Assessing the quality of pipe borne water using Magnetic Susceptibility Measurements

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Abstract- Magnetic susceptibility measurements and chemical analysis were performed on samples of water taken from the academic and residential areas of the Kwame Nkrumah University of Science and Technology (KNUST) campus, Kumasi. The aim of these measurements was to see if water delivered through metallic pipes was clean. Magnetic susceptibility measurements were performed using the Bartington MS2 magnetic susceptibility meter, with MS2G single frequency sensor and the chemical analysis was performed with the Varian SpectrAA 220FS Atomic Absorption Spectrometer. Results of the measurements showed that the water samples had negative magnetic susceptibility (χ) values of the order of 10^{-5} and were thus diamagnetic. The χ values obtained for the samples were between -1.3×10^{-6} SI and -1.23×10^{-5} SI for the Academic Area (sampled colleges) and -3.0×10^{-7} SI and -8.7×10^{-6} SI for the Residential Area (sampled Halls of residence). Chemical analysis of the samples showed variation in the concentrations of iron and zinc. Regression analysis of their concentrations with their χ values revealed zinc to have a strong inverse relationship with a correlation coefficient of 73%. Although the study showed some level of metallic contamination in the water samples of average concentration of 0.03mg/l, these were well below the concentration of 3mg/l which is of detrimental concern as outlined by the World Health Organization (WHO). This makes drinking water from the study area safe for drinking.

Index Terms- Magnetic Susceptibility, Diamagnetic, Water sample, chemical analysis, metal contamination.

I. Introduction

Water is one of the most essential needs for the continued existence of all living organisms on earth. The day-to-day activities of all living organisms require water in different forms. It is effectively and efficiently put into use by plants, animals, microorganisms and man. In the microbial world, no single microorganism has been discovered to be active at the extreme lack of water and this is the singular reason that man cannot exist without water; it is of paramount importance to monitor domestic water supply (Sofola and Lawal, 1983). Unsafe water is a global public health threat, placing persons at risk for a host of diarrhoea and other diseases as well as chemical intoxication (Hughes and Koplan, 2005). The provision of treated water to the inhabitants of the city is a civic responsibility of the city administration. The presence of good treated water is essential for good health and the elimination of some water borne diseases.

It is known that corrosion of household plumbing systems (made mostly of metallic material) can contaminate the water that passes through them through the release of metallic particles, like Fe, Al, Zn amongst others. Concentrations of iron in drinking-water are normally less than 0.3 mg/litre but may be higher in countries where cast iron, steel, and galvanized iron pipes are used for water distribution (WHO, 2003). High metallic content in water can cause liver or kidney damage or high blood pressure when one is exposed to it for a long time. Moreover, hardness of water is caused largely by calcium and magnesium salts and to a small extent by iron, aluminium, and other metals (Microsoft Encarta 2009). Since water is basically used for everything on the campus of Kwame Nkrumah University of Science and Technology (KNUST), it became imperative to ascertain the metallic content of pipe borne water on KNUST campus using magnetic susceptibility and atomic absorption spectrometry methods.

The determination of magnetic susceptibility is a useful, sensitive and fast method and is used in mineralogy and pollution research. Recently, magnetic susceptibility has been adapted as a tool for the mapping of pollutant distribution (Canbay, 2010, Canbay et al., 2009; Wang and Qin 2005). The magnetic measurement is considered as a rapid and affordable screening tool for the determination of the spatial distribution of contamination level. The use of magnetic susceptibility measurement as a proxy for the chemical method of assessing pollution is possible because pollutants and magnetic minerals are genetically related (Hanesch and Scholger 2002). During the 1970s and 1980s, scientists realised that magnetic properties were useful for describing and classifying all types of environmental materials. Many studies are available in literature where heavy metal contamination and industrial activities causing soil, air or water pollution were investigated (Canbay 2010; Vadiunina et al., 1972; Tite et al., 1975; Mullins et al., 1973, 1977).

In addition, magnetic susceptibility has shown to be a highly useful indicator of industrial pollution, gas emission into air due to traffic and other atmospheric pollutants (Canbay 2010; Thompson et al., 1986; Hay et al., 1997; Strzyszcz and Magiera , 1998; Durza, 1999; Kapicka et al., 1997, 2003; Lecoanet et al., 1999, 2001; Knab et al., 2001; Hanesch et al., 2003, 2005; Lu et al., 2007).

This paper investigates the quality of water delivered through metallic pipes at KNUST campus, Kumasi by using magnetic susceptibility measurements vis-à-vis chemical analyses.

II. MATERIALS AND METHODS

2.1 Project Site Description

The Kwame Nkrumah University of Science and Technology is located in Kumasi, the Ashanti Regional capital, bounded between latitudes 6° 41′ 15″ N and 6° 39′ 39″ and longitude 1° 35′ 11″ W and 1° 32′ 51″ of Ghana. It is about 18 square kilometres in area, and is located about 13 km to the east of Kumasi, with a student population of about 32,198 as at 2012. It is the second public university established in the country. The experiments were carried out in five halls of residence on the campus (namely Africa Hall (established in 1967), Independence Hall (established in 1959), Queen Elizabeth II Hall (established in 1959), Republic Hall (established in 1961), Hall and Hall seven (established in 2011)) and 5 colleges (namely the College of Agriculture and Natural Resources, College of Health Sciences, College of Art and Social Sciences, College of Architecture and Planning, College of Engineering, and College of Science).

