

Quality of Stored Rainwater in Surface and Subsurface Tanks and Health Implications in Makoka, Dar es Salaam, Tanzania

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Research Article

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Abstract

Rainwater harvesting and storage constitutes a viable alternative source of water in urban areas with water shortages. Understanding rainwater quality as a factor for public health is important in enhancing the supply of clean and safe water in cities facing rapid population growth. This study aimed at investigating the quality of rainwater harvested from rooftops and stored in different storage media above and below the ground for its use as an alternative or complementary water source. In this study, we used Hatch Electrode Meter and Spectrophotometer DR/4000U to investigate Electrical Conductivity, Total Dissolved Solids and Iron concentration in forty-eight water samples drawn from stored tanks located above and underground in Makoka, Dar es Salaam. The microfiltration method was used for the total bacteria count of fecal coliform. Results show that stored rainwater in the underground tanks was more polluted than those from surface tanks. High Iron concentration of 0.464mg/L and 0.92mg/L for samples S1(U) of underground and S8(M) above ground metal tanks were found to be above the WHO recommended value of 0.3mg/L. Microbial results show the presence of fecal coliform for samples S1(U) and S9(U) suggesting that underground rainwater storage tanks likely cause diarrhea surges in the area. Results from this study found higher iron concentration and fecal coliforms represent poor hygiene and the driver of many water-borne diseases of public concern in the area. The study recommends households' regular tank cleaning, chlorination, repair of cracks and leakages and healthy design of underground storage tanks.

1. Introduction

Rainwater harvesting implies collection and storage rainwater into reservoirs or tanks or infiltration of surface water into subsurface aquifers before it is lost through subsurface run off (African Development Bank, 2008). Rainwater harvesting provides an independent water supply for households, hence figures as a supplement source of water during shortages. The advantage of rainwater is that it is not saline and is free of many pollutants that may be present on surface and ground water. In some instance, rainwater manages storm water for agricultural activities (Zhu et al., 2015). In rooftop rainwater harvesting, surfaces such as tiles, metal or plastics sheets are used to intercept the flow of rainwater which is then used for household activities (Gonzalez 2012, Christopher et al., 2009).

Duke (2014) reports that rainwater harvesting technique is being implemented in many different parts of the world. For instance, Canadians use a storm water for reduction and irrigation techniques in India they utilize the technique to avoid ground water depletion; in Australia, many homes away from the city use rainwater harvesting as the primary source of water. Meanwhile, developing economies particularly in Africa experience 1.5 times losses of overall rain quantity (UN, 2006). In many areas, the quality of rainwater has been reported to be at acceptable range for human consumptions. However, diversions of the first flush and frequent cleaning of the storage tanks are encouraged so as to maintain the quality of rainwater because storage materials have been identified to have various impacts on the quality of the harvested and stored rainwater (Achadu et al., 2013).

Massawe (2016) shows that in many areas in Tanzania, scarcity of water is a significant challenge hence harvesting rainwater has increasingly become a viable option. This author adds that, while rainwater harvesting is not new in rural Tanzania, in many urban areas the adoption of the technology is still low. As a remedy to water shortage, rainwater harvesting and storage for use is taken as either an alternative water source or as a complementary water source in many areas. However, the quality of the harvested rainwater creates a major public health concern. Various studies conducted on rainwater quality in different areas such as Ile-Ife-Nigeria, Canada, Israel and Jordan (Fredlier, 2017; Christopher et al., 2009; Radaideh et al., 2009, Adeniy & Olabanji, (2005); revealed poor quality in harvested and stored rainwater. These studies mention leaves, animal droppings and dead organisms on roof among agents of rainwater pollution. However, little is known about the effect of storage tank and the location of the tanks on the quality of stored rainwater. The present study, therefore, intended to determine the quality of above surface and underground tanks focusing on Electrical Conductivity (EC), Total Suspended/Dissolved Solids (TDS), Iron (Fe) concentration and fecal coliform of the stored rainwater. The study was undertaken in Makoka sub ward of, Dar es Salaam city, Tanzania.

2. Materials and Methods

2.1 Study Area

Makoka sub ward is located in Makuburi Ward Dar es Salaam city (see Fig. 1). The area experiences an average temperature of between 21°C and 30°C. Hot season is from October to March while the cold season is between May and August. There are short light rains of October to December and the long heavy rains from March to May. The annual rainfall ranges between 1000 mm and 1300 mm respectively (Tanzania Meteorological Agency 2018).

2.2 Study Design, Materials, Sample and Data Collection

This study used case study design focusing at Makuburi because the areas experienced acute water shortage brought about by increasing human population. Water rationing for days or weeks was the main alternative to share the water shortage problem. Furthermore, gives low economic status of the majority of the inhabitants, billed water supply was limited to some households. Again, there are limited boreholes used to harvest rainwater to supplement the municipal water supply. A combination of these reasons serves as justification for the selection of Makuburi ward as the study site.

Stratified random sampling technique was adopted. This technique was adopted because the study population was divided into groups of identifiable patterns that were homogenous and non-overlapping based on the factors relevant to study requirements. The study area was therefore divided into strata based on the following factors: presence of rainwater harvesting system, types of storage tanks used, and the location of storage tank (whether underground or above ground). The strata were thus set and samples were obtained from each stratum. Households with rainwater harvesting system were identified through observation and guidance from a well-informed person in the study area. During the process, the

types of storage media and location were also identified and samples were obtained from the set categories/strata.

