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Research Article

Assessment of the corrosiveness of the water in the distribution line from intake to consumer outlets in Malawi

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Abstract

A study was carried out to assess the water quality in the distribution pipes in Malawi. In particular the study was aimed at testing the corrosiveness of the water using the Langelier Saturation index (LSI). Water hardness and total alkalinity were both lowest ($p<0.05$) at the intake but higher levels were recorded at the other three points but in each set values did not vary significantly from each other. The Total Dissolved Solids were also lowest at the intake but the values increased steadily towards the consumer's outlets. The lower values at the intake could be due to natural sources and the chlorination. There was a slight increase at and after treatment with chlorine that was attributed to the presence of ionic metals that might have dissolved from the pipe. The LSI values obtained at four sampling points from the intake to the consumer outlets; -2.5, -2.2, -6.5 and -2.1 suggested that the water in the distribution line was corrosive all the way to the consumers. This could be a health risk to the consumers and may also affect the lifespan of the pipes themselves. It is therefore recommended that frequent corrosion assessments should be done so that the levels of corrosion in the pipe distribution systems are constantly monitored and checked.

Keywords: Corrosion, distribution system, water quality, water treatment

INTRODUCTION

Corrosion is a complex series of reactions between the water and metal surfaces and materials in which the water is stored or transported (Baird, 2011). The corrosion process is an oxidation/reduction reaction that returns refined or processed metal to their more stable state. Nearly all metals will corrode to some degree. The rate and extent of the corrosion are dependent on the degree of dissimilarity of the metals and the physical and chemical characteristics of the media, metal, and environment. In water that is soft, corrosion occurs because of the lack of dissolved cations, such as calcium and magnesium. Experiments have shown that localised corrosion is the primary form of corrosion of cast iron water pipes and that the microstructure of cast irons is a key factor that affects the corrosion behaviour of cast iron pipes (Mohebbi and Li, 2011).

Several studies have been conducted on corrosion of water in distribution pipes (Wormwell and Nurse, 2007; Agatemor and Okolo, 2008; Jung et al., 2009**;** Slavickova et el., 2013; Sarver and Edwards, 2012; Liu et et al., 2014). The results of a study on the influence of water velocity on corrosion showed that the flow regime and the water quality affects the corrosion type and also that the composition of natural organic matter affects the rate of corrosion of iron and copper pipes by complex formation of the metal (Gruskevica et al., 2013). Research has also shown that aggressive potable waters characterized by high pH, free chlorine residual and low alkalinity cause copper pitting corrosion which leads to premature plumbing failures (Sarver and Edwards, 2012).

Corroded water is a common term for metal polluted water which is as a result of the reaction between water and metals. Corroded water is usually seen as blue-green stains in basins. As corroded water stands or settles in pipes or tanks it leaches metals from the piping and tanks (Trivedi and Raj, 1992). Corroded water imparts a bitter taste to water because of elevated levels of metals, making customers opt for bottled water. In addition, Corrosion can cause the degradation of the quality of drinking water containing high levels of toxic metals such as lead and copper. The consumption of such water causes both acute and chronic health problems in humans (Baird, 2011; Trivedi and Raj, 1992). Apart from this, corrosion also results in high maintenance costs to the system (Slavickova et al., 2013; Gruskevica et al., 2013). Corroded water is costly in a number of ways: firstly it decreases the efficiency of hot water heaters and may cause premature failure to the heater. It also corrodes and causes premature failure of household plumbing and plumbing fixtures resulting in high maintenance costs (Slavickova et al., 2013; Gruskevica et al., 2012).

Throughout the world, millions of miles of water distribution pipelines provide drinking water for individual and industrial use. Some of these water distribution systems have been in service for more than 100 years (Clark et al., 1993). While tap water that meets both national and international standards is generally safe to drink, there are threats to water quality and quantity. In fact, the ability to regularly deliver safe water is a constant challenge to water suppliers worldwide.

