Physicochemical Characteristics and Heavy Metal Levels in Groundwater from Selected Areas of Dar Es Salaam City, Tanzania

Addo Ndimbo[1], Stephen Mbuligwe[1], Julius Mbuna[2]
[1]Ardhi University
[2]University of Dar es Salaam
[2]*Corresponding author: email address-julius.mbuna@duce.ac.tz*

Abstract
Groundwater in Temeke and Ilala areas within Dar es Salaam city was analysed for physicochemical characteristics and heavy metal levels to assess its quality as potable water. Random sampling was used to obtain groundwater samples from three sampling sites, namely, residential areas, near petrol stations and dumping sites. Temperature, pH, and electrical conductivity (EC) were measured on-site by a water quality multimeter while heavy metals levels were determined by standard methods using Atomic Absorption Spectroscopy (AAS). Measurement of pH (pH 5.2-7.3) showed that groundwater largely satisfied TBS and WHO standards. Similarly, EC values of groundwater (256.5-5286 µScm-1) largely met TBS specifications while only 33% of groundwater complied with the WHO guidelines. Cd in groundwater from the three sampling sites (0.01-0.50 mgL-1) exceeded TBS and WHO standards. Pb in 89-94% of groundwater collected near petrol stations (0.01-1.10 mgL-1), 80% of groundwater from dumping site (0.01-1.22 mgL-1), and 25%-70% of groundwater from residential areas (0.01-0.65 mgL-1) exceeded the TBS and WHO standards. Cr concentration in 50-66% of groundwater samples collected near petrol stations (0.01-1.1 mgL-1) and 20-42% of groundwater from residential areas (0.01-0.45 mgL-1) exceeded TBS and WHO standards on total Cr. Levels of Cu (0.01-1.70 mgL-1) and Zn (0.01-1.82 mgL-1) were largely within the TBS and WHO standards. Groundwater in the study area is contaminated with non-permissible levels of Cd, Pb and Cr, which makes it unsuitable for human consumption and hence likely to affect public health.

Keywords: *Groundwater, Heavy metal, Physicochemical characteristics, TBS, WHO*

INTRODUCTION

Tanzania depends on both surface and groundwater to meet water demands for its population. Dar es Salaam city, like other metropolis in Tanzania, does not fully meet its water demands partly due to overreliance on surface water sources distributed by the infrastructure-challenged system and ever-rising demand due to rural-urban migration. Water demand for Dar es salaam city with a population of over five million (National Bureau of Statistics, 2018), is estimated at 195.24 million m3/year equivalent to 545,000 m3/day (United Republic of Tanzania, 2017). The actual water supply by the water authority, without considering water loss, is approximately 488,000 m3day-1 (United Republic of Tanzania, 2017) of which 58,000 m3day-1 is groundwater.

According to United Nations (2019) city's population is projected to grow close to 10 million by the year 2030, creating a water demand estimated at 12,000,000 m3day-1. To meet the existing and future demand, groundwater will be increasingly exploited since it is more reliable, resilient to climate change (Lapworth et al., 2013) and closer to consumers. From the aforementioned, it is necessary to monitor the quality of groundwater supplied to city residents in order to protect public health.

Groundwater is affected by geology and geochemistry of the area, climate change and anthropogenic activities including urbanization, industrialization, and landfilling (Brindha and Elango, 2013; Hailu et al., 2017). Several studies (Gonzalez et al., 2012; Balderacchi et al., 2013; Kuroda, et al., 2012) have shown that groundwater contamination is a serious environmental issue and heavy metals should receive particular attention due to bioaccumulation, biomagnification and high toxicity at low concentrations (Mucheweti et al., 2006). While some heavy metals including Fe, Cu, Zn, Ni are essential for proper functioning of biological systems at certain concentrations, exposure to elevated concentrations causes adverse effects on living systems and the environment (Liu et al., 2013). Adverse effects of heavy metals such as Cr, Mn, Fe, Ni, Cu, Zn, As, Al, Cd, Hg and Pb on the environment and living systems including human beings have been well documented (Cambra et al., 1999; Flynn and Haslem, 1995; Hutton and Symon, 1986; Khan et al., 2009; Kisamo, 2003; US EPA; 1983, 1986; Koller et al., 2004; Jomova and Valko, 2010; Borowska and Brzóska 2015). Briefly, adverse effects cover a broad spectrum from short-term exposure leading to dizziness, and irritation to

skin and nose to long-term conditions including cancer, kidney failure and brain damage in children.

The presence of heavy metals in water is widespread in many cities. Mor et al. (2006) showed that dumping sites and automobile garages are considered as some of the largest contributors to heavy metals. Dumping sites are known to introduce inorganic and organic chemical species which ultimately affect the aquatic environment and species which live in such environments (Mushtakova et al., 2005). According to Mato (2003) main sources of groundwater pollution in Dar es Salaam include domestic sewage, industrial effluents, petroleum products dispensing units and solid waste dumping sites. Based on work by Kazuva and Zhang (2019), the city's solid waste generation rate is 0.80 kg/capita/day for a population of 5 million residents (National Bureau of Statistics, 2018). Breeze (2012) estimated only 40% of the solid waste generated in the city is disposed-off, mainly at the Pugu dumping site. The area under study also hosts active urban farming, which may contaminate soil and water sources through inappropriate application of pesticides and the use of poultry manure (Howorth et al., 2001, Ravindran et al., 2017). In addition, the area hosts various industries processing food, textile and plastics (occupying 22% of the total area) which a exert negative impact on the environment.

Most of the groundwater in Dar es Salaam comes from boreholes and wells situated in residential, and commercial premises like petrol stations, industrial or institutional areas, where the ongoing anthropogenic activities are likely to affect water quality. Previous works on groundwater by Nkotagu (1996), Kassenga and Mbuligwe (2009), and Napacho and Manyere (2010) have been confined to biological, pathogenic, and physicochemical (anionic composition) water quality parameters. This work, therefore, reports on heavy metal levels, and some physicochemical characteristics which may influence heavy metals in groundwater. It further compares the metal levels and parameters against TBS and WHO standards to the assess potability of groundwater.

MATERIALS AND METHODS

Study Area

Study area covered the southern and south Eastern parts of Dar es Salaam city, where the two districts, Temeke (-6o52’8.40 S; 39o15’39.60’’E) and Ilala (-6o49’26.40’’S; 39o14’56.40’’E) are located (Figure 1(a)). The

population in the study area, which is approximately 1.4 million residents (National Bureau of Statistics, 2018) is largely dependent on groundwater supply from boreholes and wells owned by DAWASA, a parastatal water supply company (2200 boreholes) and private individuals (1800 wells).

The study area covered several wards including Kurasini and Chang'ombe in Temeke District, and Kisutu, Gerezani, Buguruni, Tabata, Vingunguti, Kipawa, Kitunda, Kiwalani, Ukonga, Segerea and Pugu wards in Ilala District. More wards in Ilala District are covered in this study because it hosts many petrol stations and dumping sites as compared to Temeke District which is mainly a residential area. Tabata dumping site in Tabata ward is a defunct municipal dumping site, which is currently populated with heavy and light engineering service garages. Pugu Kinyamwezi in Pugu ward is an active dumping site for solid waste in the city, which is located 30 km from the city centre.

Sampling and On-site Measurements

In this work, the study area (Figure 1 a) was divided into three main sampling sites: residential areas, areas near petrol stations and areas near solid waste dumping sites. Water samples were collected from a total of 54 randomly selected sampling points; 21, 18 and 15 from residential areas, near petrol stations and dumping sites, respectively. Global Positioning System receiver (Garmin GPS76CS) was used to ensure samples were collected at exactly the same location during dry and rainy seasons.

As shown in Figure 1b, Kurasini and Chang'ombe areas in Temeke District were sampled for water from residential areas (S11, S16- S21) and a few points in areas near petrol stations (PS1, PS2). Buguruni, Gerezani, Vingunguti, Kipawa, Kitunda, Kiwalani, Segerea, Ukonga and Pugu wards provided most of the samples of groundwater from both residential (S1-S15) and petrol stations (PS3-P18).

Six sampling points (D1-D6) from Tabata dumping site (Figure 1c(i)) in Tabata ward and nine sampling points (D7-D15) from Pugu Kinyamwezi dumping site ((Figure 1c(ii)) in Pugu ward provided groundwater from dumping sites. Table 1 shows GPS locations of sampling points in the three sampling sites.

Water was pumped out of boreholes or wells for ten minutes and sample collected in plastic bottles, which had been previously been soaked overnight in 10% HCl and rinsed with milliQ water. The collected samples (500 mL each) were labeled (location, date, time, source) and physicochemical parameters likely to influence metal ion composition i.e. temperature, pH and electrical conductivity (EC) were measured on site using water quality multimeter (Hach Sension 156). Four measurements were taken for each parameter at each sampling point and mean values were calculated.

The water samples were thereafter stored in cold boxes and transported to the Environmental Engineering Laboratory at Ardhi University for metal ion analysis. Samples were collected during the rainy season from March to May (long rains) and October to December (short rains), and during the dry season from January-March and June-October.

Reagents

Hydrochloric acid (ACS reagent 37%) and nitric acid (ACS reagent 70%) were purchased from Sigma Aldrich (St. Louis, MO, USA). All aqueous solutions were prepared in pure 18-MΩ MilliQ water (Millipore SA, Molsheim France), while acetylene and oxygen gas were bought from Tanzania Oxygen Company (Tanzania). Metal standards (1000 ppm) for Cd, Pb, Cr, Cu and Zn were purchased from Hach (Loveland, CO, USA).