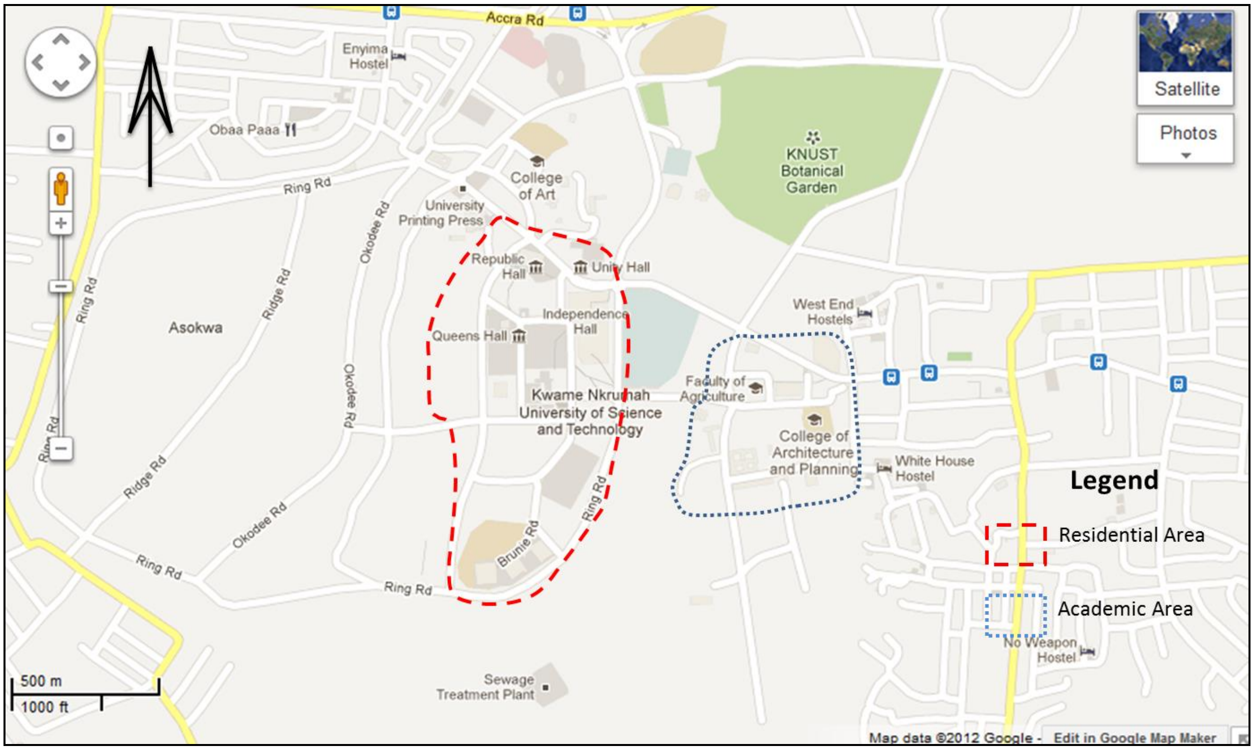

Figure 1: Satellite map of KNUST campus from Google Earth, showing Residential and Academic area

2.2 Water Supply Network at KNUST

The supply of water to the Kumasi Metropolis is from two surface water treatment plants; Owabi and Barekese head works located 10 km and 16 km respectively from Kumasi.

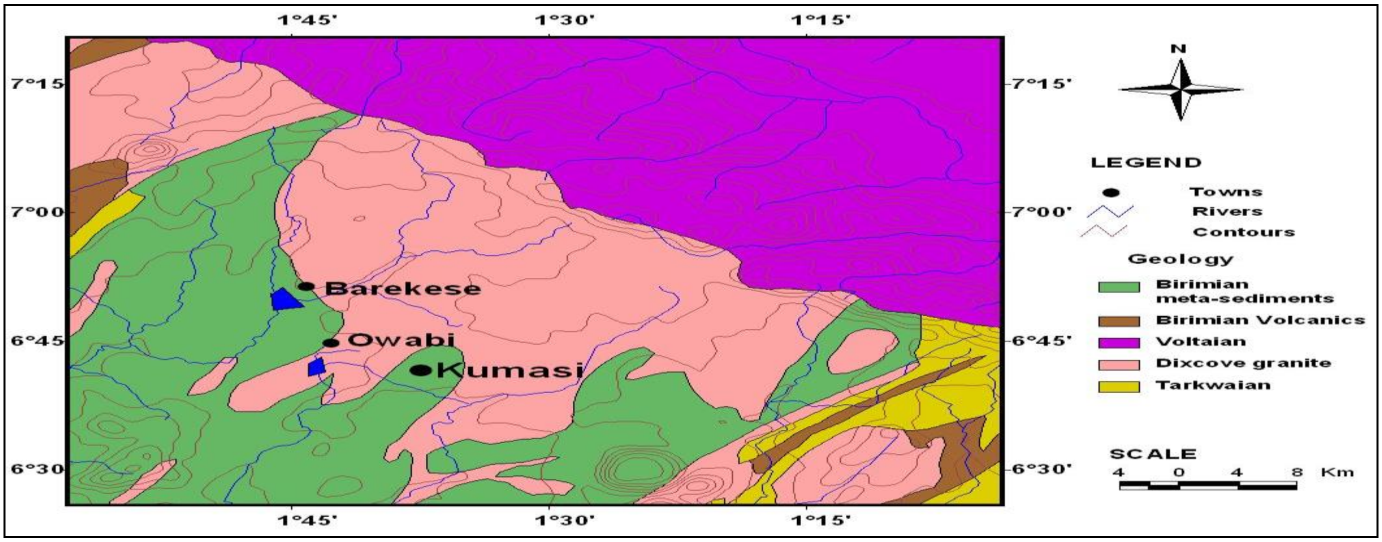

Figure 2: Geological Map of Kumasi Area showing the Catchment of Barekese and Owabi Reservoirs.

