INTERNATIONAL JOURNAL OF ENVIRONMENT
Volume-11, Issue-2, 2022 ISSN 2091-2854

Received: 30 June 2022 *Revised: 12 September 2022* *Accepted: 13 September 2022*

OCCURRENCE OF ELEVATED NITROGENOUS AND PHOSPHORUS COMPOUNDS IN GROUNDWATER SOURCES USED IN UNPLANNED SETTLEMENTS, DAR ES SALAAM – TANZANIA

Leopord Sibomana Leonard*, Rubhera RAM Mato and Mengiseny E. Kaseva
School of Environmental Science and Technology, Ardhi University, P. O. BOX 35176, Dar es Salaam, Tanzania
*Corresponding author: siboditz1@gmail.com

Abstract

Groundwater in unplanned settlements is stressed by multiple pollution sources threatening health of consumers. Elevated nitrogen and phosphorus affect the quality of groundwater as they leach through the soil to groundwater. This study aimed at establishing variations of nitrogenous and phosphorus compounds in 75 boreholes used in 8 unplanned settlements in Dar es Salaam, Tanzania. Laboratory analysis using Spectrophotometer DR/4000 was conducted at Ardhi University. Principal Component Analysis was conducted by using Paleontological Statistics (PAST) software, version 3.08 and statistical significance set at $p < 0.05$. Results indicated that about 84% and 73.3% of sampled boreholes during wet and dry seasons, respectively had nitrate nitrogen greater than WHO recommendations for drinking water quality standards. Concentration of NO_2-N showed that 12% and 14.7% of sampled boreholes during wet and dry seasons, respectively were greater than 0.9 mg/L TZS (574:2016) recommended guidelines. Phosphate concentration was greater than 2.2 mg/L TZS (574:2016) recommended guidelines in 49.3% and 12% of sampled boreholes during both wet and dry seasons, respectively. These results indicated that consuming such polluted water may be unsafe to infants and older people and therefore alternative drinking water source is recommended.
Keywords: Boreholes; Coastal Aquifer; Informal Settlements; Nutrients; Onsite Sanitation

DOI: https://doi.org/10.3126/ije.v11i2.46304

Introduction

Good water quality is essential for use in domestic activities, agriculture, industry and support of freshwater ecosystem (Tyagi *et al*., 2013 and Wu *et al*., 2021). Improving the water quality of a city and its surrounding areas fulfills an essential role in reducing poverty and diseases and promotes sustainable growth (Gao *et al*., 2012 and Mussa *et al*., 2019). Thus, according to Hall *et al*. (2014), accessing safe drinking water is of paramount importance for human beings' livelihoods.

On the other hand, degradation of groundwater quality in unplanned settlements is influenced by the location of point and diffuses pollutants sources (Ratha *et al*., 2019). Previous studies (Cruz-Fuentes *et al.,* 2014; Phiri, 2016 and Ratha *et al*., 2019) have pointed out the most common sources of groundwater pollution include domestic sewage, latrines, municipal solid wastes, agricultural manure and industrial wastes. Absences of sewerage systems and poor waste management practices in unplanned settlements lead to the dependence on onsite sanitation systems particularly septic systems and pit latrines which are located in the proximity of groundwater sources, which in turn threaten the quality of dependable water sources (Musa *et al*., 2019). In most cases pit latrines lack physical barriers to prevent movement of pollutants from the excreta to groundwater (Olonga *et al*.,2015) and such pollutants may potentially leach to groundwater and affect health of consumers (Mjemah *et al*.,2011 and Mtoni *et al*., 2012). Some studies have shown that groundwater located downstream of pit latrines are more polluted than upstream (Dzwairo *et al.*, 2006; Mdoe and Buchweishaija, 2014).

Specifically, nitrogen and phosphorus compounds threaten the quality of groundwater in unplanned settlements as they leach through the soil to groundwater (Graham and Polizzotto, 2013). Nitrogen is formed from the application of fertilizers in urban agriculture, pit latrines, decaying organic matter and other organic residues left on the environment (Zhai *et al*., 2017; Gao *et al*., 2012). It is also formed naturally in the human body (Gao *et al*., 2012; Phiri, 2016 and Elisante *et al*., 2017). High concentrations of nitrates exceeding 50 mg/L in the drinking water cause health risks including conversion of hemoglobin to methemoglobin which reduces oxygen levels in the human blood (WHO, 2008 and Ratha *et al*., 2019). Long term effects of nitrogen in drinking water include enlargement of the thyroid gland, birth defects, hypertension and cancer (especially for older people), stomach cancer and esophageal, thyroid and diabetes (Ratha *et al*.,2019).

Excessive ingestion of water containing phosphorus may cause osteoporosis and poor bone maintenance. Some studies propose that higher consumptions of phosphorus are linked with increased risk of suffering cardiovascular diseases (Pourfallah *et al.,* 2014, Saria and Thomas, 2012). WHO has no guideline set for phosphate but Tanzania has set it as 2.2 mg/L (TZS 574:2016).

The population of Dar es Salaam city which hosts about 10% of the country's population is currently projected to be over 6 million (Rosen, 2019) with annual growth rate of 5.6% (URT,2013). Rapid urbanization and lagging infrastructure construction have led to the development of plentiful informal settlements inside and at the boundaries of the city. Unplanned settlements sometimes referred to as informal settlements in Dar es Salaam are described as the unplanned neighborhood where a mix of low and middle income households lives. Physically these settlements are characterized by single storey building following Swahili type with high dense settlements (Rasmussen, 2013). Over 70% of the population lives in unplanned settlements characterized by insufficient infrastructures including poor or absence of water supplied by authorities (Mtoni, 2013 and Elisante *et al*., 2017). It is further estimated that more than 50% of the population in Dar es Salaam city depend on groundwater (Elisante *et al*., 2017) as the major source of drinking, industrial and irrigation activities (Mjemah *et al*., 2011; Mtoni *et al*., 2012 and Mtoni, 2013). Thus, most of residents in these settlements depend on groundwater accessed through shallow and boreholes drilled around the compounds in the vicinity of poorly maintained pit latrines (Mato, 2002; Mdoe and Buchweishaija, 2014 and Elisante *et al*., 2017). The quality of these shallow wells and boreholes are not well known as they are rarely monitored by mandated institutions (Leonard, 2022).