Heavy Metals Analysis

Water samples for heavy metals analysis were filtered (Whatman No. 4 filter paper) and preserved with concentrated HNO3 (0.5 mL) to make 500 mL water sample solution. Heavy metal analysis was carried out by Perkin Elmer® Analyst 100 Atomic Absorption Spectrophotometer (AAS), fitted with HGA 850 Graphite Furnace (Perkin Elmer® Germany) and AS 800 Auto-sampler (Perkin Elmer® Germany). For all measurements, a slot burner head (10 cm long), a standard air-acetylene flame and 0.7 nm slit were used. Elements were measured at 228.8 nm, 357.9 nm, 324.8 nm, 283.3 nm and 213.9 nm for Cd, Cr, Cu, Pb and Zn, respectively. Blank sample (500 mL solution containing 0.5 mL concentrated HNO3 acid) was prepared by MilliQ water. Blank and water samples were analyzed directly without any further treatment.

Working standards were prepared by diluting respective metal stock solutions to a lower concentration range (0-10 mgL-1) and the response measured. The calibration curve for each metal was prepared after correcting for blank sample reading. Water samples were finally measured, corrected for blank and concentration established. Four readings were made for each sample.

Quality Control

Sample contamination was controlled during sample collection through rinsing of sample containers (plastic bottles) with the actual sample and transporting the sample in a clean cool box. In order to control contamination of samples during analysis, the samples were directly aspirated from 50 mL beaker, which had been washed by detergent and soaked overnight in a solution containing dil HNO3 acid.

Reliability of results obtained in this work was assured by calculating accuracy and precision. Samples were spiked and recovery test for each metal was done by determining its concentration in a sample before and after adding a known amount of analyte using the equation:

$$\% \text{ Recovery} = \frac{C_a - C_b}{C_s} \times 100$$

where

C_a is the concentration after adding the standard,

C_b is the concentration before adding a standard, C_s is the concentration of the standard added

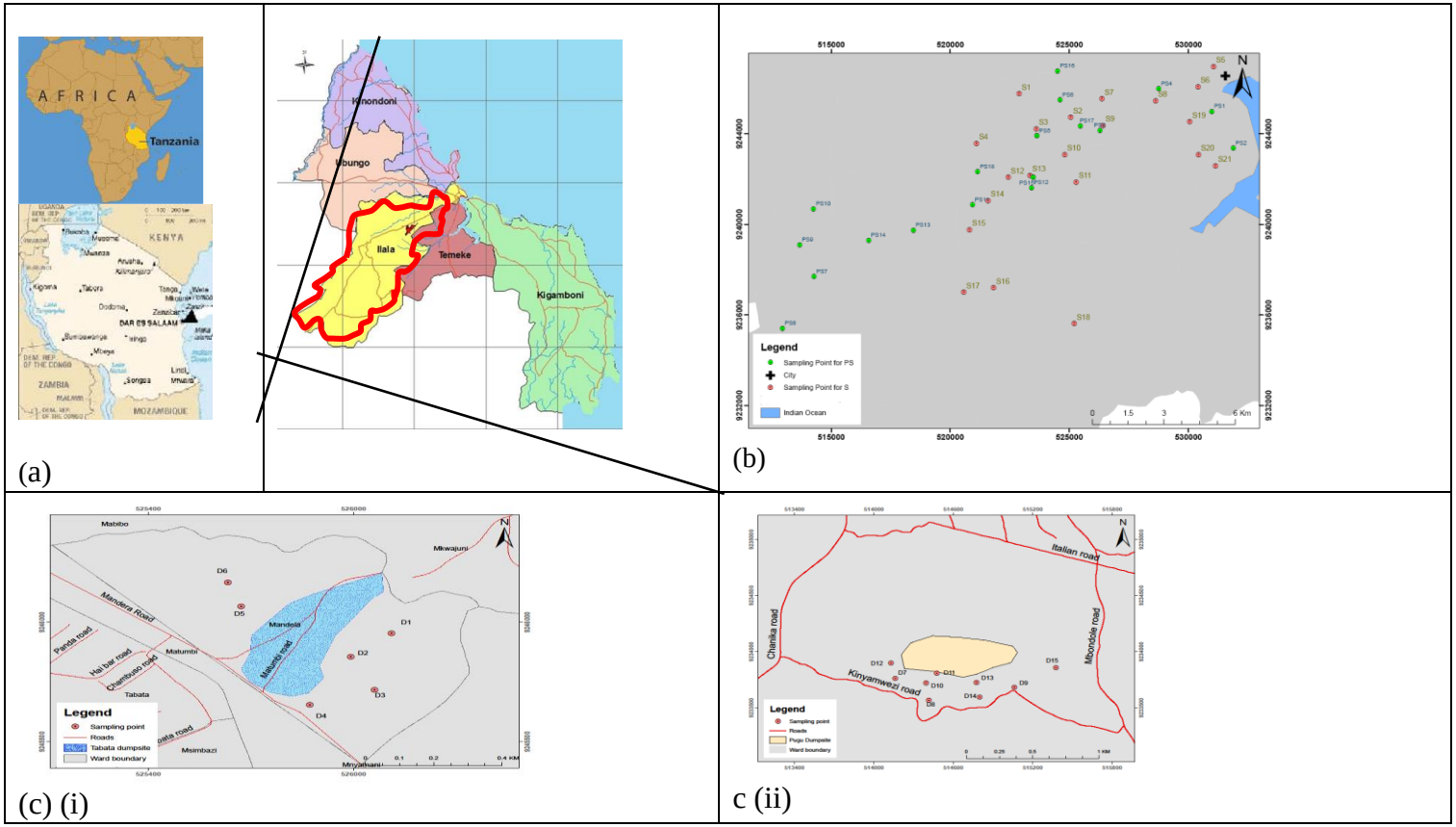

Figure 1: Study area and Sampling sites for groundwater: (a) Study area: parts of Ilala and of Temeke Districts (b) Residential areas and areas near petrol stations (c) (i) Defunct Municipal dumping site at Tabata area (ii) Active municipal dumping site at Pugu area

Table 1: Location of the Sampling Points

Near Petrol Stations			**Near Dumping sites**			**Residential areas**		
Sampling point	Easting	Northing	Sampling point	Easting	Northing	Sampling point	Easting	Northing
PS1	530975.88	9244984.60	D1	0525982	9245589	S1	522893.28	9245769.2
PS2	531877.78	9243361.20	D2	526112	9245915	S2	525052.23	9244729.5
PS3	526286.04	9244142.84	D3	525934	9245762	S3	523614.13	9244226.9
PS4	528751.21	9245986.70	D4	525790	9245723	S4	521102.4	9243576.9
PS5	519231.24	9241517.33	D5	0525690	9245950	S5	531049.61	9246964.7
PS6	522297.67	9250175.67	D6	0525672	9245991	S6	530404.54	9246080.8
PS7	514280.86	9237689.30	D7	513745	9233868	S7	526371.18	9245548.7
PS8	512958.082	9235404.501	D8	514353	9233669	S8	528617.85	9245455.4
PS9	513679.603	9239092.243	D9	514568	9233685	S9	526407.43	9244369.6
PS10	514260.810	9240675.561	D10	514276	9233840	S10	524804.69	9243080.8
PS11	520936	9240858	D11	514395	9233910	S11	525284.75	9241873.9
PS12	523477	9242085	D12	513725	9234051	S12	522433.17	9242073
PS13	518449	9239733	D13	514372	9244582	S13	523341.41	9242163.3
PS14	516573	9239290	D14	514973	923688	S14	521589.74	9241052
PS15	523477	9242085	D15	515040	9233688	S15	520809.21	9239771.2
PS16	524506	9246769				S16	521819.06	9237205.2
PS 17	525500	9244258				S17	520567.28	9237003.5
PS18	521125	9242451				S18	525200	9235619.7
						S19	530051.6	9244536
						S20	530416.5	9243082
						S21	531137.7	9242584

Four measurements were made for each metal and standard deviations were obtained to show precision of the method. As summarized in Table 2, percent recovery, precision and LoD for the heavy metals analysed are within acceptable limits.

Table 2: Recovery of heavy metals in groundwater

Metal	**% Recovery**	**LoD/ 10^{-4} mgL^{-1}**
Cd	96±1.1	5.50
Pb	99±1.3	5.49
Cr	97±1.2	5.48
Cu	107±2.8	5.49
Zn	102±2.4	5.48

To ensure consistency in measurement, blank sample was measured after 20 runs to maintain quality of results.

Statistical Analysis

Paired *t* test was used to determine whether there was a significant difference in seasonal (dry/rainy seasons) data in all measurements made. Principal Component Analysis (PCA) was applied for the analysis of experimental data to establish whether variables measured showed any correlation and to reduce the dimensionality of data collected on temperature, pH, electrical conductivity and heavy metal levels (Cd, Pb, Cr, Cu, Zn). PCA was carried out by Statistical Package for the Social Sciences, IBM SPSS Statistics software, version 28.0.0.0 (190).

RESULTS AND DISCUSSION

Physicochemical Characteristics

The measured physicochemical parameters in groundwater for the three sampling sites i.e. residential areas, near petrol stations and dumping sites are shown in Tables 3 a – c.

Temperature

As shown in Tables 3 a-c, the temperature of groundwater varied from 25.0oC to 32.1oC in the dry season and 25.5oC to 32.1oC in the rainy season. Generally, slightly higher temperatures were recorded in the rainy season than during the dry season for several sampling points. However, a paired t-test at p= 0.05 (two tailed) did not show significant difference in temperature measured between dry and rainy season since texp < tcrit: Petrol stations (student texp = 0.208, tcrit = 2.110, df = 17); dumping site (student texp = 0.304, tcrit = 2.145, df = 14); Residential areas (student texp = 0.625, tcrit = 2.086, df = 20).

Based on mean temperature, groundwater temperature was slightly lower in petrol stations (Table 3 a) than either dumping sites (Table 3 b) or residential areas (Table 3c), which showed similar temperatures. This may indicate that water from dumping sites and residential areas may exhibit slightly different physicochemical and biological characteristics such as electrical conductivity and ability to support microorganism growth (UNICEF, 2008).