Three (3) samples of water were collected using plastic bottles as sampling medium in March, April, May and June. The bottles were washed with soap and clean water and then washed 3 times with the water being sampled. A total of forty-eight (48) samples from four different types of storage tanks were involved. These samples were used for determining the quality of the rainwater harvested. The roof catchment materials from which rainwater harvested were taken as samples included corrugated iron sheet material, tile roofing material, and aluminum roof material.

The storage tank materials from which rainwater samples were collected included: plastic tanks, Ferro-cement tank- made of cement, sand, and iron, Block/ segment tanks -made of blocks/ cements and sand or Concrete tanks- made of concrete, Metal tanks- made of (iron, aluminum or steel), and constructed tanks (Ferro-cement tanks, block tanks and concrete tanks). Table 1 below display material used to make the tanks.

Table 1
ID of Water samples

Sample ID	Characteristics of the Storage tanks
S0	Captured directly from atmosphere without roof or tank contact
S1(U)	Harvested stored water from underground Ferro cement tank
S2(A)	Harvested stored water from above ground Ferro cement tank
S3(A)	Harvested stored water from above ground Ferro cement tank
S4(M)	Harvested stored water from metal tank
S5(P)	Harvested stored water from plastic tank
S6(A)	Harvested stored water from above ground block tank
S7(P)	Harvested stored water from plastic tank
S8(M)	Harvested stored water from metal tank
S9(U)	Harvested stored water from underground Ferro cement tank
S10(M)	Harvested stored water from metal tank
S11(U)	Harvested stored water from underground Ferro cement tank
S12(P)	Harvested stored water from plastic tank

2.3 Laboratory and Analytical Procedures

The collected water samples were preserved using nitric acid before being taken to the School of Environmental Science and Technology (SEST) - Ardhi University laboratory for analysis and

characterization. Distilled water was used for rinsing plates and minimizing concentration. Then laboratory tests on physicochemical biological parameters and nutrient measurement were performed. Quality analysis of rainwater harvested in existing systems helped to determine the suitability of the water for human use as well as to address any present problem in the system that contributes to lowering of the water quality.

a. Analytical procedures for physical- chemical parameters

Temperature, salinity, conductivity and Total Dissolved Solids were measured by potentiometric method using a calibrated Hatch Electrode meter. Turbidity measurement was done by Absorbometric method and color by Aphanizomenon-cobalt method using Spectrophotometer DR/4000U under program numbers 3750 and 1670 with 660nm and 455nm wavelengths respectively. pH was measured using a calibrated pH meter.

Twenty-five (25) mL of the water sample was measured and poured in clean beaker. This was followed by addition of Ferro Ver Iron reagent in the sample poured in a beaker. The mixture was vigorously shaken to mix and left for five minutes for reaction to take place. Spectrophotometer DR/4000U was then programmed at 2165, a wavelength of 510nm was set and then 10mL of distilled water was used for zeroing the spectrophotometer whereas 10mL of sample mixed with reagent was used to take readings. The procedures were repeated for the rest of the samples with the purpose of determining iron concentration.

b. Analytical procedures for biological parameters

Media to support bacterial growth of fecal and total coliform were prepared and 2 mL of the media poured into the sterilized plates was left to harden. 100mls of each sample were then passed through a filter paper placed in a micro filter so as to capture microorganisms through microfiltration. The filter paper with microorganisms was then put in plates with media and then incubated for 24 hours. The readings were then taken by the Total bacteria count method.

c. Data Analysis

Microsoft excel 2013 was used in analyzing data obtained from checklists, questionnaires and laboratory. Values of results and graphs were then produced.

3. Results and Discussion

3.1 Electrical Conductivity of Rainwater: In Fig. 2, it is shown that water samples obtained from underground storage tanks (S1, S9, and S11) had relatively higher Electrical Conductivity (EC) than the samples obtained from above surface tanks. However, samples from metal tank (S10) indicated that the water was contaminated with ions hence had higher electric conductivity rate.

The maximum average value for electric conductivity was 364.5 μ S/cm in sample S1 obtained from underground tank while the minimum was 25.75 μ S/cm in the sample obtained from above ground tank. Although all the obtained values were within the WHO Drinking Water Standards, they were above the control sample S0 that was obtained directly from atmosphere. This indicates the presence of contamination during harvesting, conveyance and storage. During these processes water conductivity increases. Similar observation was reported by Ubuoh and others (2016) on higher values of EC as high as 72 μ S/cm in underground tanks when compared with in above surface tanks (29.6 μ S/cm) indicating effect of tank location on water quality. The latter study was conducted in Oweri, Southeastern Nigeria.

Electrical conductivity in water is influenced by the presence of dissolved minerals and salts such as sodium, magnesium, calcium and potassium (Meride and Ayenew 2016). Excessive intake of such minerals and salts has several health implications such as it may lead to high blood pressure and cardiovascular disease, risks of kidney stones which causes pain and discomfort (Curhan et al., 1993; Graudal et al., 2011). High electrical conductivity in water may also alter the taste and palatability of water. In infants, consuming water with high electrical conductivity may harm their health more for instance causing acute gastrointestinal infections since they have low tolerance levels of minerals and salts.

3.2. Total dissolved solids: The maximum average value as presented in Fig. 3 indicate that, the TDS value as measured in sample S1 obtained from underground Ferro cement tank, was 204.5mg/L. The minimum value as measured in sample S2 from above ground Ferro cement tank was 10.67mg/L.

