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An Assessment of the Concentration of Iron between Galvanised Iron Riser Pipes and Stainless-Steel Riser Pipes in Borehole Water as a Result of Corrosion: A Case Study of Mbala District of the Northern Province of Zambia

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Abstract:- Iron is a problem usually associated with borehole water supplies. Iron can be found in water in two states. Water containing 'ferrous' iron usually clear when it comes out of the ground but becomes cloudy or red when it meets air, converting the iron to its 'ferric' state. The presence of iron in ground water is usually from natural process and abundant existence (Daughney and Reeves, 2005).

This study was conducted in Mbala district of Zambia. The district occupies a strategic location close to the border with Tanzania.

The study was conducted in order to improve the living standards of the people of Mbala by providing clean drinking water for hygiene and sanitation. The challenge however is providing clean drinking water particularly with Iron levels less than the World Health Organisation limit of 0.3mg/l which is adopted by the Zambia bureau of standards. The study focused on the geology of the study area as a probable source of iron but went further to compare within the same geology the two types of materials used in the construction of the water boreholes in the area. The two types of materials by which the boreholes were named are stainless steel bores and galvanised steel boreholes.

During data collection, primary data was collected through focus group interviews in order to record the impact the presence of iron in the water has had on the water users. This was done by the administration of questionnaires. The Global positioning system and pH of the water was recorded and measured in-situ. The photometric method was used to measure the amount of iron in each of the 100mls of water collected from the boreholes though laboratory analysis. It was expected that the values of the concentration of iron would be below the WHO standards but the values were so high for both types of bores that water security is threatened in the area and possess as a challenge in meeting the sustainable development goal number six.

In conclusion, the stainless-steel riser piped boreholes showed to contain more iron concentration than galvanised steel riser piped boreholes.

Keywords:- *Borehole, galvanising, Iron, stainless steel, water.*

I. INTRODUCTION

There is extreme variability in the distribution of water resources in Southern Africa. Spatial and temporal availability of surface water largely depends on the precipitation on the pattern and regional morphology. Due to buffering capacity of the soil and underground, the groundwater resources are more reliable with respect to the distribution in time. It is highly essential that groundwater studies are exploited in Zambia if groundwater is to become a major source of water for various uses such as farming.

A. Background

Groundwater is less susceptible to bacterial pollution than surface water because the soil and rocks through which groundwater flows screen out most of the bacteria. Groundwater is the water that lies below the surface of the ground and fills the pore space as well as cracks and other openings. Porosity is the percentage of a rock's volume that is taken up by openings or pore spaces (Daughney and Reeves, 2005). Most sedimentary rocks such as sandstone, shale and limestone can hold a large percentage of water. Loose sand may have a porosity of up to 40%, however, this may be reduced by half as a result of recrystallization and cementation. Even though a rock has high porosity, water may not be able to pass through it. Permeability is the capacity of a rock to transmit a fluid such as water. For a rock to be permeable, the openings must be interconnected. Rocks such as sandstone and conglomerate have a high porosity because they have the capacity to hold much water (Hughes and Thackray, 1999).

Chemical and biological character of groundwater is acceptable for most uses. The quality of groundwater in some parts of Zambia, particularly shallow groundwater is changing as a result of human activities. Bacteria, however, occasionally find their way into groundwater, sometimes in dangerously high concentrations. Freedom from bacterial pollution alone does not mean that the water is fit to drink. Many unseen dissolved mineral and organic constituents are present in groundwater in various concentrations. Most of them are harmless or even beneficial, though occurring infrequently, others are harmful, and a few may be highly toxic.

Iron is a problem usually associated with borehole water supplies. Iron can be found in two states. Water containing 'ferrous' iron is usually clear when it comes out of the ground but becomes cloudy or red when it meets air, converting the iron to its 'ferric' state. Traces of ferric iron can often be seen through the red stains found on basins, baths, toilets and staining on laundry (Fay, 2007). The WHO guideline value is 0.3 milligrams per litre. The presence of iron in groundwater is a direct result of its natural existence in underground rock formations and precipitation water that infiltrates through these formations (Daughney and Reeves, 2005).

As the water moves through the rocks some of the iron dissolves and accumulates in aquifers which serve as a source for groundwater. Since the earth's underground rock formations contain about 5% iron it is common to find iron in many geographical areas around the globe including aquifers. Iron concentration in water can be described using two terms namely clear water iron and iron bacteria. 'Clear water iron' is a non-visible ferrous form of dissolved iron found in water that is not exposed to oxygen, such as in wells and springs whilst 'iron bacteria' is dissolved iron that contributes greatly to the growth of iron bacteria. These bacteria form dark-coloured slime layers on the inner walls of the system's pipes.

