0	0.01	35.3	11.0	147.0	147.0
BH10	100.0	32.4	5.53	0	450	36.0	8.75	18.0	6.0	4.5	10.0	0.02	53.0	3.0	45.0	45.0
BH11	90.0	30.1	5.5	0	407	38.0	19.5	17.0	5.0	7.6	10.0	0.03	62.0	4.0	48.0	48.0
BH12	26.0	32.1	6.7	0	689	39.0	9.48	15.0	5.5	8.9	11.0	0.01	13.2	2.0	16.0	16.0
WW1	390.0	29.6	6.6	12.0	678	50.0	100	12.0	0.7	6.6	22.0	0.03	62.0	52.5	630.0	630.0
WW2	240.0	29.8	6.5	14.0	670	48.0	102	32.0	0.8	4.9	22.0	0.04	60.0	53.0	540.0	540.0
BH13	220.0	32.1	7.3	0	700	102.0	24.7	34.0	3.8	5.6	5.0	0.15	11.0	8.0	85.0	85.0
BH14	221.0	30.1	7.0	0	802	101.0	23.6	36.0	3.0	8.9	4.0	0.20	11.0	6.0	60.0	60.0
BH15	220.0	29.5	7.0	0	900	100.0	22.8	50.0	3.1	3.7	6.0	0.10	10.0	5.0	62.0	62.0
BH16	90.0	30.1	6.5	0	1000	90.0	22	51.0	3.0	4.8	5.0	0.30	12.0	4.0	60.0	60.0
WW3	1200	30.3	6.3	30.0	1500	56.0	15.6	54.0	3.4	3.2	28.0	0.01	65.0	81.3	200.0	200.0
WW4	1100	29.1	7.0	40.0	1600	1.30	1.9	56.0	2.1	3.1	28.0	0.02	66.0	94.1	11.0	11.0
NSDQW	500	-	6.5-8.5	5.0	1000	-	0.20	200	50	5	250	1.5	50.0	100	-	150
WHO	500	-	6.5-8.5	-	-	75	50	50	55	-	250	-	50	250	1000	500

Table 2: CLASSIFICATION OF GROUNDWATER HARDNESS (Sawyer and McCarty, 1967)

Hardness range (mg/l of $CaCO_3$)	Water classification
0 - 75	Soft
75 - 150	moderately hard
150 - 300	Hard
>300	Very hard

Table 3: Groundwater Physico–Chemical Quality Parameters Descriptive Statistics

Parameters	Minimum	Maximum	Mean	Standard Deviation
TDS	17.00	1200.00	267.52	333.53
Temp	29.10	33.00	30.89	1.28
pH	5.500	7.400	6.60	0 .59
Turb	0.00	40.00	6.47	11.19
EC	129	1600	667.81	393.41
Ca^{2+}	1.30	190.00	80.36	50.16
Mg^{2+}	1.90	115.00	40.08	37.96
Na^+	9.00	56.00	26.47	16.22
K^+	0.08	6.00	3.47	1.91
Fr	0.014	0.30	0.106	0.09
Cl^-	4.00	28.00	13.10	1.33
O_2	3.10	8.900	6.23	0.56
NO_3^-	8.85	66.00	34.99	23.08
SO_4^{2-}	0.04	94.10	22.28	27.90
HCO_3^-	11.00	630.00	176.71	184.35
TH	115.00	630.00	176.71	184.35

N=20. All the values are in mg/l except EC, in µs/cm, Turbidity in NTU and Temperature in °C