All the measured values were below the TZDWSTDs as well as WHODWSTDs, hence acceptable. However, all the measured values were above the control value of S0 that was 5.51mg/L as measured in sample obtained directly from atmosphere rainfall without roof or tank contact. The higher level of TDS in underground tanks was observed as compared to above surface tank except for S10 obtained in worn-out metal tank. This indicates that some contamination occurred during conveyance towards the underground tanks as well as contamination during storage. This higher value of TDS indicates presence of inorganic salts and small amounts of organic matter. Most of these elements were calcium, magnesium, sodium, potassium, hydrogen carbonate, chloride, arsenic, sulfates and nitrate ions. The implication of consuming water with high TDS is closely related to that of consuming water with high electrical conductivity.

3.3. Iron Concentration: Results presented in Fig. 4 show that there is high Iron concentration of samples S1 of 0.464mg/L from underground tank and Sample S8 of 0.92mg/L from above ground metal tank. The presented elements were the only values that were above the WHO recommended values of iron concentration in drinking water which is 0.3mg/L. They were also above the measured value of iron concentration in sample S0 that was obtained directly from the atmosphere without roof or tank contact. Iron is the fourth most abundant element in the earth's crust. Thus any leakages or cracks in underground tanks pave a way to contamination brought about by the ground through flood water or

groundwater. Possibly this contributed to the high level of iron in the sample S1 that was obtained from underground Ferro cement tank.

Leaching of iron used in the metal tank alloy into the stored water stands as a possible reason for high iron concentration in the water samples obtained from the metal tank. The lower pH values of water stored in metal tanks tends to increase the potential for the leaching of metals into the stored water, in addition long time storage of the slightly acidic rainwater also contributes to the high iron concentration in the respective samples. However, the increasing iron concentration in other samples especially those obtained from plastic tanks compared from that of sample S0 obtained directly from atmosphere attributes the contribution of material used for roofing on the quality of rainwater harvested.

Consuming water with high iron concentration has several effects on health including hemochromatosis which is a condition of high iron accumulation in the body resulting to damage of internal body organs such as heart, liver and pancreas (Farghaly and El- Sawy, 2014). Damage of these organs increases the risk of one getting heart disease, cirrhosis and diabetes. Also high iron concentration in drinking water may cause staining and discoloration of body tissues such as teeth and nails and also cause skin lesions (Ghimire et al., 2003; Farghaly and El-Sawy 2014). Drinking high iron concentration water may also lead to digestive problems such as vomiting, nausea, abdominal pain and interference of absorption of other nutrients by the body hence resulting in nutritional imbalances (Ghosh et al., 2020). Lastly drinking high iron concentration water may result into rising oxidative stress that allows formation of harmful free radicals which may cause inflammation and tissue damage (Galaris, Barbouti & Pantopoulou, 2019).

3.4 Fecal coliform in Rainwater: Results presented in Fig. 5 on microbial analysis of all samples obtained from underground tanks, indicated that only samples S1 and S9 showed presence of fecal coliform. In all above ground tanks, no fecal coliforms were detected hence 0 readings. These findings are contrary to Achadu et al. (2013) obtained in Wukari, Nigeria which reported a positive confirmatory fecal coliform test in above ground metal, plastic and concrete tanks.

The study has found that, presence of fecal coliform in underground Ferro cement tanks are mainly contributed by leakages and cracks in underground conduits and tanks which in turn pave way to fecal contamination from wastewater in nearby latrines as well as groundwater and floodwater that sometimes carry animal droppings. The droppings might be defecated on the ground and not mainly from catchment area. The contamination of rainwater from animal and human deposits constitutes the most common mechanism for transmission of microorganisms to human as reported by Namrata & Han (2005). In the study undertaken by Namrata & Han (2005) in Uganda, India, Sri Lanka, Pakistan, Bangladesh, Maldives it was found that ground runoff is one of the significant routes of water contamination in underground tanks. Furthermore, the present study revealed presence of thermos-tolerant coliforms and *E. coli* suggesting the presence of fecal contamination due to vectors that had way into storage tank. These pathogenic organisms are said to be responsible for the intestinal tract infections leading to diarrhea, cholera, typhoid, hepatitis as well as bacillary dysentery (WHO 2004).

4. Conclusion and Recommendation

This study investigated the effect of storage tanks and location on the quality of harvested rainwater. Results show that stored rainwater in the underground tanks was found more polluted than above ground with higher Electrical conductivity, Total dissolved solids, iron concentration and fecal coliforms suggesting easier contamination and poor hygienic driver conditions for water-borne diseases. The study recommends households' regular tank cleaning, practicing first flush diversion or interception, chlorination/boiling of drinking water, repair of cracks and leakages as well as consideration of the healthy design criteria of underground storage tanks such as distance from the latrines, septic tanks, sewer pipes. Doing these will reduce possible contamination of water during harvesting, conveyance and storage of rainwater.