The supplies of water from these head works serve Kumasi metropolis as well as surrounding communities outside the metropolis. Treated water is pumped from Barekese and Owabi head works through steel and iron mains for 22 km and 14 km respectively to the Suame town where it is centrally monitored. The quality of water is monitored in a central laboratory at Suame and at 150 other points in the distribution system (Blokhuis et al., 2005). Some treated water is later pumped to the 1,900,000 litres capacity reservoir located at KNUST. This reservoir serves the KNUST campus.

2.3 Magnetic Susceptibility Measurements

The magnetic susceptibility measurements were conducted using the magnetic susceptibility meter (Figure 3 b, MS2, Bartington Instruments Ltd., UK) with MS2G Single Frequency Sensor (Figure 3 a). The set was mounted higher up on a wooden bench to remove, as much as possible, the contaminating influence from metallic substances like buried metallic pipes or cables which might be present in the area.

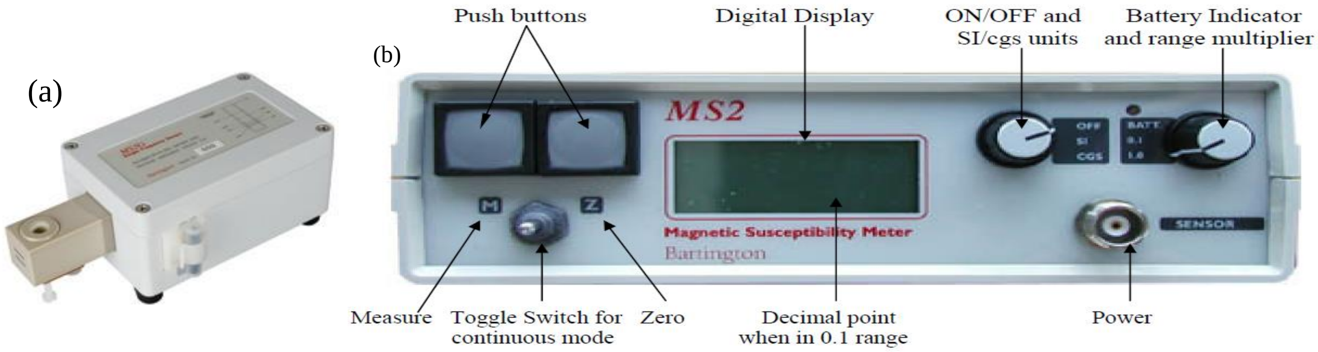

Figure 3: (a) MS2G Single Frequency Sensor (b) Bartington MS2 meter

All sampling experiments were carried out in a way to minimise contamination from ferrous metal, since that metallic contamination can affect the susceptibility readings. Furthermore, in order to minimise error in the susceptibility readings, the 1 ml sample tubes were filled fully and with the same volume of the samples while special care was taken in placing the sample in the MS2G sensor. In all a total of 100 samples of 1 ml tubes were taken from the study area, with 50 samples from the academic area and remaining 50 samples from the residential area. To enhance the quality of the readings, the more sensitive 0.1 range on the meter was used and for each measurement, three readings were taken and the average recorded.

2.4 Chemical Analysis

Metallic concentrations of As, Cu, Pb, Fe, Cd, Ni, Cr and Zn were determined for the samples by atomic absorption spectrometry using the Varian SpectrAA 220FS Atomic Absorption Spectrometer. The results of the chemical analysis are shown in Table 11. It was seen that only Zn and Fe showed variation in concentrations for the various water samples, suggesting that the magnetic susceptibility differences recorded were caused by the presence of these metals. Consequently, graphs of magnetic susceptibility were plotted against metallic concentrations for Fe and Zn with linear regression fits to establish the relationship between the metal concentrations and magnetic parameters of the water samples.

Figure 4: SpectrAA 220, Absorption Spectrometer

III. RESULTS AND DISCUSSION

The results of the experiment showed that samples taken at different locations had different responses when exposed to an externally applied magnetic field and thus had different magnetic susceptibility values. It was observed that the magnetic susceptibility values of the pipe borne water samples were negative and within the range -3.00×10^{-7} SI to -1.23×10^{-5} SI. Water samples from the Academic area were seen to be more diamagnetic than those from the Residential area. The magnetic susceptibility values obtained for the samples were between -1.30×10^{-6} SI and -1.23×10^{-5} SI for the Academic area (i.e. water samples from the colleges) and between -3.00×10^{-7} SI and -8.70×10^{-6} SI for the Residential area ((i.e. water samples from the halls of residence).