Table 4: HEAVY METAL CONCENTRATIONS IN GROUNDWATERSAMPLES

Samples Standards	Cu (mg/l)	Cd (mg/l)	Pb (mg/l)	Cr (mg/l)	Mn (mg/l)	Ni (mg/l)	Fe (mg/l)
BH1	0.50	ND	ND	ND	0.02	ND	ND
BH2	0.04	ND	ND	ND	0.30	ND	1.20
BH3	ND	ND	ND	ND	0.05	ND	ND
BH4	0.40	ND	ND	ND	ND	ND	0.80
BH5	0.05	ND	ND	ND	0.06	ND	0.90
BH6	0.20	ND	ND	ND	0.20	0.001	0.70
BH7	1.30	ND	ND	ND	0.80	ND	0.90
BH8	0.03	ND	ND	ND	ND	ND	0.80
BH9	0.04	ND	ND	ND	0.50	ND	ND
BH10	0.03	0.002	ND	ND	3.00	ND	0.60
BH11	ND	0.001	ND	ND	2.00	ND	0.90
BH12	0.01	0.50	0.10	ND	0.30	0.30	1.20
BH13	0.03	0.60	0.40	0.40	0.30	ND	1.10
BH14	0.02	0.02	ND	ND	0.30	ND	1.00
BH15	0.02	0.01	0.60	0.30	0.30	0.20	1.00
BH16	0.01	0.10	ND	ND	0.20	0.001	1.10
WW1	0.04	0.40	0.02	ND	0.04	0.001	2.10
WW2	0.04	0.01	0.30	ND	0.06	0.002	2.10
WW3	0.06	0.40	0.60	0.20	0.06	0.02	1.40
WW4	0.30	0.30	0.50	0.10	0.08	0.03	1.60

ND: Not Detected

Source: Laboratory analytical data, 2012

Table 5: Descrptive Statistics Of Heavy Metal Concentrations In Groundwater Samples

Parameters (mg/l)	Minimum	Maximum	Mean	Standard Deviation
Cu	0.01	1.30	0.232	0.316
Cd	0.001	0.60	0.245	0.230
Pb	0.020	0.60	0.390	0.230
Cr	0.10	0.40	0.280	0.129
Mn	0.022	3.0	0.608	0.780
Ni	0.001	0.30	0.095	0.115
Fe	0.60	2.10	1.11	0.437

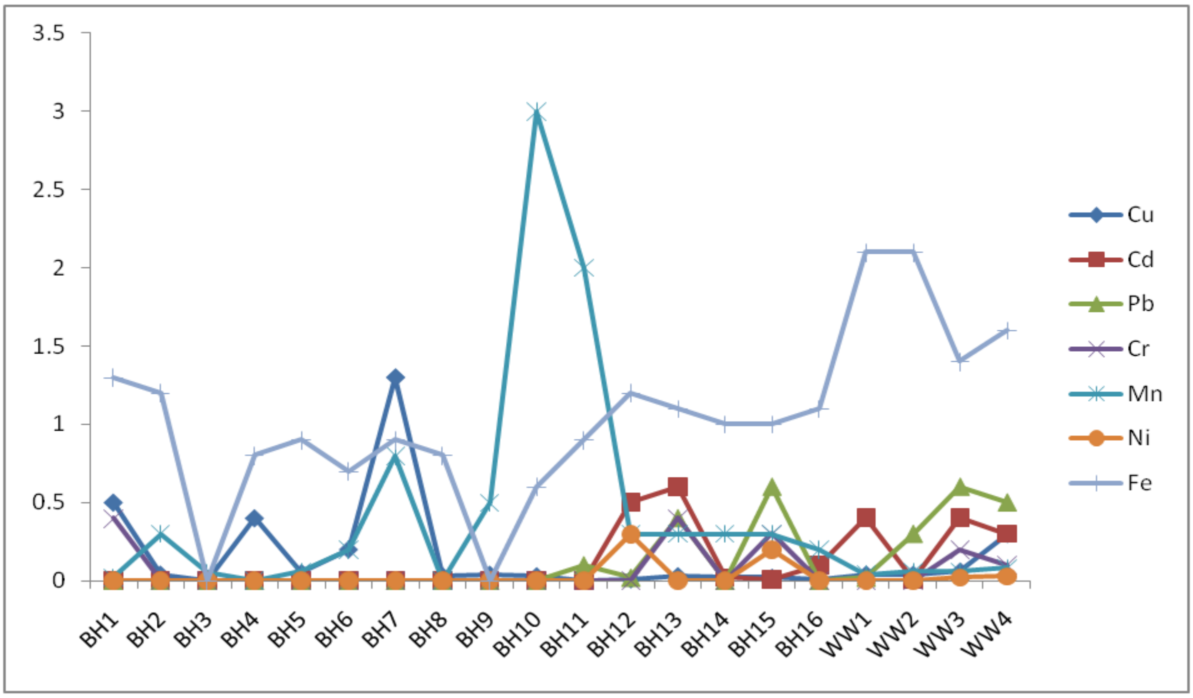

Figure 1: **A graph of Cu, Cd, Pb, Cr, Mn, Ni and Fe from the studied groundwater samples**

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