Declarations

There is no financial or non-financial conflict of interest

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References

1. African Development Bank (2008) *Rainwater Harvesting Handbook: Assessment of best practices and experience in Water harvesting*. African Development Bank
2. Ahmed W, Gardner T, Toze S (2011) Microbiological quality of roof-harvested rainwater and health risks. *J Environ Qual* 40(1):13–21
3. Achadu OJ, Aku FE, Dalla CL (2013) Quality assessment of stored harvested rainwater In Wukari, North- Eastern Nigeria. *J Environ Sci Toxicol Food Technol (IOSR-JESTFT)* 7(5):25–32
4. Adeniy I, Olabanji I (2005) The physic-chemical and bacteriological quality of Rainwater collected over different roofing materials in Ile-Ife, South- western Nigeria. *Chem Ecol* 21(10):149–166
5. Chang M, McBroom MW, Beasley RS (2004) Roofing as a source of nonpoint water pollution. *J Environ Manage* 73(4):307–315
6. Christopher D (2009) Leidi, C., & Farahbakhsh, K. Assessment of rainwater quality from rainwater harvesting systems in Ontario, Canada
7. Curhan GC, Willett WC, Rimm EB, Stampfer MJ (1993) A prospective study of dietary calcium and other nutrients and the risk of symptomatic kidney stones. *N Engl J Med* 328(12):833–838. <https://doi.org/10.1056/NEJM199303253281203>

8. Duke K (2014) Ownership of rainwater and the legality of rainwater harvesting in British Columbia
9. Eldho T (2003) Rainwater Harvesting System in the urban environment, Jal Sangrah Shibir. A National seminar and workshop on rainwater harvesting, Proceeding in CD in form 6–7, Boombay
10. Environmental protection Agency (2018) Edition of the Drinking Water Standards and Health Advisory Tables
11. Farghaly A, El-Sawy AA (2014) Effect of drinking water iron overload on the liver of rats. Possible protective role of garlic extract. *Biol Trace Elem Res* 160(39):319–328
12. Farreny R, Morales-Pinzon T, Guisasola A, Taya C, Rieradevall J, Gabarrell X (2011) Roof selection for rainwater harvesting: Quantity and quality assessments in Spain. *Water*
13. Forster J (1996) Patterns of roof runoff contamination and their potential implications on practice and regulations of treatment and local infiltration. *Water Sci Technol* 33:39–48
14. Forster J (1998) The influence of location and season on the concentrations of macro-ions and organic trace pollutants in roof runoff. *Water Sci Technol* 38:83–90
15. Friedler E (2017) Quality of Roof-Harvested Rainwater as a Function of Environmental and Air Pollution Factors in a Coastal Mediterranean City, Haifa, Israel
16. Galaris D, Barbouti A, Pantopoulou K (2019) Iron homeostasis and oxidative stress: An intimate relationship. *Biochim et Biophys Acta (BBA) - Mol Cell Res* 1866(12):118535. <https://www.sciencedirect.com/science/article/pii/S016748891930148X>
17. Ghimire TR, Watanabe C, Shindo J, Ohgaki S (2003) Chronic health effects of ingesting arsenic-contaminated drinking water. A study of a population with relatively low exposures. *Environ Health Perspect* 111(5):657–662
18. Gonzalez A (2012) Study to analyze the viability of rainwater catchment from roofs for its reuse in Tegucigalpa, Honduras
19. Ghosh GC, Khan MJH, Chakraborty TK, Zaman S, Kabir AHME, Tanaka H (2020) Human health risk assessment of elevated and variable iron and manganese intake with arsenic-safe groundwater in Jashore. *Bangladesh Sci Rep* 10(1):5206. <https://doi.org/10.1038/s41598-020-62187-5>
20. Graudal NA, Hubeck-Graudal T, Jurgens G (2011) Effects of low sodium diet versus high sodium diet on blood pressure, renin, aldosterone, catecholamines, cholesterol and triglycerine. *The Cochrane database of systematic reviews*, (11) CD004022. <https://doi.org/10.1002/14651858.CD004022.pub3>
21. Kennedy DD (2002) Review of Mid-High Temperature Solar Selective Absorber Materials. National Renewable Energy Laboratory. US Department of Energy. Midwest Research Institute Battelle
22. Kloss C (2008) Managing wet weather through green infrastructure Municipal handbook: Rainwater harvesting. Washington, D.C, U.S EPA
23. Lye JD (2009) Rooftop runoff as a source of contamination: a review. *Sci Total Environ* 407(21):5429–5434
24. Massawe HJ (2016) Feasibility and Options. for Rainwater Harvesting at the University of Dodoma
25. Malcolm S (2017) Water Treatment In Rainwater Harvesting Systems For Portable Use