Comparatively, Adekunle et al. (2020) reported a narrower temperature range in dry season (25.83 ±3.03 °C to 28.02 ± 0.79 °C) and rainy season (27.19 ± 0.00 °C to 28.93 ± 1.30 °C) for groundwater from Osun State, Nigeria. An equally narrow temperature range was

Table 3: Physicochemical parameters in groundwater

(a) Near petrol stations

Sampling point	Temperature (ºC)		pH		Electrical Conductivity (µScm^{-1})	
	Dry	Rainy	Dry	Rainy	Dry	Rainy
PS 1	28.0±0.2	29.8±0.3	6.2±0.3	6.9±0.4	1846.0±3	1885.0±7
PS 2	31.0±0.1	30.4±0.8	7.0±0.1	7.0±0.1	1360.0±14	1350.0±14
PS 3	30.0±0.5	28.5±1.0	6.0±0.1	6.0±0.3	1387.5±2	1394.5±6
PS 4	30.0±0.3	30.0±0.8	6.4±0.2	6.7±0.3	1344.0±5	1444.0±8
PS 5	30.0±0.8	31.0±0.3	6.7±0.1	6.8±0.4	1823.0±4	1816.0±4
PS 6	31.0±0.4	30.6±0.2	6.1±0.1	6.4±0.2	1599.0±12	1529.0±8
PS 7	27.6±0.2	27.9±0.3	6.2±0.1	6.5±0.4	2490.0±23	2400.0±23
PS 8	26.7±0.4	26.5±0.2	6.4±0.2	6.2±0.6	1855.0±21	1833.0±14
PS 9	29.9±0.3	29.3±0.2	6.0±0.1	6.0±0.1	1223.5±23	1247.5±3
PS 10	28.6±0.2	28.9±0.1	5.9±0.3	5.9±0.3	1276.0±19	1285.0±7
PS 11	29.0±0.3	28.5±0.2	6.2±0.1	6.2±0.2	1262.0±23	1260.0±19
PS 12	32.0±0.2	32.1±0.1	6.0±0.2	6.7±0.3	568.0±24	568.0±24
PS 13	26.0±0.1	25.8±0.2	6.2±0.1	6.5±0.2	735.5±14	779.5±14
PS 14	25.0±0.7	28.5±0.2	6.0±0.2	6.0±0.4	972.0±22	974.5±22
PS 15	28.0±0.2	29.8±0.1	7.2±0.3	7.0±0.1	1000.5±17	1009.5±18
PS 16	25.0±0.7	25.5±0.7	6.3±0.1	6.9±0.1	1978.5±19	1962.5±21
PS 17	27.0±0.1	27.5±0.2	6.2±0.1	6.9±0.1	1492.0±14	1482.0±19
PS 18	29.0±0.1	29.5±0.3	6.3±0.1	7.0±0.1	1115.0±16	1115.0±16
Mean	28.5±1.6	28.8±1.8	6.3±0.6	6.5±0.7	1407.0±48	1407.5±48
%Compliance	-	-	TBS- 100 WHO 17	TBS - 100 WHO - 55	TBS - 100 WHO - 17	TBS - 100 WHO - 17

(b) Near Dumping sites

Sampling point	Temperature (ºC)		pH		Electrical Conductivity (µScm^{-1})	
	Dry	Rainy	Dry	Rainy	Dry	Rainy
D 1	30.6±0.2	30.1±0.1	7.0±0.6	7.3±0.4	256.5±23	256.5±23
D 2	30.6±0.1	31.6±0.7	6.4±0.1	6.8±0.2	2372.0±9	2385.0±7
D 3	27.0±0.2	27.8±0.4	5.3±0.2	5.7±0.5	1864.0±11	1846.0±10
D 4	30.0±0.1	30.0±0.1	6.5±0.1	6.1±0.1	1249.0±8	1243.0±9
D 5	32.1±0.7	30.0±0.2	6.8±0.1	6.9±0.2	1286.0±12	1291.0±12
D 6	31.8±0.2	30.8±0.1	6.4±0.1	6.5±0.2	1256.0±7	1240.0±8
D 7	28.9±0.4	28.9±0.2	6.4±0.2	6.4±0.1	687.0±12	687.0±11
D 8	28.8±0.1	28.8±0.1	6.2±0.1	6.5±0.2	1444.0±13	1438.0±12
D 9	30.4±0.2	29.4±0.3	7.0±0.6	7.0±0.1	1023.0±10	1038.5±8
D 10	27.9±0.4	27.9±0.1	6.6±0.2	6.4±0.2	2464±21	2470±28
D 11	26.9±1.3	26.9±1.0	6.8±0.1	6.5±0.1	568.0±7	558.0±5
D 12	29.0±0.2	27.5±0.2	6.6±0.2	6.5±0.2	777.0±9	769.0±9
D 13	28.0±0.1	28.5±0.1	6.3±0.1	6.8±0.2	977.0±11	949.0±7
D 14	30.0±0.1	29.0±0.2	6.2±0.1	6.8±0.1	1923.0±11	1927.5±11
D 15	30.5±0.2	31.5±0.2	6.3±0.1	6.2±0.1	1496.0±13	1496.5±6
Mean	29.5±1.6	29.2±1.3	6.4±0.9	6.6±0.9	1309.5±49	1306±49
% Compliance	-	-	TBS - 93 WHO - 47	TBS - 100 WHO - 67	TBS - 100 WHO - 33	TBS - 100 WHO - 33

(c) Residential areas

Sampling point	Temperature (ºC)		pH		Electrical Conductivity (μScm^{-1})	
	Dry	Rainy	Dry	Rainy	Dry	Rainy
S1	29.0±0.3	28.4±0.3	6.2±0.1	6.8±0.2	1645.0±6	1629.5±14
S 2	30.0±0.1	29.6±0.4	6.7±0.1	6.3±0.1	1178.0±4	1174.0±9
S 3	32.0±1.0	30.1±0.5	5.2±0.2	5.9±0.2	5286.0±19	5270.5±18
S 4	31.4±0.3	29.3±0.4	5.2±0.2	5.5±0.2	1845.0±11	1865.5±8
S 5	29.0±0.2	28.4±0.2	6.3±0.1	6.9±0.3	1669.0±9	1666.5±11
S 6	31.0±0.4	31.1±0.2	6.3±0.2	6.8±0.2	1056.0±12	1048.5±7
S 7	25.6±0.4	25.6±0.7	6.4±0.1	6.7±0.2	790.0±14	783.0±9
S 8	32.0±0.9	28.0±0.4	6.1±0.1	6.3±0.2	1023.0±8	1033.0±7
S 9	29.0±0.3	29.6±0.1	6.2±0.1	6.4±0.2	1056.0±8	1098.5±12
S 10	29.0±0.2	29.6±0.2	6.3±0.3	6.0±0.1	1169.0±11	1189.0±13
S 11	30.0±0.2	30.4±0.4	5.2±0.2	5.6±0.1	1670.0±13	1660.0±9
S 12	30.0±0.1	30.2±0.2	6.2±0.3	6.6±0.1	1467.0±12	1400.5±8
S 13	28.0±0.3	28.4±0.1	6.8±0.1	7.1±0.4	1156.5±10	1168.5±11
S 14	27.0±0.2	29.6±0.3	6.2±0.2	6.1±0.1	681.0±7	681.5±12
S 15	28.0±0.3	28.8±0.4	6.1±0.1	6.3±0.2	1278.0±9	1178.5±10
S 16	29.0±0.1	29.8±0.2	6.0±0.1	6.2±0.1	387.0±5	397.0±5
S 17	31.0±0.2	30.6±0.1	6.1±0.2	6.5±0.2	376.0±6	363.5±11
S 18	29.0±0.3	31.4±0.6	6.7±0.1	6.1±0.1	295.0±23	295.5±18
S 19	25.3±0.2	29.3±0.3	6.2±0.1	6.6±0.2	2856.0±11	2895.0±13
S 20	30.0±0.3	30.8±0.4	6.3±0.2	6.5±0.2	987.0±7	982.0±7
S 21	30.0±0.1	30.1±0.1	6.7±0.4	6.0±0.1	377.0±8	390.0±4
Mean	29.1±1.3	29.4±1.3	6.2±0.8	6.3±0.8	1118.8±45	1116.4±42
% Compliance	-	-	TBS- 86 WHO-19	TBS- 100 WHO-43	TBS -91 WHO - 33	TBS - 91 WHO - 33

reported by Vunain et al. (2019) [25.4 to 28.5oC] and Owamah (2020) [25.4 to 27.9oC] on groundwater from Malawi and Niger Delta in Nigeria, respectively. However, a wider temperature range (23.4 to 32.7oC) was reported by Sheikh et al. (2018) on groundwater in Zanzibar island. The influence of ambient temperature on groundwater temperature may explain the variation of temperature in groundwater.

Groundwater pH

Results (Tables 3 a-c) generally show that groundwater is slightly more acidic in dry season than rainy season, probably due to more dissolved solids in the dry season. However, a paired t-test at p= 0.05 (two tailed) did not show significant difference in pH measured between dry and rainy seasons since texp < tcrit: Petrol stations (student texp = 0.006, tcrit = 2.110, df = 17); Dumping sites (student texp = 0.192, tcrit = 2.145, df = 14); Residential areas (student texp = 0.045, tcrit = 2.086, df = 20).

The pH of groundwater analysed in this work, which ranged from pH 5.2±0.2 to 7.2±0.3 in dry season and pH 5.5±0.3 to 7.3±0.4 in wet season largely satisfied TBS (2018) specifications. (pH range 5.5-9.5). However, the pH of several samples (PS 6-PS14; D13-D15, S3-S12), lie below the lower limit of WHO (2017) guidelines (pH range 6.5-8.5). The pH range in groundwater from Osun Nigeria, reported by Adekunle et al. (2020) in dry season (pH 6.22 ± 0.67 to 7.74 ± 0.04) and rainy season (pH 6.73 ± 0.38 to 9.93 ± 1.29) for the wet season, is higher than that determined in this work.