The average magnetic susceptibility values for the academic area and the halls of residence were -4.9×10^{-6} SI and -4.8×10^{-6} SI, respectively. The Republic Hall recorded the highest χ value of -3.0×10^{-8} SI while Hall Seven had the least susceptibility value of -8.7×10^{-7} SI. For the academic area, College of Agriculture had the highest susceptibility value of -1.3×10^{-7} SI with the College of Architecture recording the least susceptibility value of -1.23×10^{-6} SI.

It was also observed that the magnetic susceptibility values of the samples were negative indicating that they were diamagnetic. The magnetic susceptibility values for the samples were however, generally, higher than the theoretical magnetic susceptibility value of water, -9.05×10^{-6} SI. This suggests the presence of some metals (like zinc or iron particles) in the water samples. From Table 6, sample S2 from the Republic Hall had the highest susceptibility value of -3.0×10^{-8} SI. This may be attributed to the contamination of the water by magnetic materials like iron (caused by the rusting of the iron pipe-stand). At the College of Science, samples from the New Complex Building (Table 1) had the least susceptibility values and these were closer to the theoretical value than samples from the Physics Block. The physical observation on the two buildings showed that most of the plumbing systems at the Physics Block looked old and rusty as compared to the New Science Complex which had new plumbing system. Water from the Physics Block may thus be contaminated with some amount of ironic materials. At Hall Seven, Table 9, the measured susceptibility values were closer to that of the theoretical value. This indicates that the metallic content in the samples were very small amount and this is so because Hall Seven is, relatively, a new hall with new and clean plumbing system.

Generally, places with lower magnetic susceptibility values, in terms of magnitude, had their pipe stands being rusty indicating the presence of some metal content like iron or zinc in them. This is so based on the research by Talara et al (2002) which suggests that a high magnetic susceptibility anomaly could be attributed to the presence of metallic components.

Table 1: Magnetic Susceptibility value for samples from College of Science

Sample	Notation	Susceptibility, $\chi \times 10\text{-}5$ SI
Goundfloor Pipe-Stand Near The Auditorium	S1	-1.03
Physics Male Wash Room	S2	-0.60
Physics Stand-Pipe Ground Floor	S3	-0.27
Mathematics Department Male Wash Room	S4	-0.33
Mathematics Department Female Wash Room	S5	-0.43

Table 2: Magnetic Susceptibility value for samples from College of Agriculture

Sample	Notation	Susceptibility, $\chi \times 10\text{-}5$ SI
Standing Pipe	S1	-0.30
Entomology Lab	S2	-0.27
Plant Pathology Lab Ground Floor	S3	-0.17
Natural Resource Lab	S4	-0.13
Natural Resource Wash Room	S5	-0.70

Table 3: Magnetic Susceptibility value for samples from College of Architecture

Sample	Notation	Notation
Ground Floor Male Wash Room I	S1	-0.30
Ground Floor Female Wash Room I	S2	-0.67
Pipe Stand (Water Was Warm)	S3	-1.17
Ground Floor Male Wash Room Ii	S4	-0.13
Ground Floor Female Wash Room Ii	S5	-1.23

Table 4: Magnetic Susceptibility value for samples from College of Engineering

Sample	Notation	Susceptibility, $\chi \times 10\text{-}5$ SI
Second Floor Male Wash Room	S1	-0.57
First Floor Female Wash Room	S2	-0.27
Pipe Stand Adjacent Auditorium	S3	-0.50
Communication Wash Room Second Floor	S4	-0.30
Electrical Laboratory	S5	-0.20

Table 5: Magnetic Susceptibility value for samples from College of Arts

Sample	Notation	Susceptibility, χ ×10-5 SI
Painting	S1	-0.57
Wash Room Near Studio	S2	-0.17
Nursery Poly Tank I	S3	-0.60
Nursery Poly Tank II	S4	-0.67
Sculpture Wash Room	S5	-0.70

Table 6: Magnetic Susceptibility value for samples from Republic Hall

Sample	Notation	Susceptibility, $\chi \times 10^{-5}$ SI
Flat One	S1	-0.17
SRC Ground Floor	S2	-0.03
Block B	S3	-0.07
Zongo Area	S4	-0.70
SRC Second Floor	S5	-0.53

Table 7: Magnetic Susceptibility value for samples from Africa Hall

Sample	Notation	Susceptibility, $\chi \times 10^{-5}$ SI
Ground Floor Stand-Pipe	S1	-0.27
First Floor Block A	S2	-0.13
Second Floor Block A	S3	-0.10
First Floor Block B	S4	-0.30
Second Floor Block B	S5	-0.43

Table 8: Magnetic Susceptibility value for samples from Independence Hall

Sample	Notation	Susceptibility, $\chi \times 10^{-5}$ SI
Stand Pipe Near Shops	S1	-0.53
Wash Room, West Of West Wing	S2	-0.13
Wash Room, East Of West Wing	S3	-0.67
Wash Room, West Of East Wing	S4	-0.83
Wash Room, East Of East Wing	S5	-0.60

Table 9: Magnetic Susceptibility value for samples from Hall Seven

Sample	Notation	Susceptibility, $\chi \times 10^{-5}$ SI
Ground Floor Left-End Of M Block	S1	-0.77
Ground Floor Left-End Of O Block	S2	-0.63
Ground Floor Right-End Of O Block	S3	-0.87
Central Pipe-Stand	S4	-0.73
Ground Floor Right-End Of M Block	S5	-0.80