26. Mayo A, Mashauri D (1991) Rainwater harvesting for domestic use in Tanzania. A case study of University of Dar es salaam staff houses. *Water Int* 16(1):2–8
27. Meride Y, Ayenew B (2016) Drinking water quality assessment and its effects on residents' health in Wondo genet campus, Ethiopia. *Environ Syst Res* 1:5. <https://doi.org/10.1186/s40068-016-0053-6>
28. Mishra G, Rainwater Harvesting (2019) Retrieved on May from <https://theconstructor.org/water-resources/rainwater-harvesting/6739/>
29. Ministry of water and irrigation (2016) Guideline for Rain Water Harvesting in Tanzania
30. Mwakalila S (2007) Socio-economic impacts of water scarcity in Dar es salaam, Tanzania. *Tanzan J Eng Technol* 30(1):58–64
31. Neibaur EE, Anderson EP (2016) An examination of factors affecting sustainability of domestic rainwater harvesting systems in a rural, semi-arid region of Mexico. *Water supply* 16:1388–1397
32. Pathak N, Heijnen H (2005) Rainwater Harvesting and Health Aspects-Working on WHO Guidance. *University of Hawaii: Honolulu, HI, USA*
33. Radaideh J, Al-Zboon K, Al-Harashsheh A, Al-Adamat R (2009) Quality assessment of harvested rainwater for domestic uses in Jordan. *J Earth Environ Sci* 2(1):27–31
34. Rahman S, Khan MT, Akib S, Din NB, Biswas SK, Shirazi SM (2014) Sustainability of Rainwater Harvesting System In Terms Of Water Quality. *The Scientific World Journal*, 2014, 721357. <https://doi.org/10.1155/2014/721357>
35. Sarma AK, Giraud G, Baishya MD (2006) *Rainwater Harvesting for Urban Flood Peak Reduction*, My Green Earth-a *Journal of Society for Socio Economic Awareness and Environment Protection*, SSEAEP, 3(2), 2491–2494
36. Scott R, Waller D (1987) Water quality analysis of a rainwater cistern system in Nova Scotia
37. South Pacific Applied Geoscience Commission (2004) Guidelines For Rainwater Harvesting in Pacific Island Countries. *Harvesting the Heavens*
38. Spinks A, Coombes P, Dunstan HH, Kuczera G (2003). Water Quality Treatment Processes in Domestic Rainwater Harvesting Systems. *28th International Hydrology and Water Resources Symposium*, 2, 227–234
39. Sule T, Agbabiaka A, Akomolafe V (2011) Bacteriological Quality of Water Stored Exteriorly In Storage Tanks
40. Sustainable Earth technologies, Inc (1999) Rainwater Harvesting Retrieved April 2019 from www.sustainable.com.au/rainwater.html
41. Ubuoh EA, Ikwa LO, Ogbuji SI (2016) Quality determination of Harvested Rainwater in Selected Storage tanks in Oweri, South Eastern Nigeria. *Int J Environ Chem Ecotoxicol Res* 1(3):11–19
42. White KH, Soward RL, Shankle G (2004) Harvesting Storing and Treating Rainwater for Domestic Indoors use. Texas Commission on Environmental Quality
43. WHO (1997) Guidelines for drinking water quality Second edition Vol 3 surveillance and control of community supplies

44. WHO (2004) Guidelines for drinking water quality Third edition Vol 1 Recommendations
45. WHO (1997) Guidelines for drinking water quality Second edition Vol 3 surveillance and control of community supplies
46. Zhu Q, Gould J, Li Y, Ma C (2015) Rainwater harvesting for agriculture and water supply. Science, Beijing, China, pp 3–43