Based on mean pH, groundwater from residential areas showed slightly more acidic pH (Table 3c) than either groundwater from near petrol stations (Table 3a) or dumping sites (Table 3b).

This trend is consistent with compliance to TBS/WHO standards, where percentage of sampling points (Table 3c) complying with TBS/WHO standards is lowest in residential areas, followed by petrol stations and finally by dumping sites. It is worth noting that acidic pH values much lower than those specified by either WHO or TBS standards for groundwater were observed at a few points (D3, S3, S4), which are located near industries where semi-treated or untreated industrial effluents are released into the immediate environment. Basically, pH of natural water is determined by equilibrium among carbon dioxide, carbonate and bicarbonate. However, it is influenced by various factors including geological composition arising from chlorides, nitrates (Napacho and Manyere, 2010) and anthropogenic activities originating from municipal and industrial discharges (Bhattacharya, 1988).

The pH of groundwater in this work (mean: pH 6.2 to 6.6) is lower than groundwater from Temeke district reported by Napacho and Manyere (2010) (mean pH 7.4, range pH 6.2 to 8.2) on deep and shallow wells. The slightly alkaline groundwater reported by Napacho and Manyere (2010) indicate the presence of alkaline chemical species, which may be natural or anthropogenic in origin (Bhattacharya, 1988).

Electrical Conductivity (EC)

The results (Tables 3 a-c) generally show that the conductivity of groundwater is slightly higher in dry season than in rainy season. This could be due to an increase in concentration of salts, organic and

inorganic materials runoff from domestic and other human activities. Similar to temperature and pH, a paired t-test at p= 0.05 (two tailed) did not show significant difference in electrical conductivity measured between dry and rainy season since texp < tcrit: Petrol stations (student texp = 0.966, tcrit = 2.110, df = 17); Dumping sites (student texp = 0.414, tcrit = 2.145, df = 14); Residential areas (student texp = 0.593, tcrit = 2.086, df = 20).

The electrical conductivity in dry season (mean: 1278.4, range 256.5±23 to 5286±19) and rainy season (mean: 1276.8, range: 256±23 to 5270±18) are much higher than those reported by Adekunle et al. (2020) from Osun Nigeria, in dry season (mean: 336.60 µs cm-1, range:126.02 ± 15.72 µs cm-1 to 556.03 ± 106.60 µs cm-1) and rainy season (mean: 377.95 µs cm-1, range:149.88 ± 16.92 µs cm-1 to 606.65 ± 57.91 µs cm-1). Such a difference in electrical conductivity could be due to the geological composition of an area, low ion exchange between soil and water, type and concentration of ions and temperature.

Trend in electrical conductivity followed the trend (mean EC): Residential areas < near dumping sites < near petrol station. Groundwater samples analysed in this work satisfied the TBS (2018) electrical conductivity's maximum value (2500 □Scm-1 for untreated water) except for a few points which registered higher values (PS7 in Table 3 a). Results showed that the highest conductivity was registered in groundwater drawn from residential areas (S3). This may be due to the contribution of highly conducting ions like K+, Cl-, Na+, which impart a salty taste in groundwater as was observed in several sampling points. Noteworthy, groundwater from near petrol stations and dumping sites complied with the TBS specifications. A comparison of electrical conductivity against WHO guidelines (1000 □Scm-1), however, shows limited compliance (33%).

In some cases, electrical conductivity provides an indication of ocean water intrusion on groundwater as shown by several sampling points (S5, S19, PS1), which lie closer to the Indian Ocean and show high electrical conductivity.

Comparison with the study by Sojobi (2016) on groundwater from North central Nigeria (mean: 300 – 530 □Scm-1) and Owamah (2020) from

Niger Delta (mean: 84.5- 92.7 □Scm-1), shows that groundwater in this work is much higher probably due to high concentration of Cl- and Na+ in groundwater (Napacho and Manyele, 2010).

Heavy Metal Levels in Groundwater

Tables 4 a-c summarize levels of the heavy metals analysed at the three sampling sites over dry and rainy seasons. Cd, Pb, Cr, Cu and Zn were selected for analysis based on anthropogenic activities in the study area. Generally, average heavy metal levels were higher in the dry season than rainy season. Seasonal variation in levels of heavy metals can be associated with slow/poor groundwater flow since no recharge from rainfall occurs in the dry season. As a result, heavy metals tend to increasingly accumulate and settle in groundwater wells/boreholes, thereby increasing concentration in water (Mato, 2002).

Noteworthy, sampling points near petrol stations produced consistently highest average levels of Cr and Cd, while sampling points near dumping sites recorded the highest average levels for Pb, Cu and Zn. Groundwater from residential areas contained intermediate levels of Cr and Zn.

Table 4: Heavy metal levels in ground water

(a) Near Petrol stations

Sampling points	Metal Concentration/mgL^{-1}									
	Cd [0.003 mgL^{-1}]*		Pb [0.01 mgL^{-1}]*		Cr [0.05 mgL^{-1}]*		Cu [1.0 mgL^{-1}]*#		Zn [5.0 mgL^{-1}] *$	
	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy
PS 1	0.36±0.01	0.39±0.01	0.39±0.010	0.21±0.02	0.42±0.02	0.02±0.001	0.01±0.001	0.02±0.001	0.25±0.01	0.25±0.01
PS 2	0.04±0.001	0.04±0.001	0.04±0.001	0.05±0.01	0.33±0.02	0.03±0.001	0.02±0.001	0.04±0.001	0.07±0.005	0.07±0.005
PS 3	0.24±0.05	0.22±0.01	0.24±0.01	0.03±0.001	0.27±0.01	0.01±0.001	0.20±0.01	0.20±0.01	0.44±0.01	0.44±0.01
PS 4	0.06±0.002	0.04±0.001	0.06±0.02	0.03±0.001	0.06±0.001	0.08±0.01	0.50±0.01	0.02±0.001	0.05±0.001	0.09±0.02
PS 5	0.13±0.05	0.13±0.01	0.13±0.02	0.32±0.01	0.31±0.02	0.11±0.01	0.02±0.001	0.02±0.001	0.04±0.001	0.09±0.02
PS 6	0.01±0.001	0.01±0.001	0.01±0.001	0.17±0.02	0.15±0.02	0.15±0.01	0.01±0.001	0.01±0.001	0.58±0.01	0.52±0.01
PS 7	0.02±0.001	0.02±0.001	0.02±0.001	0.98±0.04	0.02±0.001	0.04±0.001	0.01±0.001	0.01±0.001	0.08±0.005	0.02±0.001
PS 8	0.03±0.001	0.03±0.001	0.03±0.001	0.20±0.02	0.01±0.001	0.03±0.001	0.02±0.001	0.01±0.001	0.07±0.005	0.06±0.005
PS 9	0.04±0.001	0.04±0.001	0.04±0.001	1.10±0.01	0.01±0.001	0.02±0.001	0.01±0.001	0.01±0.001	0.50±0.01	0.05±0.005
PS 10	0.30±0.01	0.03±0.001	0.30±0.01	0.90±0.01	0.01±0.001	0.04±0.001	0.01±0.001	0.04±0.001	0.07±0.005	0.04±0.001
PS 11	0.02±0.001	0.03±0.001	0.02±0.001	0.01±0.001	0.01±0.001	0.23±0.01	0.01±0.001	0.02±0.001	0.01±0.001	0.02±0.001
PS 12	0.04±0.001	0.03±0.001	0.04±0.001	0.30±0.01	1.10±0.01	1.00±0.01	0.03±0.001	0.03±0.001	0.01±0.001	0.01±0.001
PS 13	0.04±0.001	0.04±0.001	0.04±0.001	0.15±0.01	0.45±0.02	0.35±0.01	0.13±0.01	0.13±0.01	0.01±0.001	0.01±0.001
PS 14	0.50±0.01	0.45±0.01	0.50±0.01	0.60±0.01	0.03±0.001	0.03±0.001	0.80±0.01	0.87±0.02	0.08±0.02	0.01±0.001
PS 15	0.01±0.001	0.01±0.001	0.01±0.001	0.04±0.001	0.27±0.001	0.25±0.02	0.10±0.001	0.10±0.001	0.06±0.02	0.03±0.001
PS 16	0.01±0.001	0.01±0.001	0.02±0.001	0.08±0.002	0.58±0.01	0.21±0.01	1.70±0.01	1.30±0.01	0.02±0.001	0.06±0.005
PS 17	0.08±0.002	0.03±0.001	0.08±0.02	0.20±0.02	1.01±0.01	0.34±0.01	0.60±0.02	0.80±0.02	0.01±0.001	0.04±0.001
PS 18	0.40±0.01	0.05±0.01	0.40±0.01	0.20±0.02	0.12±0.02	0.04±0.001	0.37±0.01	0.02±0.001	0.01±0.001	0.03±0.001
Mean	0.13±0.07	0.09±0.02	0.13±0.04	0.31±0.06	0.29±0.05	0.17±0.03	0.25±0.03	0.20±0.03	0.13±0.03	0.10±0.03
% Compliance	TBS/WHO 0	TBS/WHO 0	TBS/WHO 11	TBS/WHO 6	TBS/WHO 33	TBS/WHO 50	TBS 94	TBS 94	TBS 100	TBS 100