Table 10: Magnetic Susceptibility value for samples from Queen Elizabeth II Hall

Sample	Notation	Susceptibility, $\chi \times 10^{-5}$ SI
West Wing, First Floor	S1	-0.13
Polytank Right-End, Zongo Area	S2	-0.54
East Wing, Third Poly Tank	S3	-0.43
Polytank Left-End, Zongo Area	S4	-0.83
Polytank Nearest Potters' Lodge	S5	-0.77

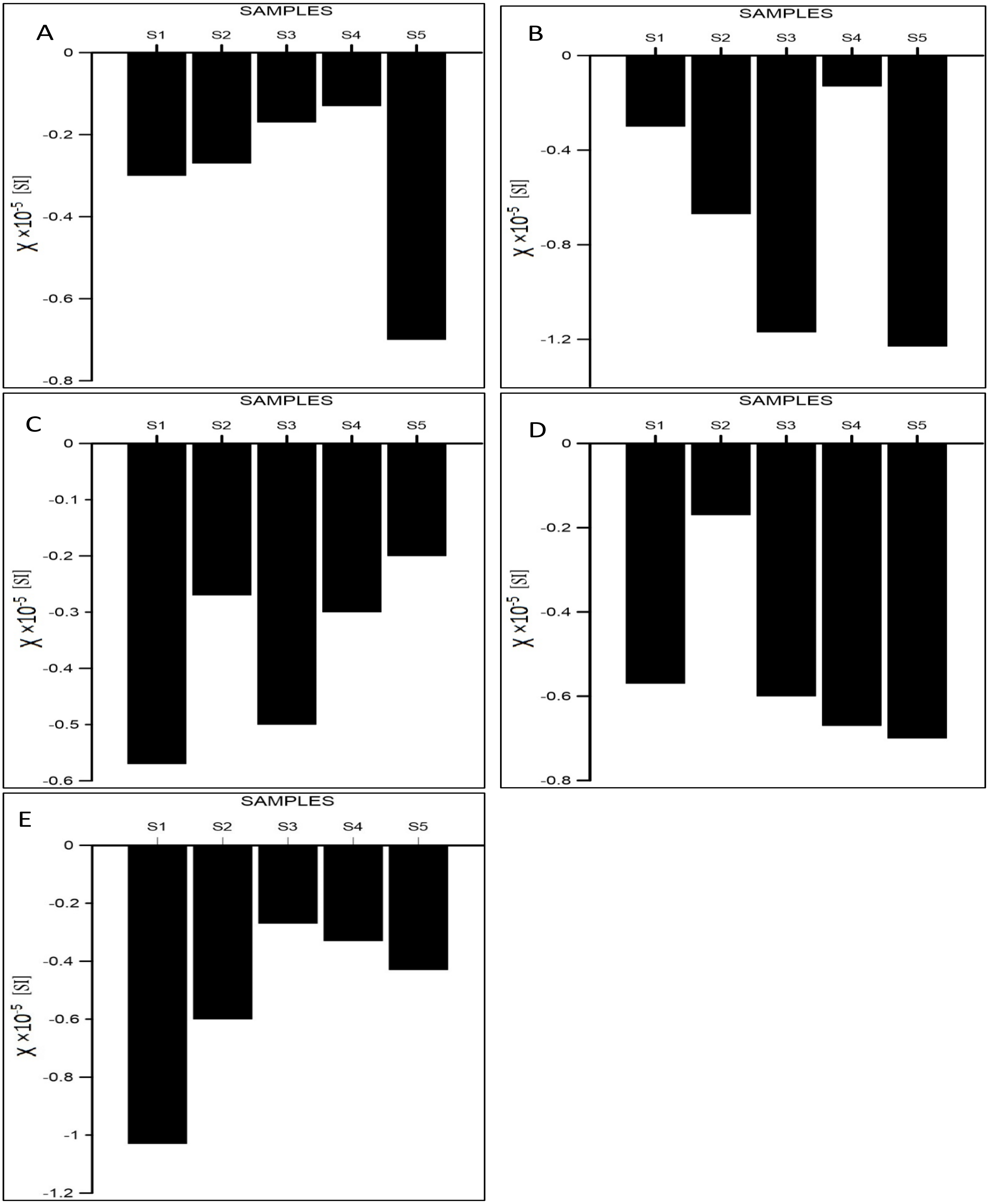

Figure 5: Bar chart of Magnetic Susceptibility value for the samples from the various colleges; A-College of Agriculture, B-College of Architecture, C – College of Engineering, D-College of Art, and E- College of Science