Figures

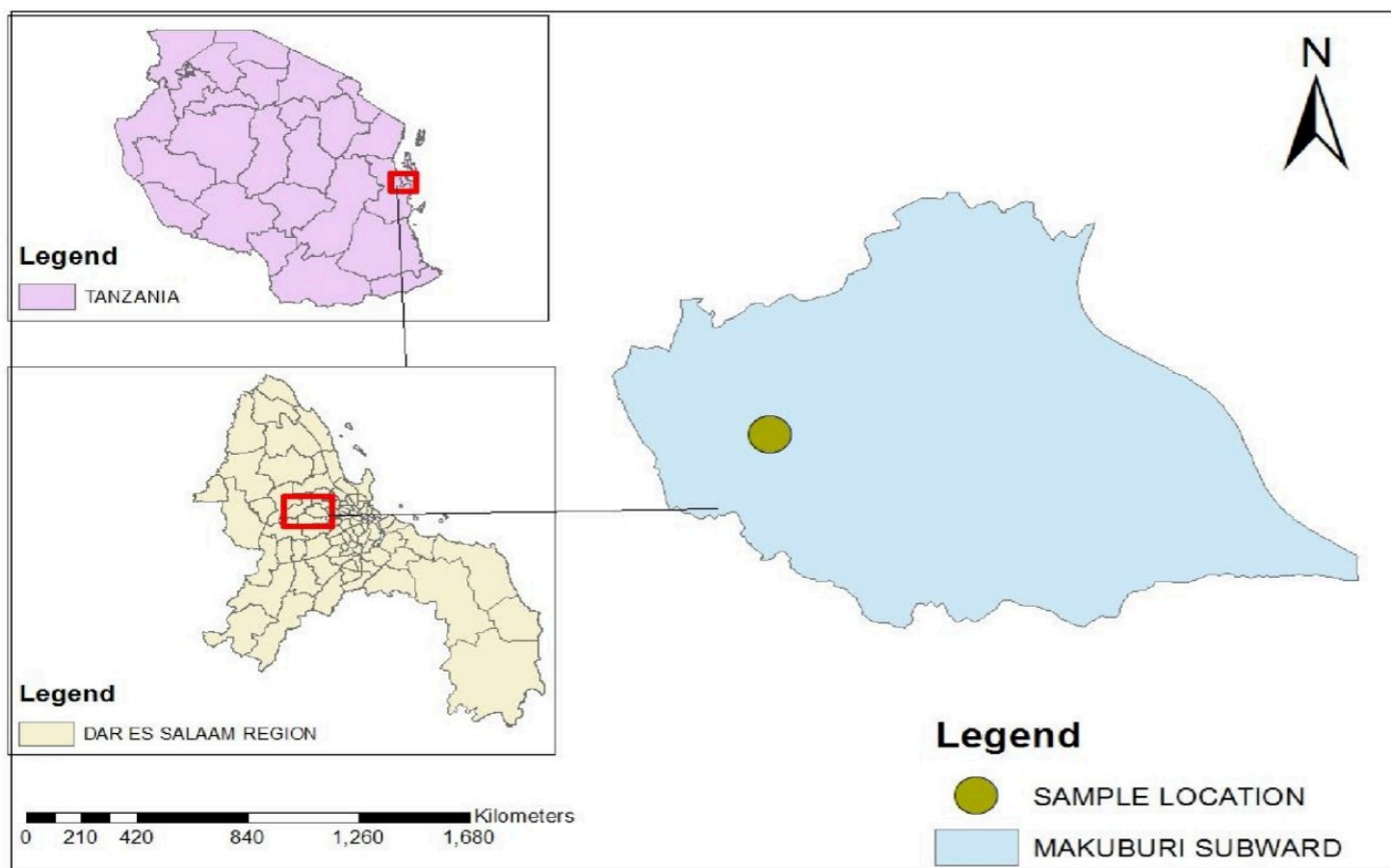


Figure 1

Map of the study area showing Makoka sub ward in Makuburi

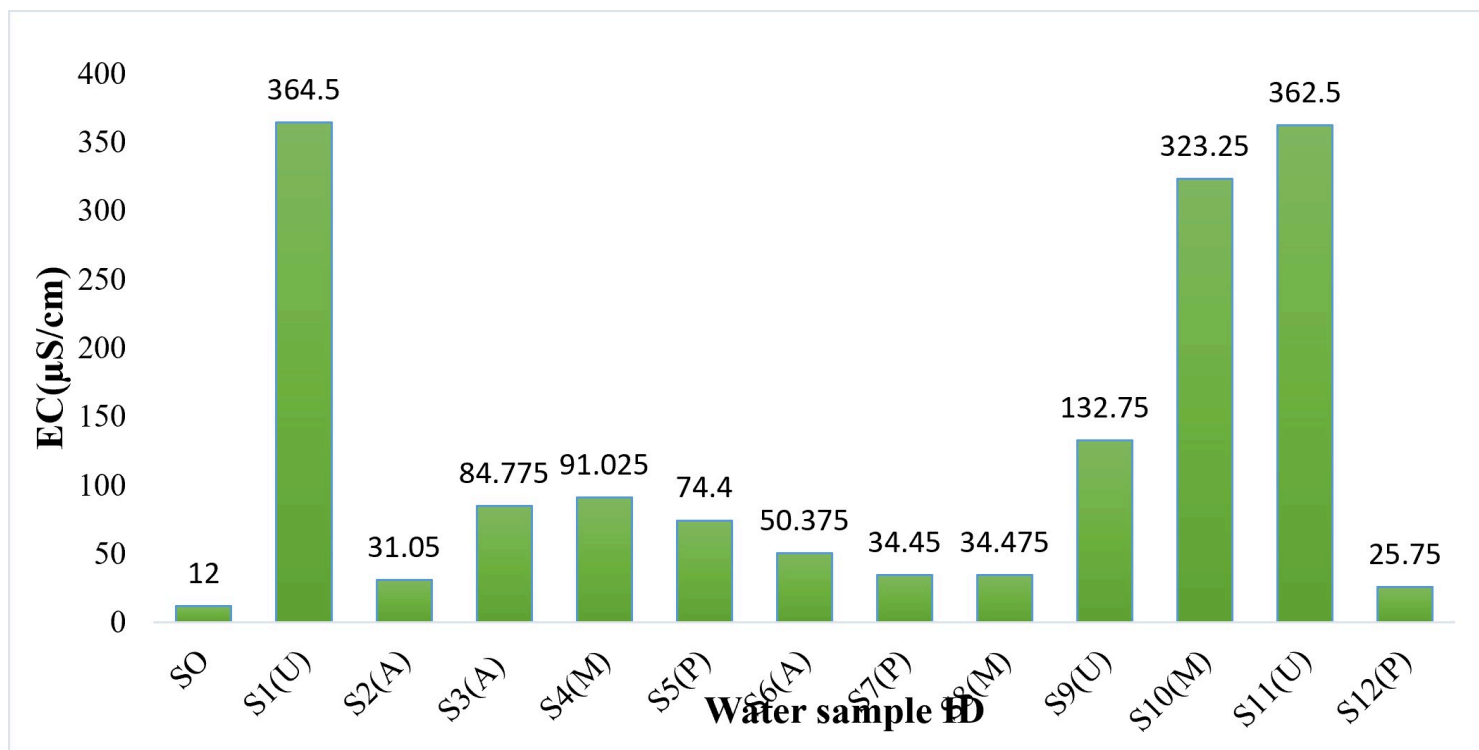


Figure 2