Effective Water delivery of portable water is a much talked about issue with regards to quality, safety and accessibility. A study by Mumba and Gomani on quality of drinking tap water in semi urban areas of Malawi showed that although the supply and consumption of portable water was available, the water was not safe for consumption due to the presence of toxic metals such as lead and the presence of fecal coliform which are a sure indication that serious deficiencies in the treatment of the water exist at the treatment plant (Mumba and Gomani, 2014). The study concluded that while potable water was essential it would be advisable for the authorities to take appropriate steps to ensure that safe water is distributed to the consumers. Unfortunately, there is another angle to water delivery that has not been looked at thoroughly in Malawi. How long water deliver pipes exist without being replaced and their consequential impacts on water safety, quality and accessibility are neglected areas.

In Malawi, the water pumping plant situated on the banks of the Shire River has been supplying water to the nearby city residents since 1963. Its establishment was a result of a rapid increase in the demand for water. The underground pipelines are made of bituminised carbon steel and are approximately 3metres deep. Carbon steel has a life span of less than fifteen years and the bitumen coating is included to ensure that the pipe is not prone to corrosion. Since their establishments in 1953 and 1997, both pipes from the intake to the consumer outlets have not been replaced and therefore, may have exceeded their life span. Once carbon steel pipes exceed their life span they are very prone to corrosion and the bitumen coating that is associated with them starts to chip off and these chips are eventually transported with the water. The exceeded lifespan of the twin pipes and their association with corrosion raises serious issues such as consumption of water with elevated levels of metals such as lead, mercury and cadmium which are highly toxic.

For instance consumption of water with lead results in problems related to physical and mental development, along with slight deficits in attention span and learning abilities in children. In adults, it can cause increases in blood pressure. Adults who drink this water over many years can develop kidney problems or high blood pressure. Furthermore these pipelines are liable to leakages which result in the contamination water with sediments (Gruskevica et al., 2013). Studies on the corrosiveness of the water in the distribution pipes can help mitigate the health effects associated with it and also help in reducing the maintenance costs. Unfortunately, no such study in Malawi has been done.

The objective of this study was to assess the water quality in the distribution pipes in Malawi. In particular the study was aimed at testing the corrosiveness of the water and to determine the levels of eroded metals.

MATERIALS AND METHODS

Study Area

The study was conducted in Blantyre City, located in the southern Malawi. The Water is pumped water from the Shire River to this city which is situated about 40 kilometres away. The intake pumps 78,000,000 litres of water per day to the City's population of 1.4 million for domestic, institutional, commercial and industrial purposes. The untreated water is pumped from the intake to another station about 15 Kilometres away where it is treated with chlorine after which the treated water is then pumped to City. In city itself, there is a pumping station that takes the water to residents and the industrial places. Water samples were collected from four pre selected points; at the point of intake (**Point 1**), at the second station but before treatment (**Point 2**), at the third station in the City after treatment with chlorine (**Point 3**) and lastly from consumers' taps that were randomly selected from a residential or commercial area nearby. Samples from the first three points were generated through stratified sampling while samples from the consumers taps were chosen at random. Six samples were collected from each point for analysis.

Chemical Analysis

Total Dissolved Solids (TDS): These were determined onsite using the Hanna HI 9812 Ph-EC-TDS metre.

pH: This was determined onsite using the Hanna HI 9812 Ph-EC-TDS metre

Temperature: Temperature of the water (°C) was determined onsite using the Hanna HI 9812 Ph-EC-TDS metre

Cadmium, Lead: These were determined on an Atomic Absorption Spectrophotometer (AAS), (AOAC, 2002).

Water hardness: Hardness: This was obtained by titrimetric methods (AOAC, 2002). To a 50 ml sample placed in a conical flask, was added 1ml of buffer (pH 10), 0.5 ml of Mg-EDTA solution and 5 drops of indicator with stirring. The solution was then titrated with 0.01M EDTA to a blue end point. The hardness was obtained as mg $CaCO_3$/l.