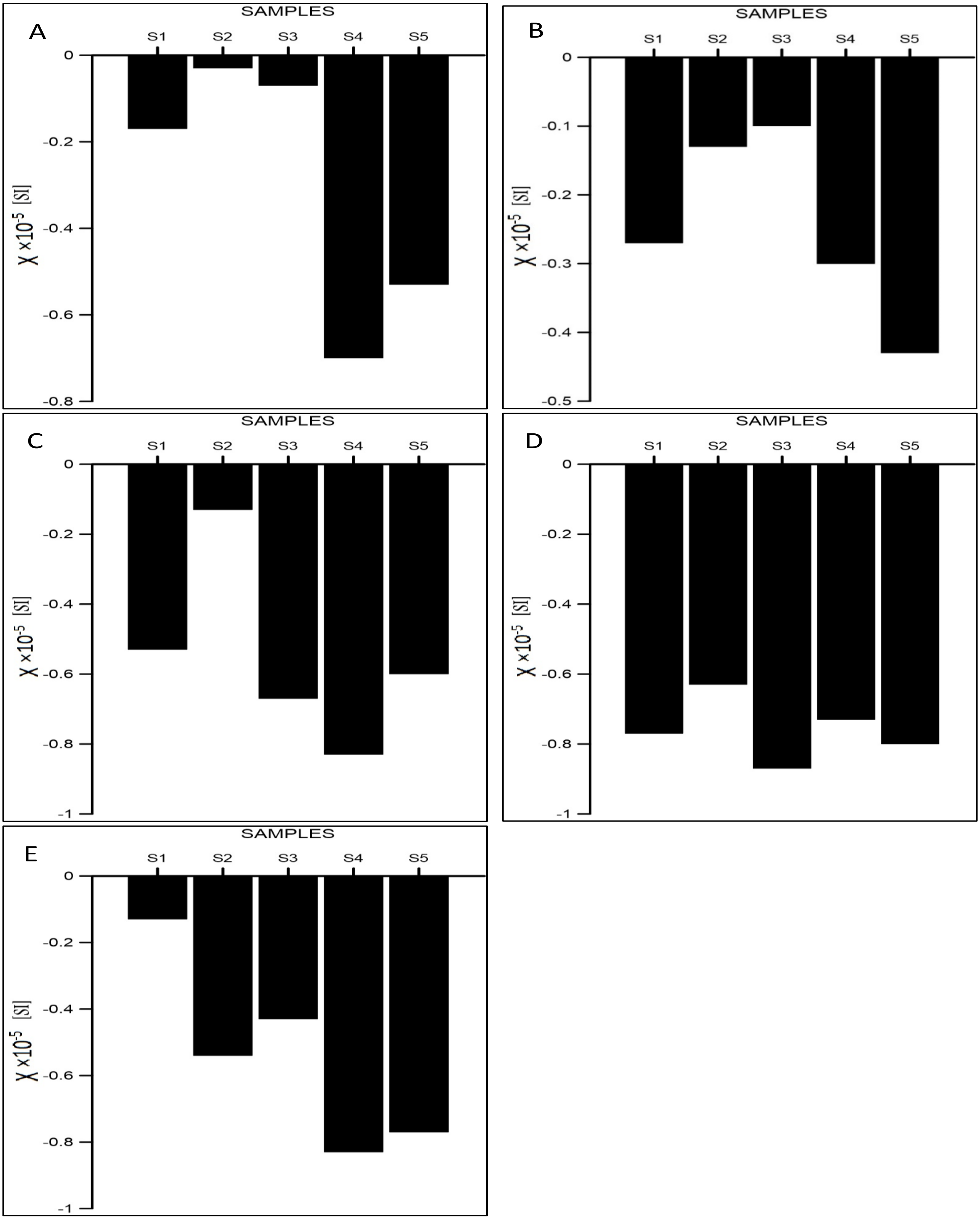

Figure 6: Bar chart of Magnetic Susceptibility value for the samples from the various Halls of Residence; A- Republic Hall, B- Africa Hall, C- Independence Hall, D- Hall seven, and E- Queen Elizabeth II Hall

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3.1 Water Chemical Analysis

Chemical analysis was carried out to determine the metallic concentrations of As, Cu, Pb, Fe, Cd, Ni, Cr and Zn using the Varian SpectrAA 220FS Atomic Absorption Spectrometer. Table 11 displays the concentrations of the various heavy metals analysed.

Table 11: Concentrations of some heavy-metal from chemical analysis

	As(ppm)	Cu(ppm)	Pb(ppm)	Fe(ppm)	Cd(ppm)	Ni(ppm)	Cr(ppm)	Zn(ppm)
Agriculture	0.003	0.006	0.003	0.026	0.003	0.003	0.003	0.023
Art	0.003	0.006	0.003	0.045	0.003	0.003	0.003	0.021
Architecture	0.003	0.006	0.003	0.012	0.003	0.003	0.003	0.035
Engineering	0.003	0.006	0.003	0.011	0.003	0.003	0.003	0.035
Science	0.003	0.006	0.003	0.021	0.003	0.003	0.003	0.035
Africa Hall	0.003	0.006	0.003	0.014	0.003	0.003	0.003	0.006
Republic Hall	0.003	0.006	0.003	0.022	0.003	0.003	0.003	0.033
Queens	0.003	0.006	0.003	0.032	0.003	0.003	0.003	0.028
Independent Hall	0.003	0.006	0.003	0.026	0.003	0.003	0.003	0.007
Hall 7	0.003	0.006	0.003	0.024	0.003	0.003	0.003	0.077

Table 12: Concentrations of Fe and Zn and the magnetic susceptibility values of water samples