EC values for stored harvested rainwater

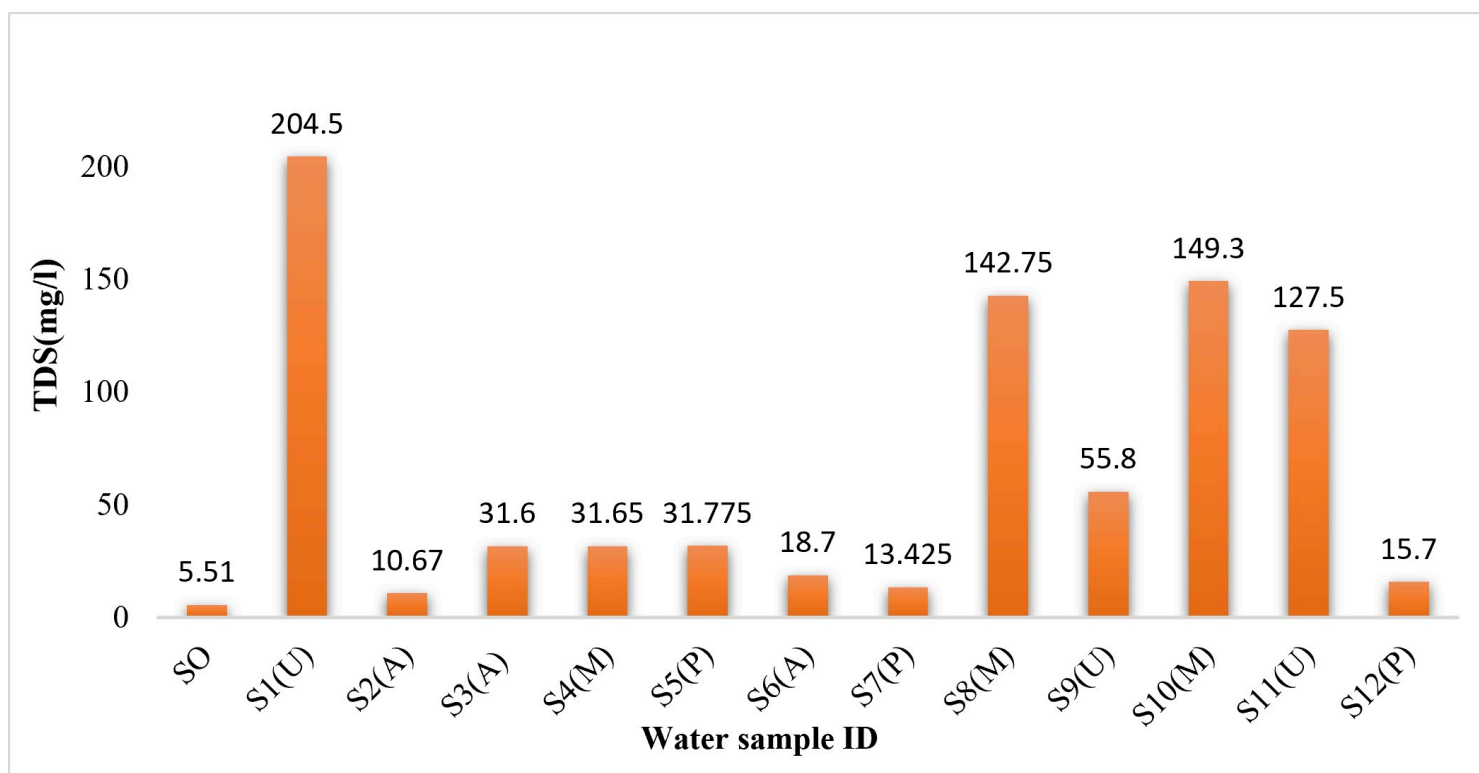


Figure 3

TDS values for stored harvested rainwater

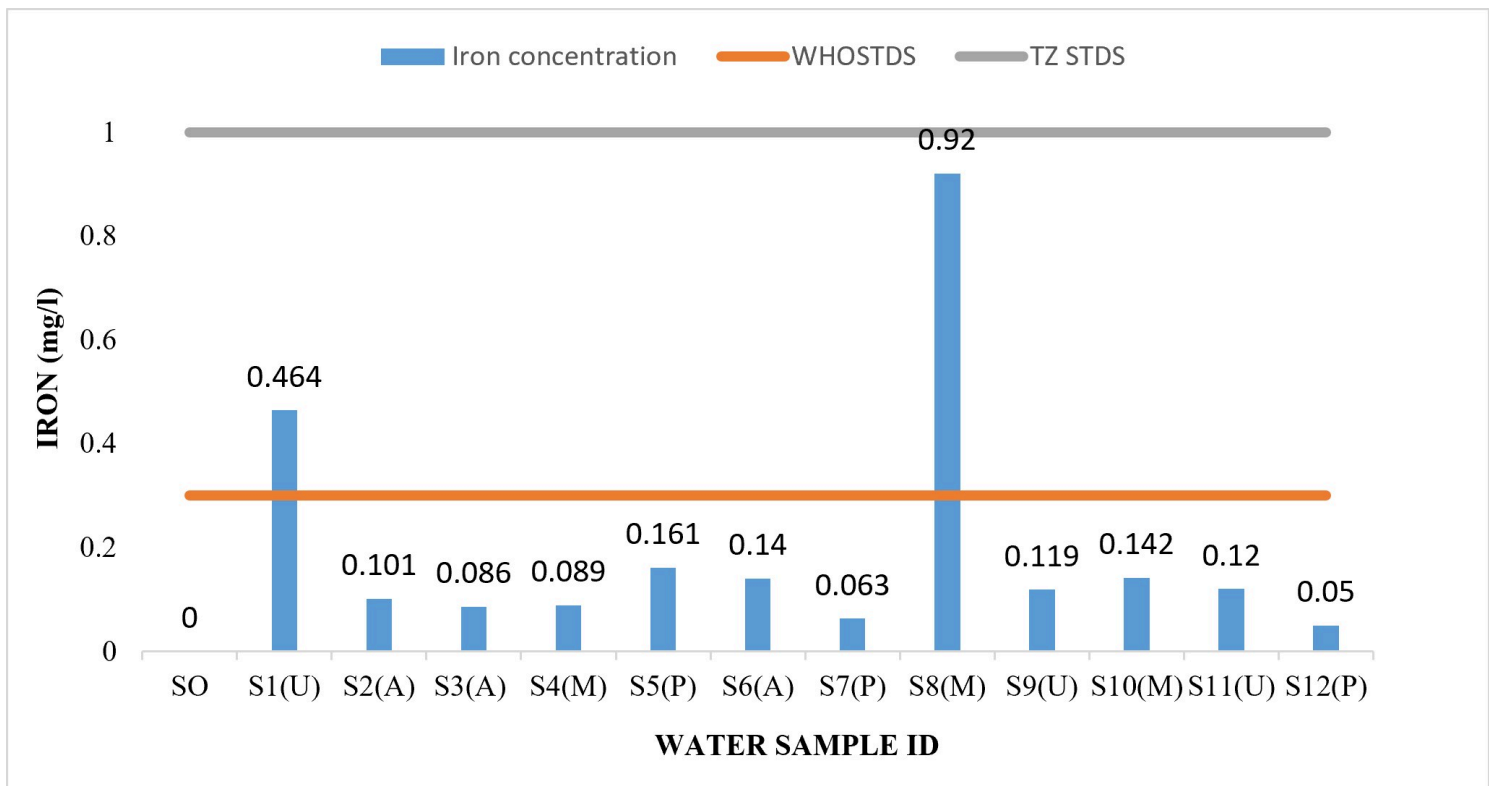