Water is a solvent and dissolves minerals from the rocks with which it comes in contact. Groundwater may contain dissolved minerals and gases that give it the tangy taste enjoyed by many people. Without these minerals and gases, the water would taste flat. The most common dissolved mineral substances are sodium, calcium, magnesium, potassium, chloride, bicarbonate, and sulphates. In water chemistry, these substances are called common constituents (Delwar and Huda, 1997).

Water typically is not considered desirable for drinking if the quantity of dissolved minerals exceeds 1,000 mg/l (milligrams per litre).

There is a challenge on reducing the iron content from the groundwater. At the same geology and almost same depth and pH, iron content is still a nuisance to the supply of groundwater to communities (Maxwell, 2010). The purpose of this study was to assess the iron concentration of iron in the groundwater in Mbala of Muchinga Province of Zambia. The study compared the level of iron in mg/l between two types of raiser pipes namely steel riser pipes and galvanised riser pipes.

B. Demography

The study was conducted in Mbala. Mbala is Zambia's most northerly large town in Mbala District, occupying a strategic location close to the border with Tanzania and controlling the southern approaches to Lake Tanganyika, 40 km by road to the north-west, where the port of Mpulungu is located. It had a population of about 20,570 in 2010. Under the name, Abercorn, Mbala was a key outpost in British colonial control of this part of south-central Africa

C. Location of study area

Mbala is located at -8.84024 [latitude in decimal degrees], 31.3659 [longitude in decimal degrees] at an elevation/altitude of meters. It is headquarters of an administrative district of the Northern Province. The town is at the edge of the plateau covering most of Zambia, at an elevation of 1670 m, about 900 m higher than Lake Tanganyika, which comes within 22 km (straight line distance). The escarpment above the lake is the end of the Albertine Rift, the western branch of the East Africa Rift, and the Mbala area experiences occasional earth tremors. It is also said that the tiny but picturesque Lake Chila within the town experiences inexplicable drying out, and sudden flooding from underground springs, but this may be just a legend (Simon et. al., 2008).