(b) Near Dumping sites

Sampling points	Metal Concentration /mgL^{-1}									
	Cd [0.003 mgL^{-1}]*		Pb [0.01 mgL^{-1}]*		Cr [0.05 mgL^{-1}]*		Cu [1.0 mgL^{-1}]*#		Zn [5.0 mgL^{-1}] *$	
	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy
D 1	0.01±0.001	0.01±0.001	0.65±0.002	0.55±0.01	0.01±0.001	0.01±0.001	0.16±0.005	0.13±0.005	0.40±0.005	0.20±0.002
D 2	0.10±0.005	0.01±0.001	1.22±0.01	1.02±0.01	0.01±0.001	0.01±0.001	0.35±0.005	0.25±0.01	0.12±0.002	0.11±0.005
D 3	0.01±0.001	0.02±0.001	0.35±0.005	0.34±0.01	0.01±0.001	0.01±0.001	0.08±0.01	0.07±0.002	0.60±0.01	0.70±0.01
D 4	0.05±0.001	0.02±0.001	0.57±0.01	0.52±0.01	0.01±0.001	0.01±0.001	0.23±0.01	0.13±0.005	0.28±0.005	0.28±0.01
D 5	0.06±0.02	0.03±0.001	0.36±0.01	0.33±0.01	0.01±0.001	0.01±0.001	1.00±0.05	0.89±0.01	0.56±0.010	0.58±0.01
D 6	0.01±0.001	0.02±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.67±0.01	0.01±0.001	0.50±0.010	0.50±0.01
D 7	0.28±0.01	0.03±0.001	1.02±0.01	1.00±0.01	0.02±0.001	0.02±0.001	1.33±0.01	1.23±0.01	1.77±0.01	1.27±0.01
D 8	0.01±0.001	0.04±0.001	0.90±0.01	0.89±0.01	0.01±0.001	0.01±0.001	0.98±0.01	0.88±0.01	1.82±0.01	1.62±0.01
D 9	0.07±0.005	0.03±0.001	0.86±0.01	0.86±0.01	0.23±0.01	0.01±0.001	0.14±0.01	0.12±0.01	0.27±0.01	0.26±0.005
D 10	0.02±0.001	0.27±0.010	0.73±0.005	0.64±0.01	0.01±0.001	0.01±0.001	0.27±0.01	0.07±0.005	0.12±0.005	0.13±0.005
D 11	0.01±0.001	0.29±0.010	0.78±0.005	0.77±0.005	0.01±0.001	0.02±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.02±0.001
D 12	0.07±0.005	0.20±0.01	0.02±0.001	0.01±0.001	0.03±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001
D 13	0.03±0.001	0.27±0.01	0.12±0.005	0.03±0.001	0.04±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001
D 14	0.09±0.005	0.07±0.005	0.01±0.001	0.01±0.001	0.03±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.03±0.001
D 15	0.01±0.001	0.02±0.001	0.01±0.001	0.22±0.01	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.02±0.001
Mean	0.06±0.02	0.08±0.02	0.50±0.03	0.48±0.03	0.03±0.01	0.01±0.003	0.35±0.06	0.26±0.02	0.43±0.03	0.38±0.03
% Compliance	TBS/WHO 0	TBS/WHO 0	TBS/WHO 20	TBS/WHO 20	TBS/WHO 93	TBS/WHO 87	TBS 87	TBS 93	TBS 100	TBS 100

(c) Residential areas

Sampling points	Heavy metal concentration/mgL^{-1}									
	Cd [0.003 mgL^{-1}]*		Pb [0.01 mgL^{-1}]*		Cr [0.05 mgL^{-1}]*		Cu [1.0 mgL^{-1}]*#		Zn [5.0 mgL^{-1}] *$	
	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy
S1	0.04±0.005	0.02±0.001	0.23±0.01	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.13±0.01	0.02±0.001
S 2	0.06±0.005	0.01±0.001	0.05±0.002	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.45±0.01	0.09±0.01
S 3	0.01±0.001	0.01±0.001	0.05±0.002	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.62±0.01	0.02±0.001
S 4	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.50±0.01	0.03±0.001
S 5	0.03±0.001	0.01±0.001	0.04±0.01	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.55±0.005	0.04±0.001
S 6	0.05±0.005	0.02±0.001	0.65±0.02	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.23±0.005	0.22±0.01
S 7	0.04±0.001	0.01±0.001	0.07±0.005	0.01±0.001	0.01±0.001	0.03±0.001	0.01±0.001	0.01±0.001	0.44±0.01	0.23±0.01
S 8	0.07±0.005	0.01±0.001	0.06±0.005	0.01±0.001	0.01±0.001	0.02±0.001	0.01±0.001	0.01±0.001	0.69±0.01	0.07±0.01
S 9	0.09±0.01	0.01±0.001	0.09±0.01	0.01±0.001	0.06±0.005	0.45±0.01	0.01±0.001	0.01±0.001	0.29±0.005	0.15±0.01
S 10	0.07±0.005	0.01±0.001	0.04±0.001	0.01±0.001	0.06±0.005	0.03±0.001	0.01±0.001	0.01±0.001	0.65±0.01	0.45±0.01
S 11	0.03±0.001	0.02±0.001	0.02±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001
S 12	0.10±0.01	0.01±0.001	0.01±0.001	0.01±0.001	0.08±0.01	0.04±0.001	0.02±0.001	0.01±0.001	0.03±0.001	0.01±0.001
S 13	0.01±0.001	0.03±0.001	0.01±0.001	0.01±0.001	0.03±0.001	0.02±0.001	0.20±0.01	0.01±0.001	0.08±0.01	0.01±0.001
S 14	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.03±0.001	0.01±0.001	0.02±0.001	0.01±0.001
S 15	0.06±0.005	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.02±0.001	0.01±0.001	0.02±0.001	0.01±0.001
S 16	0.03±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.23±0.01	0.20±0.01	0.01±0.001	0.01±0.001	0.07±0.01	0.01±0.001
S 17	0.06±0.005	0.01±0.001	0.59±0.01	0.02±0.001	0.45±0.02	0.03±0.001	0.01±0.001	0.01±0.001	0.02±0.001	0.01±0.001
S 18	0.05±0.005	0.03±0.001	0.27±0.01	0.23±0.002	0.34±0.01	0.12±0.005	0.05±0.001	0.02±0.001	0.01±0.001	0.01±0.001
S 19	0.03±0.001	0.01±0.001	0.21±0.01	0.15±0.005	0.11±0.005	0.23±0.01	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001
S 20	0.04±0.001	0.01±0.001	0.15±0.01	0.35±0.01	0.21±0.01	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001
S 21	0.01±0.001	0.01±0.001	0.34±0.005	0.04±0.001	0.20±0.01	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001	0.01±0.001
Mean	0.04±0.02	0.01±0.005	0.14±0.03	0.05±0.01	0.09±0.02	0.06±0.02	0.02±0.001	0.01±0.005	0.23±0.03	0.07±0.02
% Compliance	TBS/WHO 0	TBS/WHO 0	TBS/WHO 29	TBS/WHO 75	TBS/WHO 58	TBS/WHO 80	TBS 100	TBS 100	TBS 100	TBS 100

*TBS/WHO limits; #WHO limit for Cu is 2.0 mgL^{-1}; $ WHO limit for Zn is Not determined (ND)

Heavy metal concentration may be influenced by the temperature of water because higher temperatures tend to influence chemical reactions in groundwater and facilitate metal dispersion in water wells and aquifers. Similarly, pH influences metal ion concentration. Low pH values tend to favour increased heavy metal availability in the groundwater since low pH causes heavy metal dissolution in water (Mato, 2002). On the other hand, high pH values result in precipitation of the metal, leading to the metal's deposition on sediments and thereby reducing their availability in water (Jorgensen, 1994). Heavy metal concentration is also influenced by electrical conductivity. Higher conductivity reflects a higher concentration of free ions in water which tends to reduce heavy metals concentration in groundwater (Mazar and Ahmad, 2020). Lower values of electrical conductivity, on the other hand, represent a lower concentration of free ions hence increasing the level of heavy metals in the groundwater.

Variation in levels of heavy metals among the three sampling sites can therefore be ascribed mainly to anthropogenic activities including industrial effluent discharges and leakage of petroleum products around the sampling points.

Cadmium (Cd)

As shown in Tables 4 a-c, Cd levels were higher in the dry season compared to the rainy season. A paired t-test at p= 0.05 (two tailed), however, did not show significant difference in average Cd levels measured between dry and rainy season since texp < tcrit: Petrol stations (student texp = 0.106, tcrit = 2.110, df = 17); dumping sites (student texp = 0.372, tcrit = 2.145, df = 14); Residential areas (student texp = 0.001, tcrit = 2.086, df = 20).

Cd Levels (annual average) among sampling sites followed the trend: Near petrol stations > near dumping sites > residential areas. The highest concentration of Cd near petrol stations could be attributed to various activities carried out at sampling points including washing of cars, leakage/spillage of petroleum products (petrol, diesel) and lubricating oils containing Cd additives, and maintenance/repairs of engines in garages located in/near petrol stations. Levels of Cd in former dumping site populated with garages could be associated with paints/ pigments in body works, dumping of batteries and spillage of petroleum products. In the active dumping site, levels of Cd are enhanced by incineration, which

contributes to the Cd burden from wastes disposed at the site. Cd content in groundwater obtained from residential areas was the lowest and may originate from several sources including poor control and management of solid wastes and unregulated disposal of Cd-containing batteries (Breeze, 2012).

The results showed that Cd levels in groundwater did not comply with TBS (2018) and WHO (2017) standards in all sampling sites. This implies that a sizable proportion of residents in the study area is exposed to Cd levels beyond acceptable limits, thereby adversely affecting public health of the community. It is worth noting that Saria et al. (2011) and Mahugija (2018) reported low cadmium concentration (< 0.01 mgL-1) in tapwater from locations near the study area.