Previous studies done in the study area indicated that boreholes along coastal regions were polluted by anthropogenic activities caused due to the use of pit latrines and poor waste management practices (Mdoe and Buchweishaija., 2014; Mtoni *et al*., 2013). Shallow wells were reported to have higher concentrations of nitrates compared to deep wells (Mdoe and Buchweishaija, 2014). Mtoni *et al*., (2013) indicated that higher concentration of elemental pollutants in boreholes along Coastal region were associated with salt water intrusion and infiltration from anthropogenic activities. Another study done by Ngasala *et al.* (2019) revealed that the bivariate correlation between the distance from the well to the septic tank and nitrate concentration had negative correlation indicating possible multiple pollution sources, including leachate generated from haphazardly disposed solid wastes and pit latrines (Mode and Bucheishaija, 2014). Thus, this research work aimed at establishing seasonal variations in levels of nitrogen and phosphorus compounds in groundwater, thereby giving a scientific base for regulating nutrient pollution and protecting groundwater sources in the city.

Materials and methods

Description of the study area

This study was carried out in Dar es Salaam City, Tanzania. It involved 8 unplanned settlements (Vingunguti, Buguruni, Kigogo, Magomeni, Jangwani, Mwananyamala, Tandale and Manzese), which are shown in Figure 2. Dar es Salaam city has about 100 unplanned settlements hosting 75% of all residential houses (Rasmussen, 2013) with an average of population density of 3133 people per square kilometer (URT, 2013). The sampled settlements are characterized by having the highest population density in the city, ranging from 20,410 to 47,292 with average of 28,668 people per square kilometer (URT, 2013). The range is far above the average population density of the city. They experience poor/absence of piped water systems and most of the households use onsite sanitation systems located in the proximity of boreholes (Figure 2). Residents in these settlements depend on groundwater as a main source for domestic uses. The city is located at 6°48´South, 39°17´ in eastern Coast of the country as shown in Figure 1. It covers total land mass area of 1393 km^2. The study area is positioned between latitude 6°.79’ and 6°.79’to the South of Equator and longitude 39°23’ and 39°22’ to the east of Equator. Dar es Salaam is a business and major city in Tanzania standing out as the primate city (Wenban-Smith, 2014). The fast urbanization has increased pressure on the infrastructure and services including water supply and waste management.

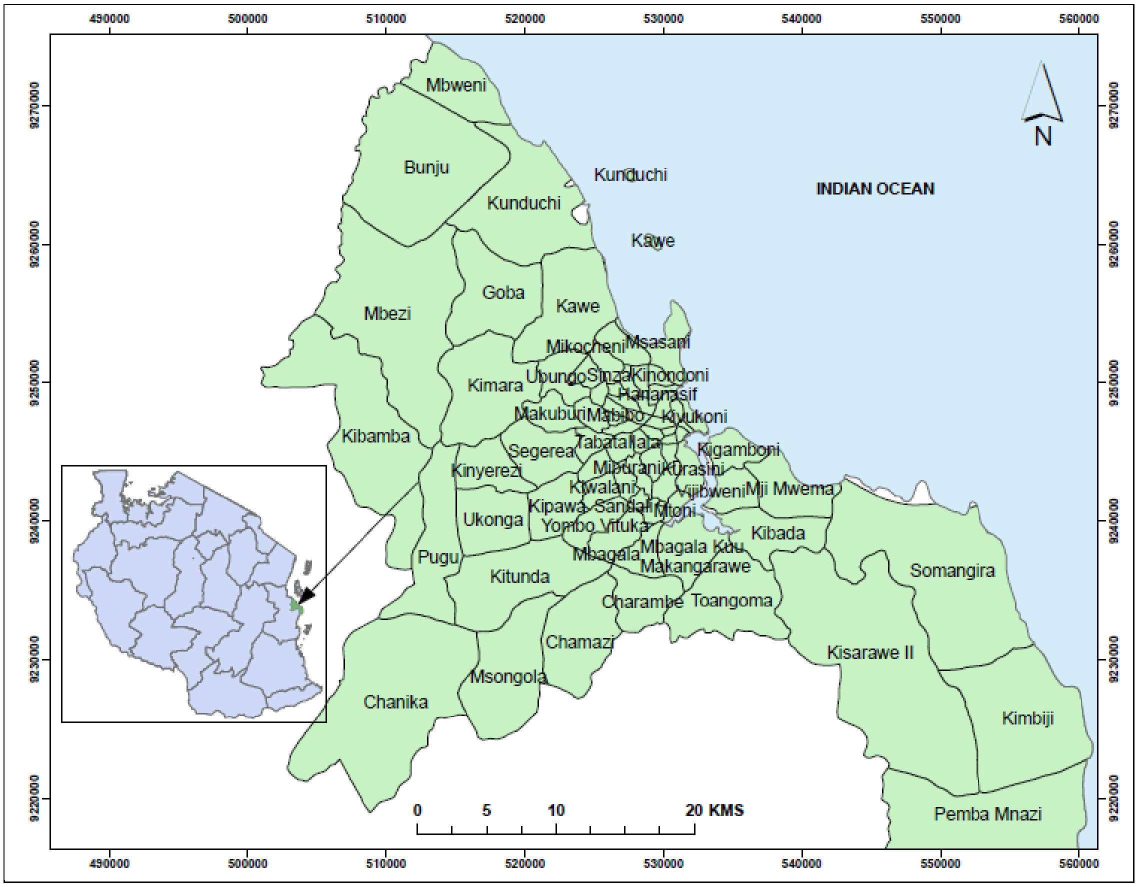

Figure 1: Location of Dar es Salaam city in Tanzania

Water sampling and analysis

A total of 75 water samples were collected from pre-selected 75 boreholes in the selected 8 unplanned settlements. Samples were collected through the dry and wet seasons (from May to June and September to October, 2017 respectively and the same months in 2018. A total of three sampling campaign during each season was conducted at the interval of two weeks. All groundwater samples were collected in pre sterilized 1000ml plastic bottles, packed in cool box and immediately transported to the School of Environmental Science and Technology laboratory at Ardhi University, Tanzania where they were preserved at 4°C before analysis.

Concentrations of nitrate nitrogen (NO_3-N), nitrite nitrogen (NO_2-N), ammonia nitrogen (NH_4-N) and phosphate (PO_4^{3-}) were determined using HARCH DR 4000 Spectrophotometer. The methods used for Nitrate nitrogen, nitrite nitrogen, phosphorus, Ammonia Nitrogen were Cadmium reduction, Diazotization, and Ascorbic Acid methods, respectively. All procedures and the concentrations of NO_3^-, NO_2^-, NH_4^+, NH_3 and P were determined using conversion factors as described by APHA (2017) presented in Table 1.