The map below shows Mbala district in the Muchinga province of Zambia

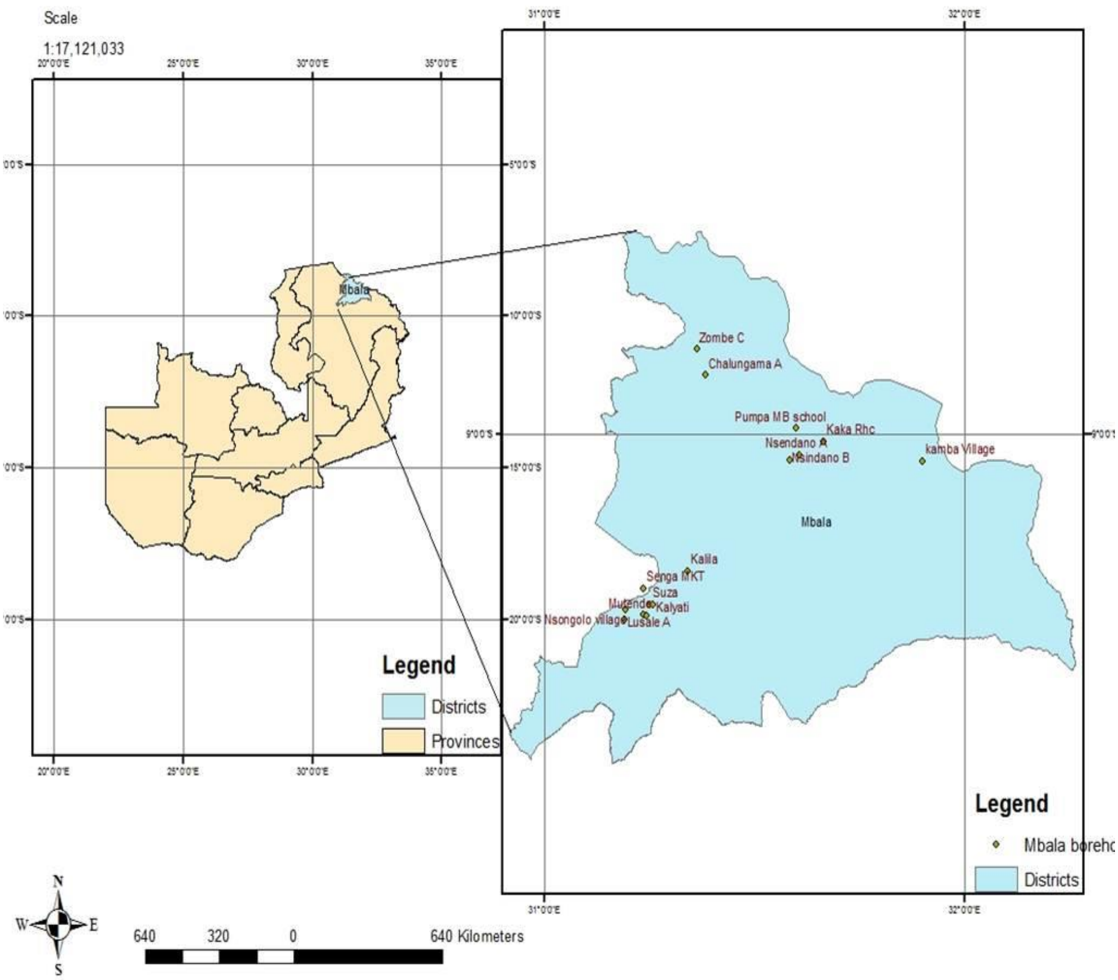

Fig 1:- Showing the map of the study area with water boreholes points

D. Hydrology, Climate and Geology of Mbala

The climatic and hydrological conditions of Mbala suggest that the month of March has the highest amount of rainfall as shown in figure 3. This is the month when the samples were collected. The aquifer in this part of Zambia is highly saturated with water that percolates into the ground thereby making most all the boreholes to have water at first stroke of pumping.

- *Hydrology and Climate data for Mbala*

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average high °C (°F)	24 (75)	25 (77)	24 (75)	25 (77)	25 (77)	24 (75)	24 (75)	25 (77)	28 (82)	29 (84)	27 (80)	24 (75)	25.3 (77.4)
Average low °C (°F)	15 (59)	15 (59)	15 (59)	15 (59)	13 (55)	11 (51)	10 (50)	12 (53)	14 (57)	15 (59)	15 (59)	15 (59)	13.8 (56.6)
Precipitation mm	226	211	231	109	18	0	0	0	5	23	119	230	1,172

Fig 2:- Hydrological and climatic conditions of Mbala District, Muchinga Province, Zambia

- *Geology of Mbala*
- *Summary of the regional geology*

The area is part of the stable Bangweulu Block. Crystalline Basement rocks are overlain by sedimentary rocks of the Mporokoso Group of the Muva Supergroup. The Basement rocks comprise mainly volcanics and granites (Kate Granite), the later dated about 1838. The Mporokoso Group represents the infilling of an intracratonic basin which rifted and subsided soon thereafter. It is represented here by the Mbala Formation which is made of mostly of fluvial sandstones, with mudstones, tuff and chert intercalations. Three subdivisions of the formation are recognized separated by unconformities or tectonic discontinuities. (Mwale, 2008).

- *Summary of the local geology*

The study is underlain by rocks of the Lower Mbala of the Formation Mporokoso Group. These comprise of pale grey to purple sandstones that are medium grained and cross-bedded. At the base of the basal sandstones are the conglomerates. Red and purple mudstone is present. Basic intrusions in form of veins are seen in some places made up of dolerite and gabbro. The general strike of the rock in the area is northwest-southeast. Kate Porphyry is exposed on the extreme north-eastern part of the area. Long inferred faults traverse the area in the NW-SE trend mainly (Mwale, 2008).

E. Problem statement

Knowing that groundwater is a source of water, many boreholes are sunk across Mbala to provide water in order to promote health and sanitation to communities within District. The challenge however lies in providing water free of iron or iron levels that meets the WHO standards of 0.3mg/l. Research has been conducted to look at the geology of the area as the source of iron in water but little has been done on comparing different materials that may be the source of iron considering the same depth of the same area and potential hydrogen so that only the materials that are used to construct the borehole are considered as one of the principal contributors of the high levels of iron in water due to corrosion. It is imperative that remedies are found to reduce iron content thereby continuously providing safe drinking water to communities.

F. General objective

The main objective of this study is to compare the level of iron in water between boreholes equipped with stainless steel raiser pipes and those with galvanised iron raiser pipes in Mbala District of Zambia.

G. Specific objectives

The specific objectives are:

- To select boreholes at the same depth, aquifer geology and life span equipped with stainless steel riser pipes and galvanised iron riser pipes.
- To determine the iron content in the water samples from the boreholes in (I) above
- To compare iron levels owing to the two types of the constructed boreholes
- To determine the challenges faced by communities on use of iron affected water

H. Research questions

The research questions answer to the objectives set above so that once these questions are answered then a conclusion can easily be made in regard to the results.

- What is the principle source of iron given the same conditions of operations?
- How have people in these communities accepted borehole water with high iron content.
- Does the corrosion of materials used in construction add significantly to the concentration of iron in water?
- Is there any remedy to the high iron content?
- What are the immediate challenges to communities using this water?
- Is iron reducing the usage of these boreholes?

I. Significance of the study

The purpose of this study is to ascertain whether the steel used in the construction of boreholes significantly adds to the high levels of iron in water collected from these boreholes as a result of corrosion. If the study proves that the constructing materials do add a significant amount of iron to the water, recommendation of the materials to be used in the construction will be made with regards to iron concentration reduction. Further this will be improving access to fresh drinking water, reduction of water poverty and will improve the lives of communities by reducing time spent in search of safe drink water.