Total alkalinity: This was determined by titrimetric methods. To 50 ml sample was added 3 drops of phenolphthalein indicator and titrated with 0.01M sulphuric acid until the solution became colourless.

Data Analysis

The quality of the water was determined by using the Langelier Saturation Index (LSI) which indicates whether the water has a tendency to be corrosive or scale forming. The LSI is given by the formula:
LSI = pH- pHs
Where Ph = actual pH of water and pHs = pH at saturation given by pHs = 9.3+(A+B)-C+D) where:
A = Total Dissolved Solids = $(\text{Log}_{10}$ [TDS]-1)/10
B= Water Temperature = -13.12 x Log10 (^{o}C - 273) + 34.55
C= Hardness as $CaCO_3$ = $(\text{Log}_{10}$ [Ca^{2+} as $CaCO_3$]- 0.4
D= Total alkalinity = $(\text{Log}_{10}$ [Alkalinity as $CaCO_3$]

Analysis of Variance (ANOVA) tables were also generated to determine the degree of significance between the values.

RESULTS AND DISCUSSION

The mean chemical species and other parameters determined are given in Table 1. Water hardness was lowest ($p<0.05$) at the intake (Point 1) and higher levels were recorded at the other three points and these did not vary significantly from each other. All values recorded were lower than the value recommended by the World Health Organisation (500 mg/l) and the Malawi Bureau of Standards (500 mg/l) (MBS, 2000). The total alkalinity was lowest at Point 3 and while the values at points 1, 2 and 4 were high, they did not vary significantly from each other.
The Total Dissolved Solids were lowest at the intake (Point 1) but the values increased steadily towards the consumer's tap (Point 4). The lower values at the intake could be due to natural sources and the chlorination process and the same might apply to the Point 2. The slight increase at Points 3 and 4 could be due to the presence of ionic metals that might have dissolved from the pipe.

Table 1. Mean chemical species and other parameters obtained along the water distribution line

	SOURCE			
Chemical parameter	**Point 1**	**Point 2**	**Point 3**	**Point 4**
Pb (ppm)	0	0	0	0
Cd (ppm)	0	0	0	0
Ca(ppm)	25.7 ± 1.1	44.3 ± 0.6	45.0 ± 1.0	44.3 ± 0.6
Hardness ($CaCO_3$ mg/l)	64.17 ± 0.02	110.8 ± 0.03	112.5 ± 0.05	110.8 ± 0.07
Alkalinity (mg/l)	20 ± 0.001	24 ± 0.001	1 ± 0.0	24 ± 0.001
pH	6.35 ± 0.03	6.36 ± 0.02	3.44 ± 0.06	6.39 ± 0.02
TDS (mg/l)	250 ± 0.001	290 ± 0.001	350 ± 0.001	300 ± 0.001
Temperature	26.5 ± 0.30	26.4 ± 0.60	26.8 ± 0.80	27.4 ± 0.50
LSI	-2.5	-2.2	-6.5	-2.1
pHs	8.8	8.5	9.9	8.5

The pH at Point 3 was lowest ($p<0.05$) and this varied significantly from the values at Points 1, 2 and 4 with the latter three, not being significantly different from each other. The lower value observed at Point 3 was significantly below the minimum (6.5) set by the World Health Organization (WHO, 2006). This low value could be due to the presence of chlorine that formed hydrochlorous acid rendering it acidic. At Point 3, the alkalinity was also lowest for the same reason.

At normal drinking water pH levels, bicarbonate, and carbonate are the main contributors to alkalinity. Water with pH less than 6.5 may contribute to the corrosion of metal pipes and release metals, such as lead and cadmium, into drinking water. Although pH less than 6.5 is not a health-risk corrosive water can dissolve metals, such as lead, cadmium, zinc, and copper, present in pipes. Fortunately, no heavy metal, lead or cadmium was detected in the water but the concentration of calcium steadily was lowest ($p<0.05$) at the intake (25.7mg/l) to 44.3mg/l at the tap. However, it is possible that the concentrations of lead and cadmium had not reached the detection limit in this study. Understandably, the presence of these metals in drinking water can cause health concerns. With over 40000 consumers in the receiving city, the risk of exposure to such health hazards may be worrisome that the pH levels are below the 6.5. Furthermore, the observed low pH may increase the chance of the bituminized carbon steel to elevate the concentration of metals in the water it transports.