Figure 4

Iron concentration values for stored harvested rainwater

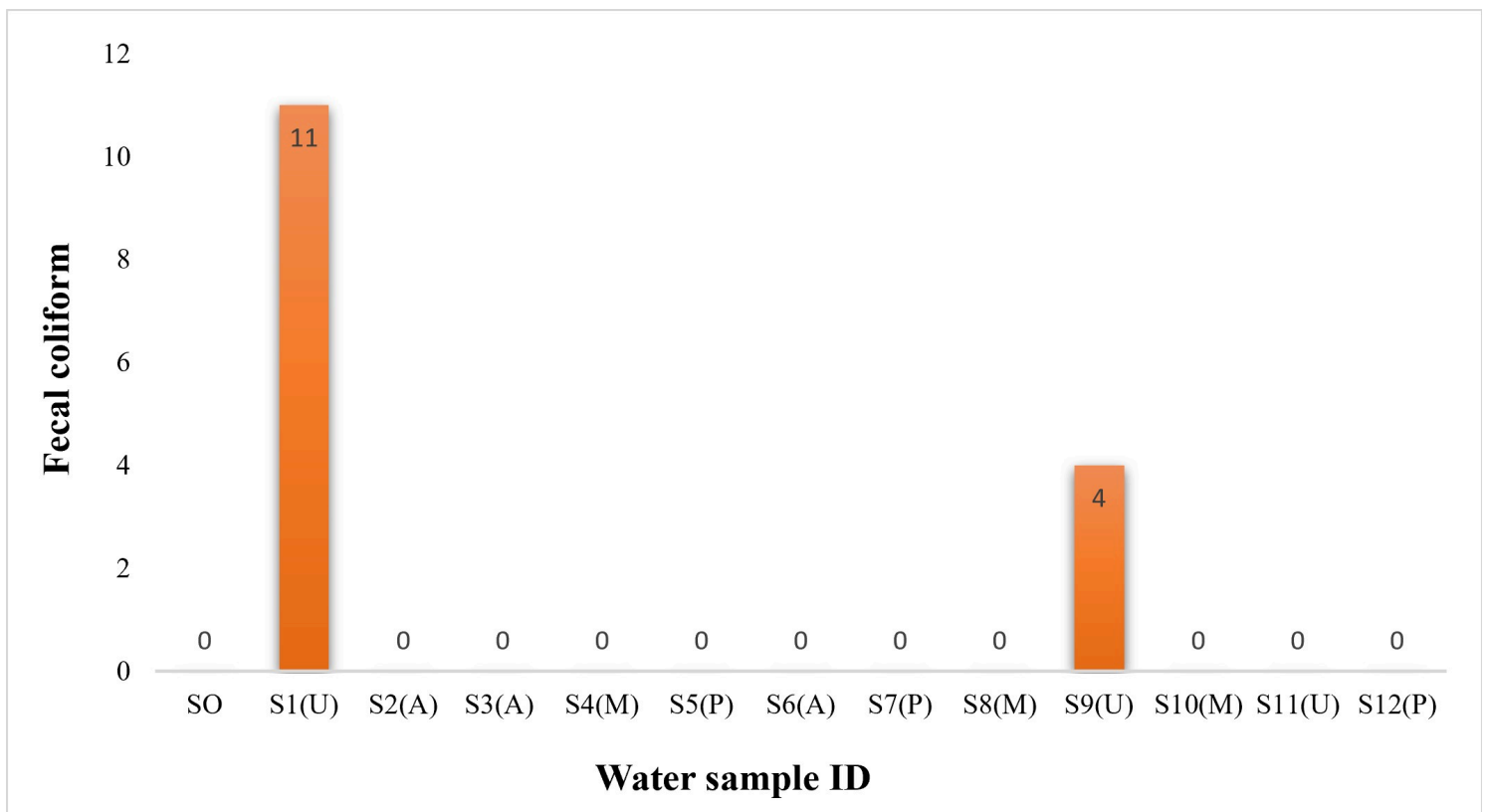


Figure 5

Fecal coliform values for stored harvested rainwater