Table 1: Methods used to estimate ions (APHA, 2017)

S/N	Parameter	Method	Unit
1	Nitrate	Conversion method (NO_3-N x 4.427)	mg/L
2	Nitrite	Conversion method (NO_2-N x 3.284)	mg/L
3	Ammonium	Conversion method (NH_3-N x 1.288)	mg/L
4	Phosphorus	Conversion method (PO_4^{3-} x 0.3261)	mg/L

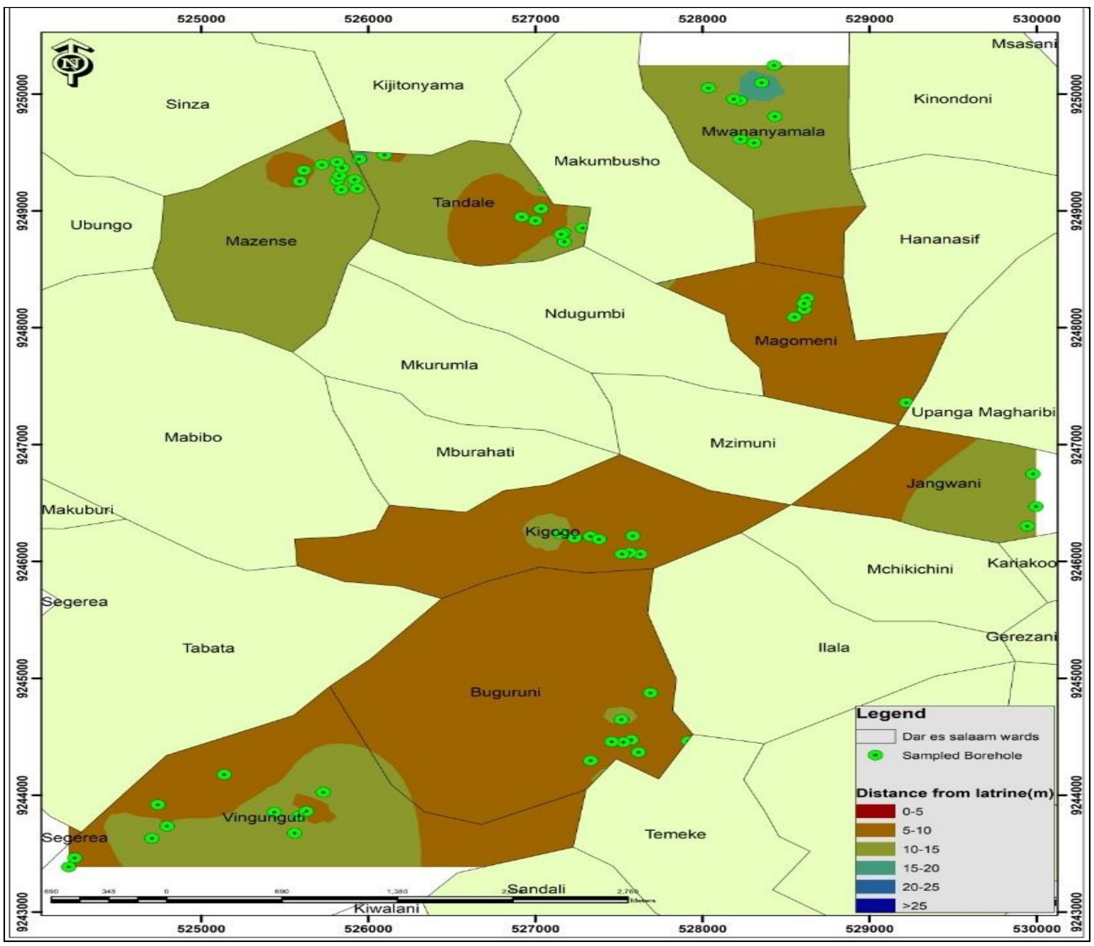

Figure 2: Location map of sampled wards and boreholes in unplanned settlements, Dar es Salaam

Statistical analysis was performed using Microsoft Excel 2007 to establish means and standard deviations. Principal Component Analysis (PCA), Hierarchical Cluster Analysis (HCA) was done by using Paleontological Statistics (PAST) software package (Chacha *et al*., 2018), version 3.08 (Hammer *et al*., 2001) with statistical significance set at $p < 0.05$. Pearson correlation was used to establish inter relationship between parameters as recommended by Divya and Belagali (2012). One way ANOVA was performed to establish significance differences between parameters among different seasons (wet and dry seasons). Before statistical analysis, normality of the data set were examined to establish any outliers.

Results and discussion

Nutrient variations in the boreholes

Findings of this study indicated that the average concentration of NO_3-N in sampled boreholes ranged from 14.9 mg/L to 106.0 mg/L and the concentration of NO_3^- ranged from 65.7 mg/L to 468.5 mg/L as shown in Table 2. Furthermore, 63 boreholes that are equivalent to 84% of the sampled boreholes during wet season and 55 boreholes that are equivalent to 73.3% of sampled boreholes during dry season had concentrations of NO_3-N greater than WHO recommended concentration levels in drinking water sources (11 mg/L and 50 mg/L of NO_3-N and NO_3^-), respectively. Similar findings (Elisante *et al*., 2017; Sawyer *et al*.,2019), indicated that some water sampling points had concentration of NO_3^- greater than 100 mg/L. Tanzania drinking water quality standards requires drinking water to have less than 75mg/L of NO_3^-. The concentration of NO_3-N was higher during wet season than dry season. This can be associated with the fact that in unplanned settlements, households empty pit latrines and discharge wastes into storm water, which eventually percolates into the groundwater.

The presence of elevated NO_3^- concentrations in groundwater might be an indirect indicator of the occurrence of other pollutants (Chacha *et al*., 2018) in groundwater derived from anthropogenic activities (Mtoni *et al*., 2012, Elisante *et al*., 2017 and Leonard, 2022). Previous studies (Mato, 2002; Mutewekil *et al*.,2007; Mjemah *et al*., 2011, Elisante *et al*., 2017; Chacha *et al*., 2018 and Leonard, 2022), also indicated elevated levels and suggested that high concentrations of NO_3-N in groundwater in urban aquifer are associated with onsite sanitation systems including solid waste disposal, pit latrines, leaky sewers and septic systems, and industrial activities. According to

Mutewekil *et al*. (2007) and Elisante *et al*. (2017), Nitrate from these sources might be introduced into groundwater systems through infiltration processes. Findings by Lewis *et al*. (1980) have shown that human excreta introduce around 5kg of nitrogen in the environment per capita per year.