Generally, the level of Cd obtained in this work is lower than that reported at Nangodi, a small-scale mining area of Northern Ghana (Cobbina et al., 2015) with a concentration range 0.001 – 2.227 mgL-1, but slightly higher than those determined at Lokpaukwu, Nigeria (Ezekwe et. al., 2012) with a concentration range of 0 - 0.258 mgL-1. In comparison, research work by Sheikh et al. (2018) reported a very low concentration of Cd (0.001 mg/L) which are within the WHO and TBS standards. Similarly, low levels were reported by Carasek et al. (2020) from the Serra Geral aquifer in Southern Brazil (0.003 mgL-1), which supply groundwater to nearby urban centres. The low level of Cd in these areas may indicate a lower contamination from the main anthropogenic sources including, paints, pigments, fertilizers and unregulated disposal of Cd-containing batteries.

Lead (Pb)

Tables 4 a-c show that Pb levels were generally higher in the dry season than in the rainy season except for some sites near the petrol station. A paired t-test at p = 0.05 (two tailed) did not show significant difference in lead levels measured between dry and rainy season since texp < tcrit: Petrol stations (student texp = 0.049, tcrit = 2.110, df = 17); Dumping sites (student texp = 0.238, tcrit = 2.145, df = 14); Residential areas (student texp = 0.038, tcrit = 2.086, df = 20).

As far as distribution among sampling sites is concerned, Pb levels (annual average) followed the trend: Dumping sites > petrol stations > residential areas. Leaching from waste disposal could be responsible for

the high availability of Pb near dumping sites whereas Pb level in sites near petrol stations could be due to leakage or minor spillages of petroleum products which contain Pb. It is worth noting that Pb is considered toxic even at low concentrations (Groyer, 1996). In comparison to tapwater in the nearby locations, Saria et al. (2011) reported Pb level below 0.01 mgL-1 while Mahugija (2018) reported mean pb concentration of 0.08 mgL-1 at Mbagala. Thus, residents relying on either tapwater or groundwater are at risk of suffering from health problems associated with acute lead poisoning (US EPA, 1986) as well as cumulative general metabolic poisoning (Khan et al., 2009).

Approximately 80% - 92 % of groundwater near petrol stations (Table 4a) and dumping sites (Table 4b), respectively, contain Pb levels above TBS & WHO standards. Despite containing the lowest concentration (annual mean) of Pb compared to the other two sites, about 25-70 % of groundwater from residential areas exceeded the TBS (2017) and WHO (2018) standards. Thus, population in the study area is exposed to non-permissible levels of lead through groundwater.

The Pb levels obtained from this work are much higher than those determined by Sheikh et al. (2018), who reported levels of Pb in groundwater in rural and urban Zanzibar (0 - 0.0027 mgL-1), which lie within WHO (2018) and TBS (2017) standards. Work by Ahmad et al. (2019) in Mathura city, Utar Pradesh India reported higher levels (0.62 - 5.888 mgL-1), which also exceed WHO limits. Results by Akinbile and Yusoff (2011) at Akure Nigeria (0 - 1.21 mgL-1) and Rezende et al. (2019) in southern Brazil (0.005- 0.92 mgL-1) on groundwater in urban areas are comparable to those determined in this work. However, Oyeku and Eludoyin (2010) reported much higher levels of Pb (0 - 14.8 mgL-1) in Ojota, Nigeria due to industrial effluents pollution. Interestingly, Ezekwe et al. (2012) reported no Pb in groundwater despite being located close to the mining site, indicating that environmental management is crucial to water quality.

Chromium (Cr) Similar to Cd and Pb, levels of Cr (Tables 4 a-c) were higher in the dry season than in the rainy season. However, paired t-test at $p = 0.05$ (two tailed) did not show significant difference in Cr levels measured between the seasons since texp < tcrit: Petrol stations (student texp = 0.026, tcrit = 2.110, df = 17); Dumping sites (student texp = 0.223,

tcrit = 2.145, df = 14); Residential areas (student texp = 0.395, tcrit = 2.086, df = 20).

Tables 4 a-c show that Cr levels (annual mean) followed the trend: Petrol stations > residential areas > dumping sites. In petrol stations, Cr originates from additives in petroleum products, and corrosion of alloys and anti-corrosion reagents from car washing machines. In residential areas, Cr may come from unregulated disposal of solid wastes containing dyes, pigments and pressure-treated lumber and refractory bricks.

Results further showed that between 50-67% of water samples drawn near petrol stations, 20-40% of samples from residential areas and approximately 10% of the water from dumping sites exceeded the TBS (2018) and WHO (2017) standards.

Previous work by Sheikh et al. (2018) on groundwater from Zanzibar, reported lower levels of Cr (0.001 - 0.028 mgL-1) compared to this work. Results obtained in this work, especially from petrol stations were similar to those reported by Akinbile and Yusoff (2011) on groundwater from a site near a landfill in Akure Nigeria (0 - 0.25 mgL-1). It is worth noting that Sharma and Dutta (2017) reported higher levels of Cr (0 - 2.66 mgL-1) in Malwa region, Punjab India, due to untreated disposal of effluents from electroplating and manufacturing industries.

Copper (Cu)
As shown in Tables 4 a-c, levels of Cu in groundwater are generally higher in dry season than in rainy season. A paired t-test at p= 0.05 (two tailed), however, did not show significant difference in copper levels measured between dry and rainy season since texp < tcrit: Petrol stations (student texp = 0.239, tcrit = 2.110, df = 17); Dumping sites (student texp = 0.045, tcrit = 2.145, df = 14); Residential areas (student texp = 0.186, tcrit = 2.086, df = 20).

The level of Cu determined in groundwater followed the trend: Dumping sites > petrol station > residential areas. Leachates of solid wastes containing Cu including leather products, and corrosion of Cu alloys may explain higher concentration of Cu in groundwater. Paints, brake pads and lubricating oils may contribute to the observed levels in petrol stations.

Compliance with TBS (2018) and WHO (2017) standards shows that groundwater from residential areas met the standards, while approximately 7-13% and 6% of groundwater from near dumping sites and petrol stations, respectively, exceeded the same standards.

Sheikh et al. (2018) reported very low values of Cu from shallow wells in Zanzibar ranging from 0 - 0.005 mgL-1. Similarly, Adekunle et al. (2020) reported a lower concentration (mean, 0.002 mg/L-1, range: 0-0.003 mg/L-1) in groundwater from Osun, Nigeria. However, Oyeku and Eludoyin (2010) reported a higher concentration (0 - 33 mgL-1) in groundwater near industrial area/landfill in Ojota Nigeria due to the disposal of industrial solid waste containing copper materials and industrial effluents. Interestingly, Nachiyunde et al. (2013) reported a lower level of Cu (0 - 0.270 mgL-1) in groundwater from the Zambia copper belt despite being located close to a mining area underscoring the importance of management of mining wastes.

Zinc (Zn)

Similar to other heavy metals analysed in this work, Zn concentration in the dry season was higher than rainy season (Tables 4a-c). Like other heavy metals analysed, a paired t-test at p= 0.05 (two tailed), did not show significant difference in Zn levels between dry and rainy season since texp < tcrit: Petrol stations (student texp = 0.287, tcrit = 2.110, df = 17); Dumping sites (student texp = 0.210, tcrit = 2.145, df = 14); Residential areas (student texp = 0.003, tcrit = 2.086, df = 20).

The Level of Zn in groundwater followed the trend: Dumping sites > residential areas ≈ petrol stations. The level of Zn in dumping areas could be contributed by leaching of zinc-containing wastes such as paints, pigments and automotive spare parts. In comparison with tap water from the nearby location (Mbagala), Mahugija (2018) reported a comparable level of Zn (mean = 0.493 mgL-1).

It is worth noting that all samples analysed in this work met the TBS specifications (2018). The permissible levels of Zn may be partly due to the fact that Zn in soil does not dissolve but is deposited primarily in sediments through adsorption and precipitation.

Zn levels in work done by Sheikh et al. (2018) on groundwater in rural and peri urban Zanzibar (0 - 0.135 mg L-1), and Oyeku and Eludoyin (2010) from Ojota Nigeria (0 - 0.23 mgL-1), were much lower than those obtained in this work, despite boreholes being located in an industrial area in Ojota Nigeria. On the other hand, results obtained in this work in groundwater drawn from petrol stations and dumping sites are similar to those reported by Akinbile and Yussof (2011) on boreholes (0 - 2.3 mg L-1) located near a landfill in Akure Nigeria. Similar results were also reported by Mazah and Ahmad (2020) in Bareilly City, in Uttar Pradesh, India (0.75 - 2.245 mg L-1). Noteworthy, WHO guidelines do not specify permissible limits for this metal since it is not considered to exhibit any direct adverse effects at levels it occurs in water. However, elevated levels can make the water less acceptable for drinking.

Statistical Evaluation of physicochemical parameters and heavy metals content in groundwater

PCA was carried out on all seasons' data (Tables 3 a-c and Tables 4 a-c) from 54 samples on Temperature (T), pH, Electrical Conductivity (EC), levels of Cd, Pb, Cr, Cu, and Zn. Table 5 shows the correlation matrix generated. For variables to show any correlation, matrix values should be equal to or greater than 0.3. Most values in Table 5 are indicative of a weak correlation suggesting a weak correlation among the variables measured. The Kaiser-Meyer-Olkin (KMO) value, which measures sampling adequacy, gave a value of 0.51. The KMO value is acceptable although ideally, it should be 0.7-0.8. In addition, the Bartlett test of sphericity yielded $p = 0.04$ indicating the results are significant at $p=0.05$. Both KMO and Bartlett test values show that PCA treatment can produce meaningful relationships on data analysed.

In order to determine principal components, eigen values (initial) equal to or greater than 1 were considered as shown in Table 6. Although all the eight variables measured are regarded as components, the analysis yielded three principal components accounting for 55.3% of the data as shown by the cumulative % loadings (extracted).