II. RESEARCH METHODOLOGY

This chapter introduces the methods used in collection of data:

A. Data Collection

The research methods involved field measurement, questionnaires administration, and lastly laboratory and data analysis.

- *Primary data collection*

Primary data was collected through the interviews conducted to ascertain the extent to which people are affected by the presence of iron in the water from the boreholes.

- *Structured interviews*

A structured questionnaire was used to collect data from the care takers of the boreholes in the study area. This was done in order obtain their general views of the communities using the boreholes for water. The questionnaire further aimed at gathering information on the knowledge that the communities have on the extent of iron.

- **Informal conversation interview.** The qualitative research interview was used to seek the community's level of awareness of the content of iron in the water. The main task in the interview was to gather the meaning of corrosion and how it affects them and how it has negatively affected them. Interviews were particularly useful in getting the story behind community's experiences with water from the borehole unlike moving long distance to collect stream water. The interviews sort to pursue in-depth information around the topic. Informal Interviews were useful towards the administration of questionnaires.

- **Structured interviews**. Questionnaires were used because they are very cost effective when compared to other types of data collection. Written questionnaires were used because it is a systematic way of gathering data. Questionnaires are easy to analyse. Data entry and tabulation for most surveys and can easily be done with many computer software packages such as SPSS and Microsoft Excel. Questionnaires were familiar to most people in the study area as World Vision Zambia has conducted many operations in the areas using questionnaires. Nearly all the members interviewed had some experience with questionnaires and they generally did not make people apprehensive. There was uniform question presentation and no middle-man bias so that respondents were not influenced to answer questions in a certain manner. There were no verbal clues to influence the respondent during the interview. Therefore, based on the reasons above, the structured interviews were done by the administration of questionnaires.

➢ *Water sampling and chemical measuring*

In order to ascertain the extent of the concentration of the iron, 150ml of water were collected from boreholes of two different types of raiser pipes. The samples were classified into two: (I) those collected from boreholes with riser pipes made of steel and (II) those made riser pipes made of G.I riser pipes.

➢ *Sampling procedure*

Water was collected from the spout of the boreholes after ten seconds of pumping. Each sample was filled to brim and closed tightly to avoid any further oxidation of the elements present in the water and then stored in a cooler box. The samples were analysed for the extent of iron concentration at the University of Zambia laboratory.

III. RESULTS, DATA ANALYSIS AND DISCUSION

This chapter introduces the results from the interviews and the laboratory on the water samples collected from the boreholes.

A. Laboratory results

The results Tables 1 and 2 are from all the selected boreholes with same geology. Some of the other factors that influence corrosion of a metal are pH, depth, and time and are further discussed below.

➢ *pH results*

All the boreholes selected have were in the pH range of 6.5 to 7.8. Extreme levels of alkalinity or acidity have a significant influence on corrosion of metal. All the boreholes were within the WHO guidelines of 6.5 to 8.5 (Table 1).

SAMPLE ID	GPS Decimal Coordinates(WGS84)	PH
NSONGOLO VILLAGE	E 31.19250 S 9.35722	7.3
SUZA	E 31.25152 S 9.34607	6.8
CHILUNGAMA A	E 31.38499 S 8.87972	6.6
SENGA MKT	E 31.23522 S 9.31241	6.7
NSINDANO B	E 31.58472 S 9.05222	7.8
KALILA	E 31.34213 S 9.27864	7.1
KALYATI	E 31.25836 S 9.34498	7.0
NDENDANO A	E 31.60722 S 9.04222	7.6
SENGA CENTRAL	E 31.23611 S 9.36611	6.5
PUMPA MB SCHOOL	E 31.60007 S 8.98799	6.6
MUTENDE	E 31.24361 S 9.36889	6.7
KAKA RHC	E 31.66528 S 9.01389	6.9
KAMBA VILLAGE	E 31.90111 S 9.05467	7.4
ZOMBE C	E 31.36277 S 8.82766	6.9
LUSALE A	E 31.19059 S 9.37722	7.6
SENGA NORTH	E 31.22875 S 9.36158	6.8

MBENI	E 31.58472 S 8.96056	7.0
PAKASANGA	E 31.61861 S 9.02389	7.2
KALUKANYA	E 31.37167 S 9.36611	6.9

Table 1:- Showing the pH of water from the boreholes in Mbala District

Table 1 shows all the names of the boreholes and their GPS points. The handheld GPS was used to locate the actual geographic points of these boreholes during sampling.

➢ *Borehole depth Time*

Boreholes with almost the same depth and usage were selected so as not to compromise the quality of the results that may results from aquifer depth. Further the boreholes were all sunk in the same year because time is a factor of corrosion.