The average NO_2-N concentration in groundwater varied from 0.027 mg/L to 1.54 mg/L while the concentration of NO_2^- ranged from 0.09 mg/L to 5.05 mg/L as shown in Table 2. Analysis of individual borehole indicated that 9 boreholes (12%) during wet seasons and 11 boreholes (14.7%) during dry seasons had high concentrations greater than WHO recommended concentrations (0.9 mg/L and 3mg/L) of NO_2-N and NO_2^- ion, respectively). Generally NO_2-N was high during dry season compared to wet season except for some few boreholes. Most of the boreholes had NO_2^- concentrations below the WHO specified standards which is 3 mg/L except for some few boreholes. About 9 and 10 boreholes equivalent to 12% and 13.3% during wet and dry seasons, respectively had NO_2^- concentrations greater than WHO recommended values. Such values are likely to expose bottle-fed infants to methemoglobinemia (Khaniki *et al*., 2008; Ratha *et al*., 2019). Figure 3 shows NO_3^- and NO_2^- concentrations in the case study areas.

The average concentration of NH_4-N ranged from 0.29 mg/L to 3.09 mg/L as shown in Table 1. As was the case with other parameters, the concentration of NH_4-N was higher during dry season compared to wet season. According to WHO, ammonia is not of direct relevance to health and thus no health-based guidelines have been set. However, when ammonia is present in water, it can react with chlorine and thus reduce free chlorine to form chloramines. WHO recommends a threshold odour concentration of ammonia at alkaline pH, which is 1.5 mg/L (WHO, 2011). The average concentrations of NH_4^+ ranged from 0.35 mg/L to 3.76 mg/L. All concentrations were below the taste threshold established by WHO (35 mg/L of the NH_4^+).

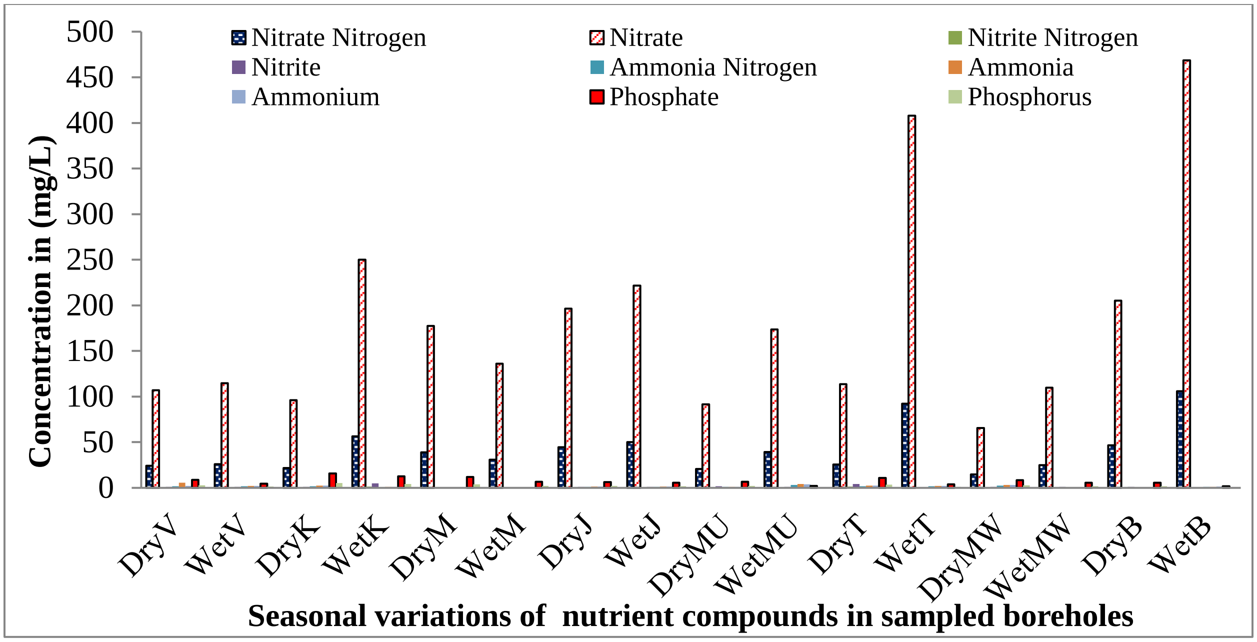

Figure 3: Variations of nutrients in groundwater sources in the study area. V=Vingunguti, K=Kigogo, M=Magomeni, J=Jangwani, MU=Manzese, T=Tandale, MW=Mwananyamala, B=Buguruni

The average concentrations of phosphate in the boreholes ranged from 1.81 mg/L to 15.94 mg/L in all seasons as shown in Table 2. Descriptive analysis shows that 38 boreholes or equivalent to 50.7% during wet and 66 boreholes or equivalent to 88% during dry seasons had concentrations of PO_4^{3-} within recommended Tanzania drinking water permissible limit of 2.2 mg/L. Largely, the concentration of PO_4^{3-} was higher during dry than that in wet seasons, probably due to dilution effects from precipitation recharging groundwater (Gao *et al*., 2012).

The major sources of phosphate in unplanned settlements are possibly from the use of organophosphates insecticide including malathion, diarthion and parathion applied by urban farmers in gardens. Mwegoha and Kihampa (2010) and Leonard *et al.* (2012) have reported that urban farming is a common practice in Msimbazi Valley in Dar es Salaam city. Also the use of detergents could be the major contributor of phosphate in groundwater as most of detergents used at household consist of phosphates which are flushed through onsite sanitation systems.