	Fe(ppm)	Zn(ppm)	Fe [mg/l]	Zn [mg/l]	Magnetic Susceptible Values		
					Average	High	Low
Africa	0.014	0.006	0.0140	0.0060	-0.27	-0.13	-0.43
Republic	0.022	0.033	0.0220	0.0330	-0.17	-0.03	-0.70
Hall 7	0.024	0.077	0.0240	0.0769	-0.63	-0.73	-0.87
Independent	0.026	0.007	0.0260	0.0070	0.53	-0.13	-0.83
Queens	0.032	0.028	0.0320	0.0280	-0.77	-0.13	-0.83
Agriculture	0.026	0.023	0.0260	0.0230	-0.30	-0.13	-0.70
Art	0.045	0.021	0.0449	0.0210	-0.57	-0.17	-0.70
Architecture	0.012	0.035	0.0120	0.0350	-1.17	-0.13	-1.23
Engineering	0.011	0.035	0.0110	0.0350	-0.50	-0.20	-0.57
Science	0.021	0.035	0.0210	0.0350	-0.43	-0.27	-1.03

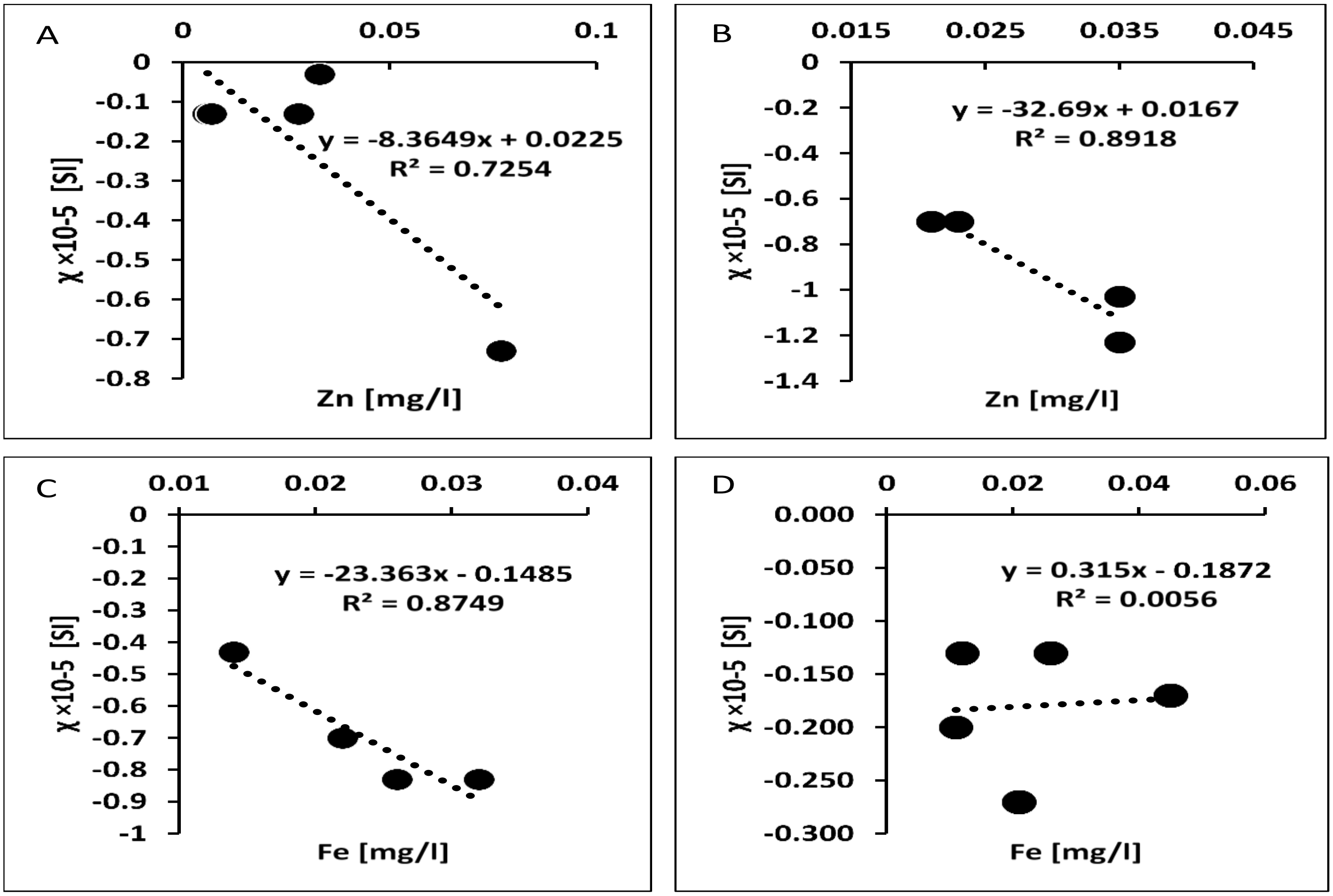

Figure 7: Graphs showing the magnetic susceptibility values against concentration of Zn at the Halls, A) and at the Academic Area, B), and those of Fe, C) and D), respectively.