There were no significant differences in the temperature levels of the water at all the sampling points. This may overshadow its effects on corrosion of the pipes. If the pipe is exposed to temperature gradients or cycling, these differences can cause mechanical stresses in the pipe, leading to scaling or crack formation. Some studies on the role of different temperatures in distribution system corrosion have shown a decrease in weight loss for iron samples held at 13ºC versus 20ºC (Fiksdal, 1995). Other studies found lower iron concentrations and fewer customer complaints of red water during the colder winter months (Volk et al., 2000).

The Lingelier Saturation Index (LSI) values obtained at the four points (-2.5, -2.2, -6.5 and -2.1) suggest that the water in the distribution line is moderate (LSI = -2.1) to severe (LSI = -6.5) corrosive. This could be attributed to the fact that waters along the intake river are surrounded by four main classes of soils, latosols, lithoslos, calcimorphic and hydormorphioc soils (Malawi government, 1998). The calcimorphic soils are grey to greyish brown and are weakly acidic in which water movement is upward during part of the year. This group comprises alluvial soils, vertisols, and mopanosols that occur on nearly level depositional plains with imperfect drainage. The calcimorphic soils around the intake river make the water already corrosive. Fortunately, the Water Board responsible for pumping the water has put in place corrosion prevention measures such as cathode protection throughout the pipe and this might be the reason why the LSI increased after Point 1. When water dissolves chlorine it forms hypochlorous acid (HOCl) and hydrochloric acid (HCl). At Point 3 the LSI rapidly rose because the water became acidic due to the addition of chlorine. It should be noted that it is at Point 3 that Chlorine is added to the system and the LSI is also most negative and the water also becomes more corrosive. Studies have shown that one cause of corrosion is high pH, low alkalinity, and free chlorine residual (Sarver and Edwards, 2012). The studies have also shown that reducing free chlorine residual also reduces the rate and extent of pit initiation, but under continuous flow conditions, pits eventually form in the presence of fairly low chlorine levels. The drop in the LSI value at Point 4, could therefore be due to the chlorines volatile nature, which could also have caused a decrease in the pH. Studies have also indicated that free chlorine residual can cause corrosion of pipes in a combination of high pH (i.e., ~9) and low alkalinity (i.e., ~40–80 mg/L as $CaCO_3$) waters (Sarver and Edwards, 2012). Other studies have also shown that at a neutral pH, an increase in alkalinity promotes metal dissolution, while at pH 9.0 the effect of alkalinity on leaching is marginal (Tam and Elefsiniotis, 2009). In this study while both pH and alkalinity were low, and therefore reduced corrosion at the consumers' outlets. In general, disinfectant residuals increase corrosion rates. Studies have shown that Monochloramine is less aggressive than free chlorine (Treweek et al., 1985). However, if the corrosion is microbial induced, higher disinfectant residuals may decrease corrosion (Treweek et al., 1985; LeChevallier et al., 1993). The low LSI at Point 3 could be due to low pH and this could mean that this point is the most vulnerable to corrosion because of its association with corrosion inducing chemicals. It was also observed that at Point 3 the acid buffering capacity was also zero compared to Point 4 where the alkalinity was 24 which meant that the pH had been stabilized and therefore not as risky as at Point 3 with regards to corrosion.

Unfortunately by the time the water is reaching the consumer through the distribution line the water is still corrosive. This may induce health and economical problems to individual household when the water reacts with household plumbing systems. As such treatment of the water is highly recommended.