Table 2: Variation of nutrients concentrations in boreholes used in unplanned Settlements (Mean±Stdev)

Variables		**NO_3-N (mg/L)**	**NO_3^- (mg/L)**	**NO_2-N (mg/L)**	**NO_2^- (mg/L)**	**NH_3-N (mg/L)**	**NH_3 (mg/L)**	**NH_4^+ (mg/L)**	**PO_4^{3-} (mg/L)**	**P (mg/L)**
Vingunguti	Dry	**24.24**±0.6	**107.15**±2.65	0.31±0.09	1.03±0.3	1.63±0.08	**5.67**±0.15	**2.09**±0.1	**8.86**±0.18	2.89±0.06
	Wet	**25.97**±0.34	**114.83**±1.52	0.34±0.01	1.12±0.02	1.7±0.05	**2.07**±0.06	**2.2**±0.06	**4.48**±0.08	1.46±0.03
Kigogo	Dry	**21.72**±0.22	**96.02**±0.95	0.35±0.002	1.14±0.006	1.93±0.02	**2.35**±0.02	**2.49**±0.02	**15.94**±0.13	5.2±0.04
	Wet	**56.59**±1.16	**250.12**±5.14	**1.54**±0.01	**5.05**±0.04	0.8±0.04	1.0±0.04	1.02±0.05	**12.60**±0.34	4.11±0.11
Magomeni	Dry	**38.97**±2.68	**177.57**±5.72	0.06±0.003	0.19±0.01	0.46±0.05	0.55±0.06	0.59±0.07	**12.05**±0.16	3.94±0.05
	Wet	**30.8**±1.83	**136.15**±8.10	0.027±0.002	0.09±0.01	0.35±0.02	0.42±0.03	0.45±0.03	**6.75**±0.09	2.24±0.06
Jangwani	Dry	**44.48**±0.71	**196.58**±3.12	0.35±0.03	1.14±0.08	1.1±0.09	1.34±0.1	1.42±0.1	**6.17**±0.16	2.0±0.03
	Wet	**50.15**±1.73	**221.6**±7.63	0.28±0.02	0.92±0.05	1.07±0.15	1.3±0.18	1.39±0.19	**5.6**±0.06	1.9±0.13
Manzese	Dry	**20.70**±0.31	**91.47**±1.35	0.55±0.01	1.82±0.05	0.95±0.04	1.16±0.04	1.23±0.05	**6.6**±0.07	2.15±0.02
	Wet	**39.31**±0.41	**173.77**±1.79	0.36±0.01	1.17±0.02	3.09±1.03	**4.26**±0.85	**3.76**±1.26	**2.11**±0.05	0.69±0.02
Tandale	Dry	**25.69**±0.4	**113.55**±1.78	**1.33**±0.02	**4.37**±0.06	1.9±0.05	**2.31**±0.06	**2.45**±0.06	**11.03**±0.13	3.6±0.04
	Wet	**92.28**±0.56	**407.89**±2.48	0.21±0.02	0.7±0.07	1.77±0.14	**2.28**±0.18	**2.15**±0.17	**3.80**±0.11	1.24±0.04
Mwananyamala	Dry	**14.85**±0.28	**65.66**±1.25	0.28±0.01	0.91±0.02	2.52±0.1	**3.06**±0.12	**3.24**±0.1	**8.52**±0.25	2.78±0.1
	Wet	**24.83**±0.86	**109.73**±3.81	0.28±0.01	0.92±0.04	0.29±0.01	0..37±0.01	0.35±0.01	**5.49**±0.15	1.79±0.05
Buguruni	Dry	**46.53**±0.46	**205**.25±2.75	0.34±0.002	1.13±0.005	0.67±0.03	0.81±0.03	0.86±0.04	**5.68**±0.17	1.85±0.05
	Wet	**105.99**±0.64	**468.47**±2.83	0.12±0.002	0.4±0.01	0.96±0.29	1.16±0.35	1.34±0.35	1.81±0.09	0.59±0.03
TZS 574:2016		NM	75	0.5	NM	NM	0.5	2	2.2	NM
WHO :2011		10	50	0.9	3		1.5			

NM: Not mentioned.

Correlation coefficient matrix between nutrient compounds during dry seasons

The Pearson correlation was applied to analyze the correlation between nutrients concentration during dry seasons as shown in Table 3. The correlation shows that NO_3-N had moderate positive correlation with NH_3-N with r = 0.4626 while NH_3-N had strong correlation with PO_4^{3-} and NO_3-N with r = 0.7158 and 0.9191, respectively. There is the existence of a positive correlation among nitrogen compounds and phosphate signifying a possible common source of pollution. This is in line with the previous studies (Mtoni, 2013, Elisante *et al*., 2017, Chacha *et al*.,2018 and Leonard, 2022) that suggested that potential source of groundwater pollution in unplanned settlements include domestic wastewater percolating from onsite sanitation systems, urban agriculture, buried organic wastes and cemeteries.

Table 3: Pearson correlation among nutrients during dry seasons

	PO_4^{3}-	NO_3-N	NO_2-N	NH_3-N	NH_4^+	NH_3
PO_4^{3-}	1	**0.4626**	0.1588	**0.7158**	**0.7157**	**0.7163**
NO_3-N		1	0.0095	**0.9191**	**0.9188**	**0.9186**
NO_2-N			1	0.1818	0.1818	0.1821
NH_3-N				1	0.0000	0.0000
NH_4^+					1	0.0000
NH_3						1

Correlation among nutrient analyzed during wet seasons

Findings from this study indicate that during wet seasons, NO_3-N strongly positively correlated with PO_4^{3-} with r = 0.6828, while it was poorly correlated with NH_3-N with r = 0.0031. NO_2-N was strongly correlated with NO_3-N (r = 0.6441). Moreover, NH_3-N yielded positive correlation with PO_4^{3-} and NO_2-N with r = 0.6468 and 0.6551, respectively, as summarized in Table 4. It can be concluded that there is possible common source of nitrogen compounds (NO_3-N, NH_3-N, NH_4^+ and NH_3) during wet season as there is moderate to strong correlations among them (Zhou *et al*.,2019). The possible source of these nutrients in surveyed areas are decomposition of organic matter, percolation of organic wastes and discharge of wastewater from onsite sanitation systems, urban agriculture, urban runoff and general poor waste management practices which ultimately percolates to the groundwater (Mjemah *et al*., 2011, Mtoni *et al*., 2011; Mtoni, 2013; Sappa *et al*., 2015 and Elisante *et al*., 2017).

Table 4: Pearson correlation matrix of nutrients during wet seasons

	PO_4^{3-}	NO_3-N	NO_2-N	NH_3-N	NH_4^+	NH_3
PO_4^{3-}	1	**0.6828**	0.3749	**0.6468**	**0.8113**	0.4119
NO_3-N		1	**0.6441**	0.0031	0.2110	0.0645
NO_2-N			1	**0.6551**	**0.6374**	**0.8833**
NH_3-N				1	0.0000	0.0000
NH_4^+					1	0.0000
NH_3						1

Pearson correlation showed moderate positive correlations between nitrate nitrogen concentrations measured during dry and wet seasons with $r = 0.524$. Further statistical analysis using ANOVA one way factor at $\alpha = 0.05$ showed a significance difference between the NO_3-N and PO_4^{3-} concentrations measured between two seasons as the analysis yielded p value of 0.0001 and 0.0029, respectively, suggesting that precipitation has effects in groundwater quality as also reported by Sappa *et al*. (2015).