It is necessary to extract the component matrix (Table 7a) in order to determine the variables in each component. Ideally, values should be close to 1 or -1 in only one component (mutually exclusive). Accordingly, the first component PC 1 contains Zn, Cu and Pb while the second

component PC 2 consists of Cr, EC and pH. The third component constitutes of Cd and T.

Mathematical rotation of the factors generated in Table 7a is necessary to increase the usefulness and interpretation of results. Orthogonal rotation was applied in this analysis since no correlation among the variables is assumed to exist. Rotation by varimax method confirmed variables in each of the three components as shown in Table 7b. The first component, PC1 made up of Zn, Cu and Pb shows a strong correlation among Zn, Cu and Pb, which is consistent with correlation coefficient determination by Sojobi (2016) and Owamah (2020) on the same heavy metals. As noted by Sojobi (2016) and Owamah (2020), strong correlation may indicate that the three heavy metals either come from

Table 5: Correlation Matrix of the Experimental Variables

	T	pH	EC	Cd	Pb	Cr	Cu	Zn
T	1.000	-0.014	-0.032	-0.199	-0.007	0.092	-0.264	-0.007
pH	-0.014	1.000	-0.127	0.018	-0.005	0.139	0.139	-0.037
EC	-0.032	-0.127	1.000	-0.018	0.022	-0.137	-0.014	-0.037
Cd	-0.199	0.018	-0.018	1.000	0.158	-0.135	0.108	-0.048
Pb	-0.007	-0.005	0.022	0.158	1.000	-0.109	0.330	0.355
Cr	0.092	0.139	-0.137	-0.135	-0.109	1.000	0.045	-0.153
Cu	-0.264	0.139	-0.014	0.108	0.330	0.045	1.000	0.520
Zn	-0.007	-0.037	-0.037	-0.048	0.355	-0.153	0.520	1.000

Table 6: Total Variance of the Variables Measured based on Eigen values

	Initial Eigen values			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	1.904	23.802	23.802	1.904	23.802	23.802	1.818	22.727	22.727
2	1.318	16.477	40.279	1.318	16.477	40.279	1.308	16.348	39.075
3	1.200	14.998	55.277	1.200	14.998	55.277	1.296	16.202	55.277
4	0.949	11.867	67.145						
5	0.866	10.827	77.972						
6	0.811	10.141	88.113						
7	0.596	7.448	95.561						
8	0.355	4.439	100.000						

Table 7: Component matrices of variables measured

(a) Extracted component matrix

	Principal Component		
	PC 1	PC 2	PC3
Cu	**0.804**	0.264	
Zn	**0.750**		0.423
Pb	**0.668**		0.194
Cr	-0.234	**0.675**	
pH		**0.602**	-0.339
EC		**-0.560**	0.144
T	-0.333	0.176	**0.658**
Cd	0.282	-0.274	**-0.640**

(b) Rotated component matrix[b]

	Principal Component		
	PC 1	PC 2	PC 3
Zn	**0.852**		-0.142
Cu	**0.775**	0.232	0.252
Pb	**0.682**	-0.123	
pH		**0.674**	0.160
Cr	-0.135	**0.664**	-0.231
EC		**-0.577**	
T			**-0.754**
Cd			**0.748**

.

Rotation Method: Varimax with Kaiser Normalization.[b]

similar sources or metals are mutually dependent on one another. The second component, PC2 contains pH, Cr and Electrical Conductivity (EC), which reveal a moderately strong correlation among the variables. A strong correlation coefficient between pH and electrical conductivity was also reported by Sojobi (2016) and Owamah (2020). The third principal component, PC 3 comprises of temperature (T) and Cd showing the existence of a strong correlation between the two variables. Thus, statistical treatment shows that there is no correlation between temperature of groundwater and all variables except level of cadmium.

According to Owamah (2020), Cd and Cu were correlated to pH and electrical conductivity. This work, however, has shown that Cd and Cu may originate from different sources or are not mutually dependent, since they belong to different Principal Components.

Figure 2 graphically illustrates the variables measured in the three principal components following varimax rotation. As shown in Figure 2, Zn has the strongest influence in PC 1 followed by Cu and Pb. Similarly, Cr and pH show a stronger influence than EC with which they are inversely related, in PC 2. In PC 3, T and Cd show similar influence despite being inversely related.

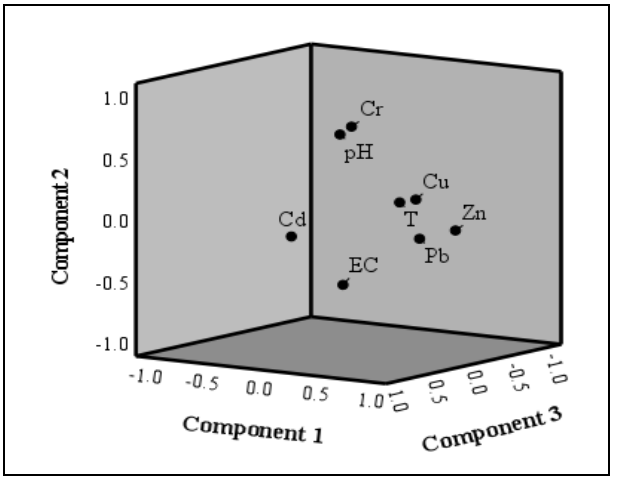

Figure 2: Component plot in rotated space

CONCLUSION

This study examined some physicochemical characteristics and heavy metal levels in groundwater, which is used by approximately 25% of the residents in Dar es Salaam city. Paired t- test shows that there is no significant difference in physicochemical parameters and heavy metal levels between dry and rainy seasons. The temperature of groundwater was influenced by ambient temperature and was similar to reported values from previous works. The study has shown that pH of the groundwater in both dry and rainy seasons largely complied with TBS (2018) and WHO (2018) permissible limits. A comparison of parameters between sampling sites shows that pH of groundwater was lowest in residential areas than either dumping sites or petrol stations. Similarly, the electrical conductivity of groundwater largely satisfied TBS specifications but 67-83% of groundwater exceeded WHO limits. Electrical conductivity was highest in residential areas than either near petrol stations or dumping sites. While groundwater in the study area contains Cd, Pb, Cr, Cu and Zn, levels of Cd, Pb and Cr exceeded TBS and WHO standards in both seasons. Groundwater near petrol stations contained the highest levels of Cd and Cr while groundwater near dumping sites contained the highest levels of Pb. Despite largely satisfying TBS and WHO standards in Cu and Zn in groundwater, the population is exposed to negative effects from the metals, since the heavy metals bioaccumulate. Overall, groundwater contains non-permissible levels of Cd, Pb and Cr which affect quality of groundwater as potable water, making it unsuitable for human consumption. Principal Component Analysis has shown a correlation

exists among Zn, Cu and Pb; Cr, electrical conductivity & pH; and Cd & temperature. The existence of correlation indicates either variables originate from similar sources or mutual dependence.

ACKNOWLEDGMENTS
The authors thank Ardhi University for laboratory analysis of samples and University of Dar es Salaam for allowing a member of its constituent College to participate in this work.

REFERENCES

Adekunle, A.S., Oyekunle, J.O. A., Ojo, O.S., Makinde, O.W., Nkambule, T.T.I., and Mamba, B. B**.** (2020), Heavy Metal Speciation, Microbial Study and Physicochemical Properties of Some Groundwaters: A Case Study**,** *Chemistry Africa*, 3, 211–226.

Ahmed, P.S., Khurshid, S., Qureshi, F., Hussaind, A., and Bhattacharya, A. (2019), Heavy Metals and Geo-Accumulation Index Development for Groundwater of Mathura City, Uttar Pradesh, *Desalination and Water Treatment*, 138, 291-300.

Akinbile, C.O., and Yusoff, M.S. (2011), Environmental Impact of Leachate Pollution on Groundwater Supplies in Akure, Nigeria. *Int J Environ Sci Develop*, 2, 81–86.

Balderacchi, M., Benoit, P., Cambier, P., Eklo, M., Gargini, A., Gemitzi, A, Gurel, M., Kløve, B., Nakic, Z., Predaa, E., Ruzicic, S., Wachniew, P., and Trevisan, M. (2013), Groundwater Pollution and Quality Monitoring Approaches at the European Level. *Critical Reviews in Environmental Science and Technology*, 43, 323-408.

Bhatacharya, S.K. (1988), Urban Domestic Water Supply in Developing Countries. CBS Publishers, New Delhi, India

Borowska, S., and Brzóska, M.M. (2015), Metals in Cosmetics: Implications for Human Health. *J. Appl. Toxicol.*, 35(6), 551-572.

Breeze, R. (2012), *Municipal Solid Waste Management in Dar es Salaam: Baseline Report prepared for the World Bank*, DC. Toronto, Canada.

Brindha, K., and Elango, L. (2013), Occurrence of Uranium in Groundwater of a Shallow Granitic Aquifer and its Suitability for Domestic Use in Southern India. *Journal of Radioanalytical and Nuclear Chemistry*, 295, 357–367.

Cambra, K., Martnez, T., Urzelai, A., and Alonzo, E. (1999), Risk Analysis of a Farm Area near a Lead and Cadmium contaminated Industrial Site. *Soil Contam*., 8, 527-540.

Carasek, F.L., Baldissera, R., Oliveira, J. V., Scheibe, L.F., and Dal Magro, J. (2020), Quality of the groundwater of the Serra Geral Aquifer System of Santa Catarina West Region, Brazil; *Groundwater for Sustainable Development*, 10, 1-8.

Cobbina, S.J., Duwiejuah, A.B., Quansah, R., Obiri, S., and Bakobie, N. (2015), Comparative Assessment of Heavy Metals in Drinking Water Sources in Two Small scale Mining Communities in Northern Ghana. *Int. J. Environ. Res. Public Health* 12(9), 10620-10634.