CONCLUSION

The results of this study have shown that the water from the intake to the tap is quite corrosive. Interestingly, the water appeared to be corrosive even before it entered the pipeline and this poses as a great threat to the consumers. The absence of heavy metals means that there are currently no health risks associated with them. Although the amount of corrosion may not be significant, the fact that corrosive water reaches the consumers, may be a health risk for many of them in the future and may also affect the lifespan of the pipes themselves. It is therefore recommended that frequent corrosion assessments should be done so that the levels of corrosion in the pipe distribution systems are constantly monitored and checked.

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References

Agatemor C, Okolo PO(2008). Studies of corrosion tendency of drinking water in the distribution system at the University of Benin. The Environmentalist, 28(4): 379-384.

AOAC (2002). Association of Official Analytical Chemists. (Maryland, USA:AOAC)

Baird GM(2011). The epidemic of Corrosion, Part 1: Examining pipe life. J. American water works Association. Pp. 14-19.

Clark RM, Goodrich JA, Wymer LJ(1993). Effect of the distribution system on drinking-water quality. Journal of Water Supply Research and Technology – Aqua. 42(1): 30-38.

Fiksdal L(1995). Water Quality and Internal Corrosion of Iron Pipes. Proc. Internal Corrosion in Water Distribution Systems. (Goteborg, Sweden)

Gruskevica K, Tihomirova K, Juhna T, Osterhus SW(2013). Influence of water verocity and NOM composition on corrosion of iron pipes. Retrieved August 3, 2014, from http://www.techneau.org/fileadmin/files/publications/deliverables/D5.5.15.pdf.

http://onlinelibrary.Wiley.com/doi/10.1002/jctb.5010022123/abstract.

Jung H, Kim U, Seo G, Lee H, Lee C(2009). Effect of Dissolved Oxygen (DO) on Internal Corrosion of Water Pipes. Environ Eng Res. 14(3): 195-199.

Lechevallier MW, Lowry CD, Lee RG, Gibbon DL(1993). Examining the Relationship between Iron Corrosion and the Disinfection of Biofilm Bacteria. J. Amer. Water Works Asso. 85(7): 111-123.

Liu Y, Zhang Y, Yuan J(2014). Influence of produced water with high salinity and corrosion inhibitors on the corrosion of water injection pipe in Tuha oil field. Engineering Failure Analysis. 45:225-233.

Malawi Bureau of Standards(MBS) (2000). MBS guidelines on constituents of health significance. (Malawi: MBS).

Malawi Government (1998). State of Environment Report for Malawi. Environmental Affairs Department. Lilongwe, Malawi.

Mohebbi H, Li CQ(2011). Experimental Investigation on Corrosion of Cast Iron Pipes. Int. J. Corrosion. Pp. 1-17.

Mumba P, Gomani GM(2014). Quality of drinking tap water in semi urban areas of Malawi. Res. J. Agric. Env. Mgt. 3(9): 467-471

Sarver E, Edwards M (2012). Inhibition of Copper Pitting Corrosion in Aggressive Potable Waters. Int. J. Corros. Pp. 1-16.

Slavickova K, Grunwald A, Stastny B(2013). Monitoring of the corrosion of pipes used for the drinking water treatment and supply. Civil Engineering and Architecture. 1(3): 61-65.

Tam YS, Elefsiniotis P(2009). Corrosion control in water supply systems: Effect of pH, alkalinity, and orthophosphate on lead and copper leaching from brass plumbing. J. Environ. Sci. Health. Part A: Toxic/Hazardous Substances and Environmental Engineering. 12: 1251-1260.

Trivedi PR, Raj G(1992). Encyclopaedia of Environmental Science, Vol. 1 and 13, (Akashdeep Publishing House, New Delhi, India).

Volk C, Dundore E, Schiermann J, Lechevallier M(2000). Practical Evaluation of Iron Corrosion Control in a Drinking Water Distribution System. Water Research. 34(6): 1967-1974.

World Health Organization(2006). Guidelines for drinking-water quality. First addendum to third edition. (Geneva: WHO).

Wormwell F, Nurse TJ(2007). The corrosion of mild steel and brass in chlorinated water. J. Appl. Chem. Retrieved August 27, 2014 from