Principal Component Analysis

Principal Component Analysis (PCA) was used to identify factors which might be controlling correlations among nutrient concentrations during dry and wet seasons. Factor with eigenvalue of 1.0 or greater are considered significant and factors with highest eigenvalues are the most significant. Results of this study showed that three principal components (PC1-PC3) with eigenvalues >1 accounted for about 79.6% of the total variances are as presented in Table 5. The loading of analyzed data showed that PO_4^{3-}, NH_3-N, NH_4^+ and NH_3 constituted one related group (PC1) which accounted for 35.2% of the total variance.

PC2 which accounted for 27.7% of total variance has high loadings from NO_3-N and NO_3^- and moderately from NO_2-N and NO_2^- which is an indication of anthropogenic enrichment in most of sampling points probably from domestic wastewater percolating from onsite sanitation systems. PC3 which accounts for 16.7% of the total variance has moderately loadings from PO_4^{3-}, NO_3-N and NO_3^- as shown in Table 5. Onsite sanitation systems especially pit latrines and septic tanks which dominate in unplanned settlements and located in the proximity of boreholes are probably the major common source of pollutions as evidenced by PCAs (Mutewekil *et al*., 2007 and Elisante *et al*., 2017).

Table 5: Principal components and Eigenvalues using correlation matrix

	PC 1	PC 2	PC 3	PC 4	PC 5
PO_4^{3-}	0.0639	0.0098	0.4355	0.0715	**0.895**
P	0.0142	-0.0189	0.2594	**0.944**	-0.2024
NO_3-N	0.1223	**0.5092**	-0.4127	0.159	0.1738
NO_3^-	0.1223	**0.5092**	-0.4127	0.159	0.1738
NO_2-N	0.2801	0.4043	0.4294	-0.1606	-0.2204
NO_2^-	0.2807	0.4055	0.4267	-0.1611	-0.2194
NH_3-N	**0.5192**	-0.2259	-0.1096	0.0215	0.0170
NH_4^+	**0.5192**	-0.2260	-0.1096	0.0213	0.0171
NH_3	**0.5191**	-0.226	-0.1096	0.0214	0.01699
Eigenvalue	3.1686	2.4929	1.5006	0.9670	0.8705
% variance	35.207	27.699	16.674	10.745	9.6718
Cumulative %	**35.207**	**62.907**	**79.6**	**90.345**	**100**

The PCA among nutrients during wet season shows that the first 4 components had eigenvalue >1.0, thus are the most significant as they account for 94.7% of the total variance as shown in Table 6. PC1 accounted for 32.4% of the total variance showing strong positive loading on NO_3^-N, NO_3^-, NH_3-N, NH_4^+ and NH_3 which are the major variables constituting PC1. The presence of nitrate indicates the source of anthropogenic activities mainly domestic wastewater from pit latrines, thus leading to high loading factor as suggested by Ahmed *et al. (*2002) and Dzwaro *et al.* (2006). PC2 accounted for 24.6% of the total variance showing strong positive loading with PO_4^{3-}, P, NO_2-N and NO_2^- while PC3 constituted 19.5% showing positive loading with PO_4^{3-}, P and negative loading NO_2-N and NO_2^-. Furthermore, PC4 which accounted for 18.3% of the total variances showed positive loading with NO_3-N and NO_3^-. The results is in agreement with findings reported by Musa *et al.* (2019) who also found that presence of nitrates in groundwater was a good indicator of anthropogenic sources of pollution mainly from pit latrines.

Table 6: Principal components and eigenvalues using correlation Matrix

	PC 1	PC 2	PC 3	PC 4	PC 5	PC6
PO_4^{3-}	-0.195	**0.729**	**0.646**	0.112	-0.003	0.008
P	-0.196	**0.729**	**0.646**	0.112	-0.003	0.008
NO_3-N	**0.657**	0.056	-0.068	**0.747**	0.053	0.004
NO_3^-	**0.657**	0.056	-0.068	**0.747**	0.053	0.004
NO_2-N	0.142	**0.754**	**-0.619**	-0.165	-0.002	0.005
NO_2^-	0.142	**0.754**	**-0.619**	-0.165	-0.002	0.005
NH_3-N	**0.834**	0.017	0.190	-0.235	**-0.441**	-0.134
NH_4^+	**0.747**	0.027	0.237	-0.467	0.364	-0.189
NH_3	**0.826**	-0.045	0.221	-0.420	0.031	0.301
Eigenvalue	2.9	2.21	1.8	1.6	0.33	0.14
% variance	32.4	24.6	19.5	18.3	3.7	1.6
Cumulative %	32.4	56.96	76.43	94.69	98.4	100

Figure 4 which is the Biplot between PC1 and PC2 during dry season shows that NO_3-N and NO_3^- forms the first group followed by the second group which is NO_2-N and NO_2^- while NH_3, NH_3-N and NH_4^+ forms another related group. The Biplot between PC1 and PC2 during wet season shows that NO_3-N, NO_3^-, NH_3-N, NH_3 forms the first group followed by the second group which is NO_2-N and NO_2^- while PO_4^{3-} and P forms another group. Similar group shows the related characteristics including possible sources and thus, the correlations among nutrients measured during dry and wet seasons, as shown in Figure 4 and Figure 5, respectively. Mineralization processes could also contribute to the formation of various nitrogen compounds as reported by Ratha *et al.* (2019).