SAMPLE ID	TYPE OF RAISER PIPE	IRON (mg/l)	WHO GULDLINES
SUZA	G.I	4.89	0.3
SENGA MKT	G.I	2.60	0.3
NSINDANO B	G.I	0.38	0.3
KALILA	G.I	0.46	0.3
KALYATI	G.I	1.20	0.3
NDENDANO A	G.I	<0.01	0.3
SENGA CENTRAL	G.I	<0.01	0.3
PUMPA MB SCHOOL	G.I	0.95	0.3
MUTENDE	G.I	2.02	0.3
KAKA RHC	G.I	0.10	0.3
KAMBA VILLAGE	G.I	2.32	0.3

Table 2:- shows iron concentration in boreholes with G.I raiser pipes

Table 2 shows all the names of the boreholes equipped with galvanised iron riser pipes. The values of the concentration of iron in each sample are compared with the WHO standards.

Mean iron content= 4.89+2.60+0.38+0.46+1.20+0.01+0.01+0.95+2.02+0.10+2.32=14.94/11=1.358181818.
Variance= 2.0555
Standard deviation, =1.4337160

The mean and the variance were used in the calculation of the standard deviation which is the focus. The standard deviation shows the variability of the concentration of iron in the boreholes with galvanised iron riser pipes. The variability of the iron content in the sample is compared with the acceptable level of the concentration of 0.3mg/l. it shows that its highly probable that all the boreholes with galvanised iron riser pipes that have not been sampled.

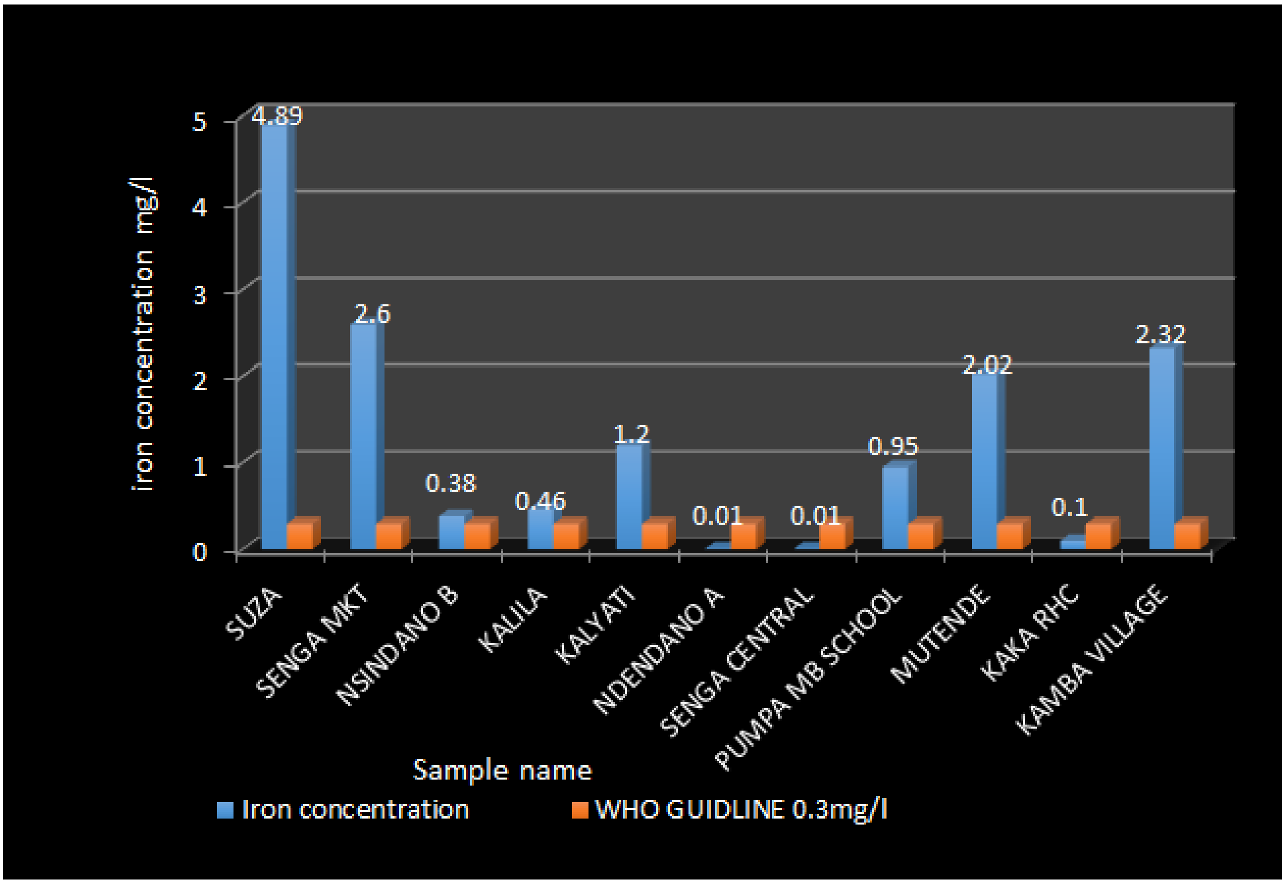

Fig 3:- Relates the amount of iron in water for various samples (G.I) to WHO standard

The bar chat above shows that in most cases the level of the concentration of the iron in the water is much higher than the recommended 0.3mg/l. This means that the water for most boreholes was not fit for consumption.