Ezekwe, I.C., Odu, N.N., Chima, G.N., and Opigo, A. (2012), Assessing Regional Groundwater Quality and its Health Implications in the Lokpaukwu, Lekwesi and Ishiagu Mining Areas of Southeastern Nigeria Using Factor Analysis. *Environ Earth Sci.*, 67, 971- 986.

Flynn, C.M., and Haslem, S.M. (1995), Cyanide Chemistry Precious Metals Processing and Waste Treatment. *U.S Bureau of Mines Information Circular*, 9429, p. 282.

Gonzalez, M., Miglioranza, K.S.B., Shimabukuro, V. M., Orlando, M., Londoño, Q., Martinez, D. E., Aizpún, J. E., and Moreno, V. (2012), Surface and Groundwater Pollution by Organochlorine Compounds in a Typical Soybean System from the South Pampa, Argentina, *J. Environ Earth Sci*., 65 (2), 481-491.

Goyer R.A. (1996), Results of lead research: prenatal exposure and neurological consequences. *Environ Health Perspect*, 104:1050–1054.

Hailu, T., Beyene, A., Tesfahun, E., Getaneh, A., Gize, A., and Mekonnen, Z. (2017), Fecal Contamination of Soil and Water in Sub-Saharan Africa Cities: The Case of Addis Ababa, Ethiopia. *Ecohydrology and Hydrobiology*, 18, 225-230.

Howorth, C., Covery, I., and O'Keefer, P. (2001), Gardening to Reduce Hazard: Urban Agriculture in Tanzania. *Land Degr. Develop*. 12, 285-291.

Hutton, M., and Symon, C. (1986), The Quantities of Cadmium, Lead, Mercury and Arsenic entering the U.K. Environment from Human Activities. *Science of the Total Environment*, 57, 129-150.

Jomova, K., and Valko, M. (2010) Advances in Metal-Induced Oxidative Stress and Human Disease. *Toxicology*, 283, 65-87.

Jorgensen, S.E. (1994), Fundamentals of Ecological Modelling. Elsevier Science, Amsterdam, pp. 628-660.

Kassenga G.R., and Mbuligwe, S. E. (2009), Impacts of a solid waste disposal site on soil, surface water and groundwater quality in Dar es Salaam City, Tanzania. *J Sustain Dev Afr.*, 10, 73–94.

Kazuva, E., and Zhang, J. (2019), Analyzing Municipal Solid Waste Treatment Scenarios in Rapidly Urbanizing Cities in Developing Countries: The case of Dar es Salaam, Tanzania. *Int J Environ Res Public Health.*, 16(11), 2035-2054.

Khan, S., Farooq, R., Shabhaz, S., and Sadique, M. (2009), Health Risk Assessment of Heavy Metals for Population via Consumption of Vegetables. *World Appl Sci J*, 6(12), 1602-1611.

Kisamo, D.S. (2003), Environmental Hazards Associated with Heavy Metals in Lake Victoria Basin (East Africa), Tanzania. *Afr. Newslett. Occup. Health and Safety.*, 13, 67-69;

Koller, K., Brown, T., Spurgeon, A., and Levy, L. (2004), Recent Developments in Low-Level Lead Exposure and Intellectual Impairment in Children. *Environ. Health Perspect.*, 112(9), 987-994.

Kuroda, K., Murakami, M., Oguma, K., Muramatsu, Y., Takada, H. and Takizawa, S. (2012), Assessment of Groundwater Pollution in Tokyo Using PPCPs as Sewage Markers. *Environ. Sci. Technol.*, 46, 1456-1464.

Lapworth, D.J., MacDonald, A.M., Tijani, M.N., Darling, W.G., Gooddy, D.C., Bonsor, H.C. and Araguás-Araguás, L.J. (2013), Residence Times of Shallow Groundwater in West Africa: Implications for Hydrogeology and Resilience to Future Changes in Climate, *Hydrogeol J.*, 21(3), 673–686.

Liu, X., Song, Q., Tang, Y., Li, W., Xu, J., Wu, J., Wang, F., and Brookes, P.C. (2013), Human Health Risk Assessment of Heavy Metals in Soil–Vegetable System: A Multi-medium Analysis. *Science of the Total Environment*, volumes 463-464, 530-540.

Mahugija, J.A.M. (2018), Levels of Heavy Metals in Drinking water, cosmetics and fruit juices from selected areas in Dar es Salaam, Tanzania (2018), *Tanz. J. Sci.*, Vol. 44(1), 1-11.

Mato, R. A. M. (2002), Groundwater Pollution in Urban Dar ss Salaam, Tanzania: Assessing Vulnerability and Protection Priorities. PhD Dissertation, Eindhoven University of Technology, the Netherlands.

Mazhar, S. N., and Ahmad, S. (2020), Assessment of Water Quality Pollution Indices and Distribution of Heavy Metals in Drinking Water in Ramganga Aquifer, Bareilly District Uttar Pradesh, India, *Groundwater for Sustainable Development*, 10, 100304.

Mor, S., Ravindra, K., Dahiya, R.P., and Chandra, A. (2006), Leachate Characterization and Assessment of Groundwater Pollution near Municipal Solid Waste Landfill Site *Environmental Assessment*, 118 (1), 435-456.

Mucheweti, A., Birkett, J.W., and Chinyaga, E. (2006), Heavy Metal Content of Vegetables Irrigated with Mixtures of Wastewater and Sewage Sludge in Zimbabwe: Implications for Human Health. Agric. *Ecosyst. Environ*., 112(1), 41-48.

Mushtakova, V.M., Fomina, V.A., and Rogovin, V.V. (2005), Toxic Effect of Heavy Metals on Human Blood Neutrophils. *Biological Bulletin*, 32(3), 276-278.

Nachiyunde, K., Ikeda, H., Tanaka, K., and Kozaki, D. (2013), Evaluation of Portable Water in Five Provinces of Zambia using a Water Pollution Index. *Afr J Environ Sci Technol.,* 7,14–29.

Napacho Z. A. and Manyele S. V. (2010), Quality Assessment of Drinking Water in Temeke District (Part II): Characterization of Chemical Parameters, *Afr. J. Environ. Sci. Technol.,* Vol. 4(11), 775-789.

National Bureau of Statistics, (2018), Tanzania in Figures, Government Printing Office, pp 16-20.

Nkotagu, H. (1996), Origins of high nitrate in groundwater in Tanzania. *J Afr Earth Sc.,* 22, 471–478.

Owamah H. I. (2020), A comprehensive assessment of groundwater quality for drinking purpose in a Nigerian rural Niger delta community. *Groundwater for Sustainable Development*, 10, 100286, 1-13.

Oyeku, O., and Eludoyin, A. (2010), Heavy Metal Contamination of Groundwater Resources in a Nigerian Urban Settlement. *Afr J Environ Sci Technol.,* 4, 201–221.

Ravindran, B., Mupambwa, H.A., and Mnkeni, N.S. (2017), Assessment of Nutrient Quality, Heavy Metals and Phytotoxic Properties of Chicken Manure on Selected Commercial Vegetable Crops. *Heliyon, 3*, e00493.

Rezende, D., Nishi, L., Coldebella, P.F., Mantovani, D., Soares, P.F., Valim, N.C., Vieira, A.M.S., Bergamasco, R. (2019), Evaluation of the Groundwater Quality and Hydrogeochemistry Characterization using Multivariate Statistics Methods: Case Study of a Hydrographic Basin in Brazil, *Desalination and Water Treatment*, 161, 203-215.

Saria, J.A, Semiono, P., Shija, S., Kyobe, J.W.M.P, and Mbwiliza, J. (2011), Determination of Water Quality Supplied to Residents on the Outskirts of Dar es Salaam City. *Tanz. J. Nat. and Appl. Sci.,* 2 (1): 277-280.

Sharma, R., and Dutta, A.A. (2017), Study of Heavy Metal Pollution in Groundwater in Malwa of Punjab, India: Current Status, Pollution and its Potential Health Risks. *International Journal of Engineering Research and Applications*, 7(3), 81-91.

Sheikh, M.A., Ali, A.H., Khamis, A.A., Rashidi, R.J., Ali, H.R., Ikeno, J., and Tanaka, U. (2018), Quality of Groundwater from Open-Wells in Rural and Peri Urban Areas of Unguja Island, Zanzibar, Tanzania, *African Study Monographs*, Suppl. 55, 119–142.

Sojobi, S.O., (2016), Evaluation of Groundwater Quality in a Rural Community in North Central of Nigeria. *Environ. Monit. Assess*., 188, 192-209.

Tanzania Bureau of Standards (2018), Drinking (potable) Water Specification (TZS 789:2018 -EAS 12: 2018) pp. 5-6;

UN. (2019), World Urbanization Prospects (2018) [Online]. United Nations. Available: https://population.un.org/wup/ [Accessed 1 March 2019]

United Nations Children's Fund (UNICEF) (2008), *Handbook on Water Quality*, New York, USA, pp 1-179.

United Republic of Tanzania (2017), Securing Watershed Services through Sustainable Land Management in the Ruvu and Zigi Catchments (Eastern Arc Region*).* Wami/Ruvu Basin, Tanzania.

US EPA (1983), Independent Peer Review of Selected Studies Concerning Neuro Behavioral Effects of Lead Exposures in Nominally Asymptomatic Children: Official *Report of Findings and Recommendations of an Interdisciplinary Expert Review Committee*, EPA-600/8-83-028.

US EPA (1986), Handbook for Conducting Endangerment Assessments. U.S. Environmental Protection Agency, Research Triangle Park, NC; EPA/540/1-86/060.

Vunain, E., Nkhuzenje, C., Mwatseteza, J., and Sajidu, S. (2019), Groundwater Quality Assessment from Phalombe Plains, Malawi, *ChemSearch Journal* 10(1), 1-10.

World Health Organization (2017), *Guideline for Drinking Water Quality*. 4th Ed. Incorporating First Addendum. World Health Organization, Geneva. Switzerland**,** pp. 307-433.