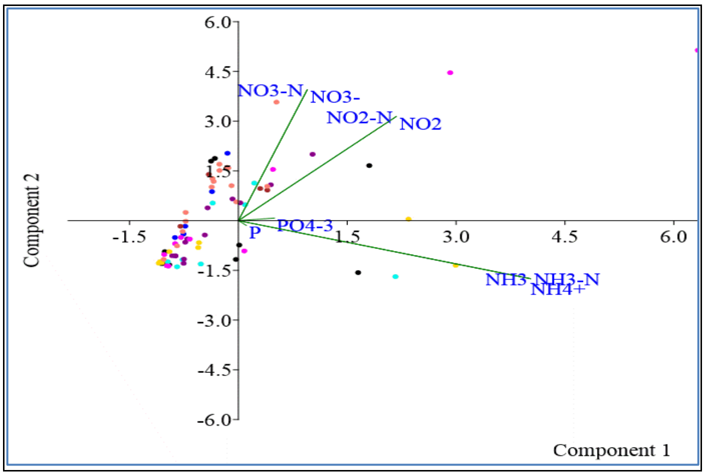

Figure 4: Biplot between PC1 and PC2among nutrients during dry season

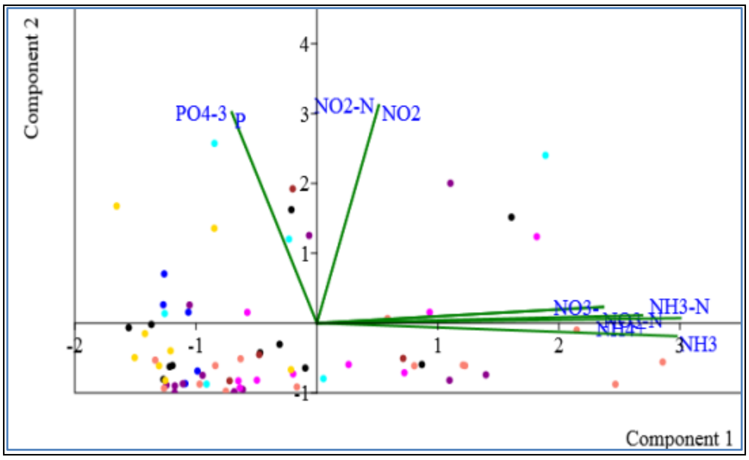

Figure 5: Scatter plot using Biplot among nutrient compounds during wet seasons

Conclusion

This study showed that most of boreholes in the surveyed area contain concentrations of nitrogen compounds (NO_3-N, NO_2-N, and NH_3-N) greater than recommended WHO and Tanzania drinking water quality guidelines. There is a significant difference between the concentration of nitrate nitrogen and phosphate concentrations measured during wet and dry seasons, indicating the contributions of precipitation and percolation of pollutants during wet season. Furthermore, positive correlations between nitrogen compounds indicated that there is possible common source of pollutions which threatens the quality of groundwater and health of users. The current groundwater pollution suggested that if no proper groundwater management actions are adequately addressed, the use of onsite sanitations systems as well as groundwater pollution will remain a major threat to consumers' health.

Author's contribution statement

Leopord Sibomana Leonard devised the general idea, literature reviews, water sample collection, laboratory analysis, data analysis, manuscript preparations and editing, Mengiseny Kaseva contributed ideas, manuscript editing and proofreading and Rubhera Ram Mato contributed ideas and proofreading.

Conflict of interest

The authors declare that they have no conflict of interest.

Acknowledgements

The authors wish to acknowledge the financial support from DAAD/ARU PhD in country support program (reference number 91604381). The excellent work performed by field assistants, borehole owners and cooperation provided by the central and local government authorities including permission to carry out field work and interviews in selected case studies are also highly appreciated.

References

APHA., 2017. Standard methods for the Examination of water and wastewater, 23rd edn, American Public Health Association, Washington DC. ISBN: 9780875532875

Ahmed, K.M., Khandkar, Z.Z., Lawrence, A.R., Macdonald, D.M.J., Islam M.S., 2002. An investigation of the impact of on-site sanitation on the quality of groundwater supplies in two peri-urban areas of Dhaka, Bangladesh. In assessing risk to groundwater from on-site Sanitation: Scientific review and case studies. Key worth, UK : *British Geological Survey*, 37-67.

Cruz-Fuentes, T., Heredia, T., Cabrera, M.C., Custodio, E., 2014. Behavior of a small sedimentary volcanic aquifer receiving irrigation return flows, La Aldea, Gran Canaria, Canary Islands (Spain). *Hydrogeology journal, 22*: 865 – 882; https://doi.org/10.1007/s10040-013-1094

Divya, J., Belagali, S.L., 2012. Impact of chemical fertilizers on water quality in selected agricultural areas of Mysore district, Karnataka, India. *International Journal of Environmental Sciences, 2*:1449-1458; https://doi:10.6088ijes.00202030030

Dzwairo, B., Hoko, Z., Love D., Guzha, E., 2006. Assessment of the impacts of pit latrines on groundwater quality in rural areas: A case study from Marondera district, Zimbabwe. *Physics and Chemistry of the Earth, 31*:779-788; https://doi.org/10.1016/j.pce.2006.08.031

Elisante, E., Alfred, N., Muzuka, N., 2017. Occurrence of nitrate in Tanzanian groundwater aquifers: A review. *Appl Water Sci, 7*:71-87; https://doi 10.1007/s13201-015-0269-z

Gao, Y., Yu, G.,Luo ,C., Zhou ,P., 2012. Groundwater nitrogen pollution and assessment of its health risks: A case study of a typical village in rural-urban continuum, China .*PLoS One*, *7*:1-8; https://doi.org/10.1371/journal.pone.0033982

Graham, J.P., Polizzotto, M.L., 2013. Pit latrines and their impacts on groundwater quality. A systematic review. *Environmental Health Perspectives*, *121*; 521-530;

https://doi.org/10.1289/ehp.1206028

Hall, R. P., Van Koppen, B., Van Houweling, E., 2014. The human right to water: The importance of domestic and productive water rights. *Science and Engineering Ethics*, *20*: 849 - 68. https://doi 10.1007/s11948-013-9499-3

Hammer,O.,Harper,D., Ryan,P., 2001. Paleontological Statistics Software: Package for Education and Data Analysis. *Palaentologia Electronica.4*;1-9

Khaniki, Gh, R, J., Dehghani, M.H., Mahvi., A. H., Rafati., L., Tavanafar., F., 2008. Concentrations of nitrate and nitrite in groundwater resources of Hamadan Province, Iran. *Research Journal of Chemistry and Environment, 12*: 56 -58

Leonard, L. S., 2022. Assessment of groundwater quality along cemeteries and associated potential health concerns in Dar es Salaam, Tanzania. *Water practice and Technlogy; 17*: 1218-1229; https://doi.org/10.2166/wpt.2022.041

Leonard, L.S., Mwegoha, W.J.S., Kihampa, C., 2012. Heavy metal pollution and urban agriculture in Msimbazi river valley: Health risk and public awareness. *International journal of plant, animal and environmental sciences, 2*:107-118

Lewis, J.W., Foster, S.D., Draser, B.S., 1980. The risk of groundwater pollution by on-site sanitation in developing countries, a literature review. International Reference Centre for Wastes Disposal (IRCWD) Report No. 01/82, Duebendorf, Switzerland