SAMPLE ID	TYPE OF RAISER PIPE	IRON (mg/l)	WHO GULDLINES
NGONGOLO VILLAGE	S.S	2.12	0.3
CHULUNGAMA A	S.S	0.01	0.3
ZOMBE C	S.S	1.38	0.3
LUSALE A	S.S	9.81	0.3
SENGA NORTH	S.S	1.92	0.3
MBENI	S.S	1.48	0.3
PAKASANGA	S.S	0.01	0.3
KALUKANYA	S.S	2.61	0.3

Table 3:- shows iron concentration in boreholes with stainless steel raiser pipes

Mean iron content= 2.12+0.01+1.38+9.81+1.92+1.48+0.01+2.61=18.34/7=2.62
Variance= 9.8425
Standard deviation= 3.1372

The deviation shows that the confidence of the results is highly probable that the value of the concentration of the iron in the water will be higher than the WHO standard of 0.3mg/l. These further shows that it is highly probable that the boreholes equipped with stainless steel riser pipes will have a higher concentration of iron in the water than those boreholes equipped with galvanised iron riser pipes.

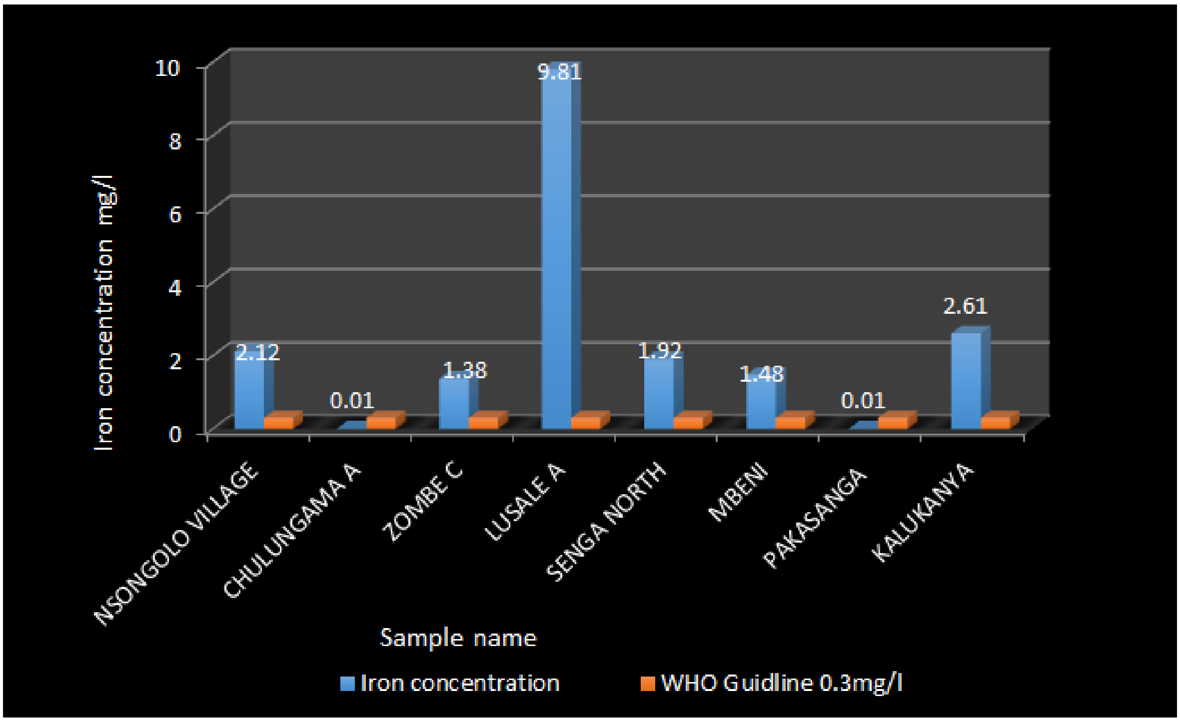

Fig 4:- Compares the amount of iron in the water from boreholes equipped with stainless steel riser pipes to WHO standard

B. Discussion

The discussion of the research was done based on the following reasons:

➢ *Evidence of iron as a result of corrosion*

- *Effect of pH on General Corrosion Rate*

The evidence of iron in the water with regards to pH is because Corrosion is affected by the concentration of the Hydrogen ions in the water to which iron or steel is exposed.

Firstly, consideration to the exposure of iron to aerated water at room temperature (aerated water will contain dissolved oxygen) is made.

The corrosion rate for iron as a function of pH is illustrated in figure below.