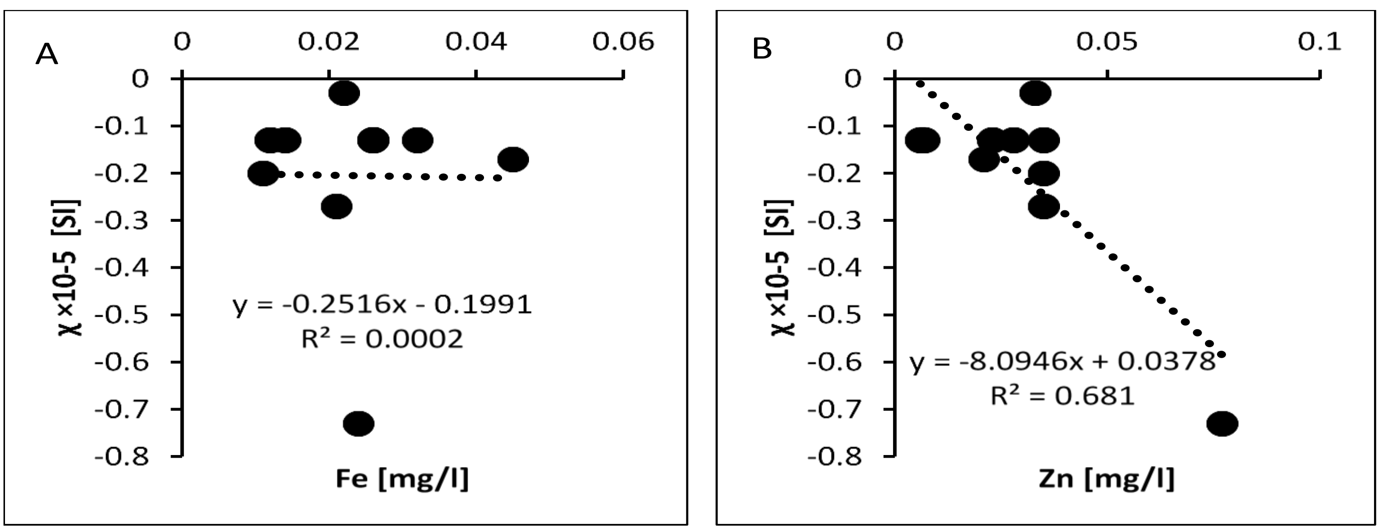

Figure 8: Graphs showing the magnetic susceptibility values against the concentrations of Fe, A), and that of Zn, B), for both Residential and Academic areas.

Magnetic susceptibility values, χ, correlated well with the concentration of Zn with a correlation coefficient of 0.725 at the residential area, figure 7A, with χ values decreasing with increasing Zn concentration. A good correlation coefficient of 0.892 was also attained at the academic area as shown in Figure 7B. As expected, the graph showed an inverse relationship with increasing concentration of Zn resulting in decrease in χ values as was evident at the residential area. Magnetic susceptibility showed a correlation coefficient of 0.875 with Fe concentration Figure 7C. Again, the parameters depicted an inverse relationship. The χ values increased with increasing concentration of Fe at the Academic area with a weak correlation coefficient of 0.006, Figure 7D.

Averagely for both academic and residential areas, Fe concentration did not have a good correlation with χ values as seen in Figure 8A, which reveals a correlation coefficient of 0.0002. This suggests that Fe may not be the main cause of the variation in χ values of the water samples. In Figure 8B, the concentration of Zn shows good correlation coefficient of 0.681 with χ values. The negative slope suggests an inverse relationship. Thus, increasing concentration of the Zn results in a decrease in the χ values. Zn concentration in drinking water is higher as a result of the leaching of zinc from piping and fittings in tap water (WHO, 2003).

Zinc has the potential of imparting an undesirable astringent taste to water. According to WHO (2003), drinking water usually makes a negligible contribution to zinc intake (Table 12) by humans unless high concentrations of zinc occur as a result of corrosion of piping and fittings. Given certain situations, tap water can provide up to 10% of the daily intake. Acute toxicity arises from the taking in of excessive amounts of zinc salts, either accidentally or deliberately as an emetic or dietary supplement. Consuming more than 500 mg of zinc sulphate may cause vomiting. Drinking water containing zinc at levels above 3 mg/l tends to be opalescent, develops a greasy film when boiled, and has an undesirable astringent taste. The concentrations of zinc in the pipe-borne water for both the residential and academic areas of KNUST were well below harmful levels, thus, proving good potable water for all kinds of use.

IV. CONCLUSIONS AND RECOMMENDATIONS

Results of the measurements showed that the water samples had negative values of magnetic susceptibility of the order of 10^{-5} and were thus diamagnetic. The magnetic susceptibility values obtained for the samples were between -1.3×10^{-6} SI and -1.23×10^{-5} SI for the Academic Area (sampled colleges) and between -3.0×10^{-7} SI and -8.7×10^{-6} SI for the Residential Area (sampled Halls of residence). These point to the fact that the samples from the study area may contain some amount of metallic content. The mean magnetic susceptibility values of the samples significantly deviated from the EPA or WHO value for water (-9.05×10^{-6} SI).

Chemical analysis of the samples, by absorption spectrometry, showed varying concentrations of iron and zinc in the water samples. Statistical analysis proved zinc concentration to have an inverse relationship with magnetic susceptibility and a good correlation coefficient of 0.726. Whereas, iron proved not to be the main cause of the variation of the magnetic susceptibility values having a poor correlation coefficient of 0.0002. The average concentration of zinc, 0.030mg/l, is well below the amount of detrimental concern, 3mg/l (WHO, 2003), in the pipe-borne water for both the residential and academic areas of KNUST. Thus, making the water here potable for all purposes and usage.

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