Mato, R. R. A. M., 2002. Groundwater pollution in urban Dar es Salaam, Tanzania: assessing vulnerability and protection priorities Eindhoven: Technische Universiteit Eindhoven 10.6100/IR554794

Mdoe, J.E.G., Buchweishaija, J., 2014. The quality of groundwater from wells in squatter and non-squatter settlements in Dar es Salaam city, Tanzania. *International Journal of Engineering Research and Technology, 3*:1442-1444, IJERTV3IS090369

Mjemah, I. C., Van Camp.M., Martens. K., Walraevens. K., 2011. Groundwater exploitation and recharge rate estimation of quartenary sand aquifer in Dar es Salaam area, Tanzania. *Environ Earth Sci, 63*: 559-569; https://doi:10.1007/s12665-010-0723-z

Mseli, Z. H., Goeller, D., Scharenberg, M., Mwegoha, W. J., Gianotti, R., Bongiorno, D., Sawyer, A. H., 2019. Physical factors limiting access to clean groundwater in Tanzania villages. *Journal of Water, Sanitation and Hygiene for Development*, *9*(3), 531-539; https://doi.org/10.2166/washdev.2019.198

Mtoni, Y., Mjemah, I.C., Bakundukize, C.,Van Camp, M., Martens, K., Walraevens, K., 2013. Saltwater intrusion and nitrate pollution in the coastal aquifer of Dar es Salaam, Tanzania. Springer, *Environmental Earth Sciences.* https://doi:10.1007/s12665-012-2197-7

Mtoni, Y.E., 2013. Saltwater intrusion in the coastal strip of Dar es Salaam quaternary aquifer, Tanzania. PhD thesis, Ghent University, Faculty of Sciences, Belgium. http://hdl.handle.net/1854/LU-4268883

Mtoni, Y.,Mjemah, I.C., Msindai, , Van Camp,M., Walraevens, K., 2012. Saltwater intrusion in the quartenary aquifer of the Dar es Salaam region, Tanzania. *Geologica Belgica, 15*: 16-25;
http://hdl.handle.net/1854/LU-1897437

Mtoni,Y .,Mjemah, I.C.,Van Camp,M., Walraevens, K., 2011. Enhancing protection of Dar es Salaam quaternary aquifer: Groundwater recharges assessment. *Advances in the research of aquatic environment*, vol 1, https://doi:10.1007/978-3-642-19902-8

Mwegoha, W.J.S., Kihampa, C., 2010. Heavy metal contamination in agricultural soils and water in Dar es Salaam city, Tanzania. *African Journal of Environmental Science and Technology, 4*:763-769

Mussa, K.R., Mjemah, I.M., Walraevens, K., 2019. Quantification of groundwater exploitation and assessment of water quality risk perception in the Dar es Salaam Quartenary Aquifer, Tanzania.*Water,11*, 2552; https://doi:10.3390/w11122552

Mutewekil, M.O., Adnan, M.M., Ahmad, M.A., Faisal, S.A., 2007. Analysis and evaluation of nitrate levels in groundwater at Al-Hashimiya area, Jordan. *Environ Monit Assess*, *135*: 475-486; https://doi.org/10.1007/s10661-007-9667-5

Olonga, R.O., Nduna, E.,Makokha, M., 2015. Seasonal variations of physicochemical and microbiological characteristics of groundwater quality in Ruiru, Kiambu county, Kenya. *International Journal of Scientific and Research Publications, 5*: 411-423; http://ir-library.ku.ac.ke/handle/123456789/23849

Phiri, A., 2016. Risk of domestic underground water sources in informal settlement in Kabwe, Zambia. *Environment and Pollution, 5*:1-14; https://doi:10.5539/ep.v5n2pl

Pourfallah, F., Javadian, S., Zamani, Z., Siadat, S.D., Sh-Khatami, Saghiri, R., Kordi, T., 2014. Physico-chemical analysis of drinking groundwater of around Tehran by seasonal variation Pakistan. *Journal of Biological Sciences, 17*: 287- 291; https://doi:10.3923/pjbs.2014.287.291

Rasmussen, M. I., 2013. The power of informal settlements. The case of Dar es Salaam, Tanzania. *Platinum, The Journal of Urbanism*; 26:1-11,ISSN 1723-0993

Ratha, P., Nandalal, K.D.W., Weerakoon, S.B., Dharmagunawardhane, H.A., Pitawala, H.M.T.G.A., 2019. Groundwater contamination due to nitrate in a coastal aquifer: Conjecture and Identification along the West Coast from Katana to Negombo, Sri Lanka. *International Journal of Engineering Research and Technology (IJERT), 8*:905-912; ISSN: 2278-0181

Rosen, J. W., 2019. This Tanzanian city may soon be one of the world's most populous. Is it ready; https://www.nationalgeographic.com/environment/2019/04/tanzanian-city-may-soon-be-one-of-the-worlds-most-populous/

Sappa, G., Luciani, G., 2014. Groundwater management in Dar es Salam coastal aquifer (Tanzania) under a difficult sustainable development. *WSEAS transactions on Environment and Development, 10*:465-477

Saria, J, A., Thomas, I.M., 2012. Water Quality in Selected Shallow Wells in Dar es Salaam. *Huria Journal*. Volume XI, ISSN 0856 6739

Tyagi, S., Sharma, B., Singh, P., Dobhal, R., 2013. Water quality assessment in terms of water quality index. *American Journal of Water Resources, 1:* 34-38; https://doi: 10.12691/ajwr-1-3-3

United Republic of Tanzania., 2013. Population and Housing Census: Population Distribution by Administrative Areas, National Bureau of Statistics, Ministry of Finance, Dar es Salaam

Wenban-Smith, H., 2014. Population Growth, internal migration and urbanization in Tanzania, 1967-2012: A Census based regional analysis. Working Paper on Urbanization in Tanzania, *International Growth Centre*

World Health Organization., 2008. Guidelines for drinking-water quality: Second addendum. *Vol. 1, Recommendations*. Geneva, Switzerland. ISBN 9789241547604

World Health Organization., 2011. Guidelines for Drinking-Water Quality (forth ed.). Geneva, *Switzerland*. ISBN 9789241548151

Zhou, J., Xiang, J., Zhu, G., Lei, L., Cao, J., Shi, W., Feng, W., 2019. Spatiotemporal hydrochemical variations in river water in the Qilian Mountains and their sources: a case study of the Binggou River Basin. *Journal of Water, Sanitation and Hygiene for Development, 9(4),* 731-742. https://doi.org/10.2166/washdev.2019.049