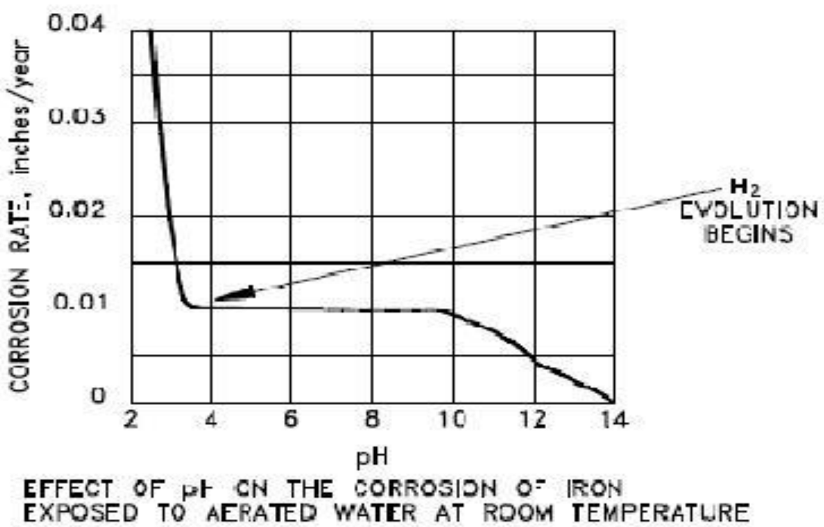

Fig 5:- Effect of pH on Iron Corrosion rate in water

In the range of pH 4 to pH 10, the corrosion rate of iron is relatively independent of the pH of the solution. Looking at the results in the table 1, 2 and 3, all the pH ranges show that the rate of corrosion is relatively independent of pH.

The corrosion rate in this pH range, is governed largely by the rate at which oxygen reacts with absorbed atomic hydrogen, thereby depolarizing the surface and allowing the reduction reaction to continue.

The high presence of the iron in water due to corrosion can be based on the corrosive nature of water which is as a result of a low pH, other mineral constituent and the material of construction involved. Therefore, it is imperative that the corrosive nature of water and the materials of the equipment are discussed to know whether they are the source of the iron in the water. The presence of iron according to Tables 2 and 3 suggests that high levels of iron in the water are higher than the WHO guideline of 0.3mg/l. This is complimented with the bar charts in Figure 3 and 4 respectively. A comparison of two boreholes with the same pH of 6.9, same time frame and area show a significant amount of iron deposited in the water. Therefore, it is conclusive to say the source of the iron is as a result of corrosion. The same tendency is observed when the boreholes namely Suza and Senga are compared in the same manner. Several factors were put in place so as to avoid clusters in the result, therefore, to augment the comparison of the same type of borehole equipment and pH as made above, the corrosive nature of water would actually cause varying amounts of iron content in the water according the Ryznar Stability Index (RSI) (Metcalf and Eddy, 2003).

SAMPLE ID	pH	IRON (mg/l)
SUZA	6.8	4.89
SENGA MKT	6.7	2.60
NSINDANO B	7.8	0.38
KALILA	7.1	0.46
KALYATI	7.0	1.20
NDENDANO A	7.6	<0.01
SENGA CENTRAL	6.5	<0.01
PUMPA MB SCHOOL	6.6	0.95
MUTENDE	6.7	2.02
KAKA RHC	6.9	0.10
KAMBA VILLAGE	7.4	2.32

Table 4:- Showing pH and Iron concentration of all G.I installed riser pipes.

The Table 5 shows that there was no consistence in the results when comparing the level of concentration of the iron against the pH. It was expected that those samples with low pH would have high levels of iron present.

SAMPLE ID	pH	IRON (mg/l)	RI	Comment
NSONGOLO VILLAGE	7.3	2.12	7.6	Little corrosion scale
CHULUNGAMA A	6.6	0.01	6.2	Little corrosion scale
ZOMBE C	6.9	1.38	6.8	Little corrosion scale
LUSALE A	7.6	9.81	8.2	Heavy corrosion
SENGA NORTH	6.8	1.92	6.8	Little corrosion scale
MBENI	7.0	1.48	7.0	Little corrosion scale
PAKASANGA	7.2	0.01	7.4	Corrosion significant
KALUKANYA	6.9	2.61	6.8	Little corrosion scale

Table 5:- Showing pH and RI values of all S.S installed riser pipes.

Table 5 shows that most of the water was corrosive subsequently corrosion adding a significant amount of the iron in the samples apart from that which has dissolved from the ground. The most outstanding is Lusale with a high concentration of iron that is as result of heavy corrosion.

➢ *Iron content in water as a result of the geology*

The results above show that the source of the iron in the water is as the result of the corrosion, however, water from the ground comes with dissolved iron but since we are dealing with Precambrian deposit, the amount of iron should be less than 0.01mg/l but the laboratory results in Table 2 and 3 show iron concentration higher than 0.01. Therefore, it is sufficing to say that the borehole equipment was corroding significantly. Having concluded based on the results that the source of the iron was as a result corrosion of the metal and the corrosive nature of water; it is imperative to add that more iron enters solution as the age of groundwater increases. Concentrations of iron exceed 1 mg/L in aquifers occurring in geologic materials that contain large amounts of iron, such as Cretaceous and some Precambrian deposits. Concentrations are also high in aquifers with reducing conditions, such as many of the buried Quaternary aquifers. Aquifers with reducing conditions are characterized by low concentrations of oxygen and nitrate and Eh values less than about 250 mV. Under these conditions, microbes utilize ferric iron during food consumption. Conversion of ferric iron to ferrous iron results in dissolved iron concentrations that exceed the acceptable standards. Aquifers occurring in low- iron rocks, such as some of the Precambrian deposits, and aquifers containing oxygen, will have iron concentrations less than 0.10 mg/L (Friday, 1999)

Therefore, it is conclusive to say that source of the iron in the water was as the result corrosion with additional dissolved iron.

C. Interview results on iron related

The results in Figure 5 show the iron related factors with regards to colour of water and smell.

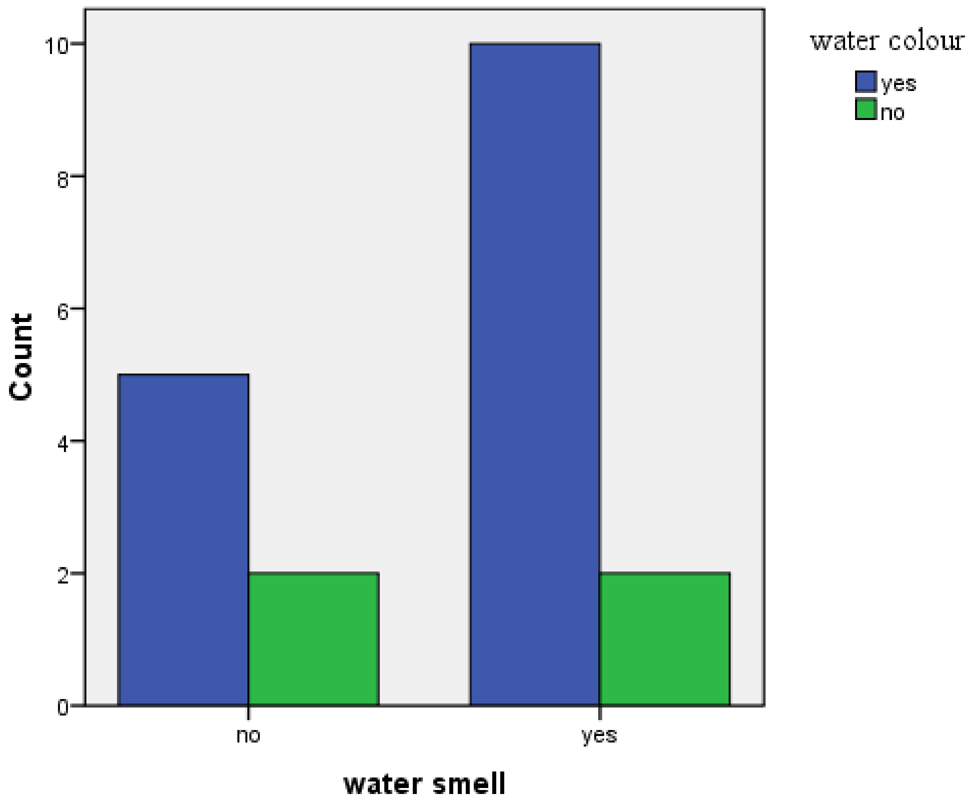

Fig 6:- shows the quality of water in terms of smell and colour in Mbala District

Figure 6 shows the response of the communities with regards to the presence of iron in the water. The results show that there were two groups of people of which some responded 'yes' presence of smell in the water and others responded 'no'. Those that responded negative to the presence of smell equally were less than those that responded positive to the presence of smell in the water. Therefore, the results show that many people in the communities are aware about the presence of iron in the water and has subsequently forced them to seek alternative sources of water for consumption. The water collected from the boreholes is used in gardening and other outdoor activities.

IV. CONCLUSION AND RECOMMENDATIONS

The conclusion is made based on the results and the subsequent recommendations.

A. Conclusion

In conclusion, the high levels of high iron concentration in the water are as a result of the borehole equipment corroding. pH values show that an electric potential was created by the water causing corrosion of borehole material. The presence of iron in water affected the communities negatively as they had to seek other sources of water because of the foreign colour and odour of the water.

B. Recommendations

The following are the recommendations:

- Non-government Organisation in Zambia with projects in supplying water should introduce iron filters to boreholes with very high iron content and equip the borehole with corrosion inhibitors;
- The Government under the Ministry of Mines, Energy and Water Development as well as the Ministry of Local Government and Housing through the various Departments of Water Affairs across the nation should encourage the use of PVC pipes and coat the inside of casings with PVC;

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