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Original Research

Application of Factor and Cluster Analyses in the Assessment of Sources of Contaminants in Borehole Water in Tanzania

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Abstract

Our study assesses the quality of water in Dar es Salaam city, Tanzania. Borehole water samples collected were analyzed for physicochemical and microbiological characteristics of the underground water. All functional boreholes in the study area were sampled. Pearson correlation coefficient was employed to establish the interaction of the physicochemical characteristics in the underground water. Factor analysis and cluster analysis were employed to determine source apportionment of contaminants in underground water. Results showed that calcium was significantly correlated with electrical conductivity (r=0.624), total dissolved solids (r=0.627), and total hardness (r=0.881) for underground water sources. Calcium concentration is attributed to anthropogenic activities, terrigenous influx in run-off, and/or natural processes within the aquifers. Faecal coliform counts exceeded the World Health Organization maximum permissible limit of 0/100ml at 44ºC at Shauri Moyo and Kigogo Primary School and, therefore, the water was contaminated; the rest of the boreholes were safe. Factor analysis revealed three sources of pollutants in the underground water:

(1) mixed origin of human wastes and soil in runoff
(2) dual origin of turbidity (human wastes and soil/organic matter)
(3) natural/geochemical processes in aquifers.

In conclusion, water hardness is controlled by calcium and faecal contamination is attributed to entry of sewage (human wastes) and organic matter into underground water. There is a need for water to be treated/filtered and/or boiled before consumption.

Keywords: borehole, coliform, factor analysis, underground water, water quality

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Introduction

Deterioration of fresh water is a global problem. In many developing countries, availability of potable water has become critical and communities depend on a non-public supply system. Population growth and living standards of the developing world have increased and resulted in increasing demand for clean water [1]. Direct contamination of surface water from anthropogenic activities such as municipal sewage, industrial effluents, and terrigenous influx is a long-standing phenomenon [2-4]. Today there is trace contamination not only of surface water but also of groundwater bodies, which are susceptible to leaching from waste dumps, septic systems such as pit latrines that are commonly used in slum areas where there is no sewer system, and industrial effluents [5] containing disease-causing micro-organisms and chemicals. Organic manure, municipal waste, and agricultural wastes such as fungicides in runoff often contain fairly high concentrations of chemicals and substances that end up into groundwater [6]. These impurities may give water a bad taste, color, odor, or turbidity, and cause hardness, corrosiveness, staining, or frothing. Material mixing and reactions changes the borehole water physicochemical and biological characteristics, affecting water quality. Water quality reflects the composition of water as affected by natural processes and human activities, and therefore a need to establish water quality in the natural hydrological cycle.

Groundwater is usually reserved for the subsurface water that occurs beneath the water table in soils and geological formation. It supports drinking water supply, livestock needs, irrigation, industry and many commercial activities. Groundwater is generally less susceptible to contamination and pollution when compared to surface water bodies. Also, the natural impurities in rainwater and runoff, which replenishes groundwater systems, get removed while infiltrating through soil strata. But in Tanzania, where groundwater is used intensively for domestic, agricultural, and industrial purposes, a variety of land and water-based human activities are causing pollution of this precious resource. This area is experiencing deteriorating water quality resource associated with unplanned urbanism. Importantly, groundwater also can be contaminated by naturally occurring sources such as soil and geological formation that contain high levels of chemicals that can leach into groundwater depending on soil type and depth of water table [6]. Pollution of groundwater due to industrial effluents and municipal waste is another major concern in many cities and industries of developing countries.

Until recently, most of the water supplied to Dar es Salaam came from the Ruvu River, the single most important water source. New water sources for the city were proposed by Dar es Salaam Supply Authority in 2005 that included groundwater in and around the city. Most of the shallow wells are used to augment local water supplies in the city.

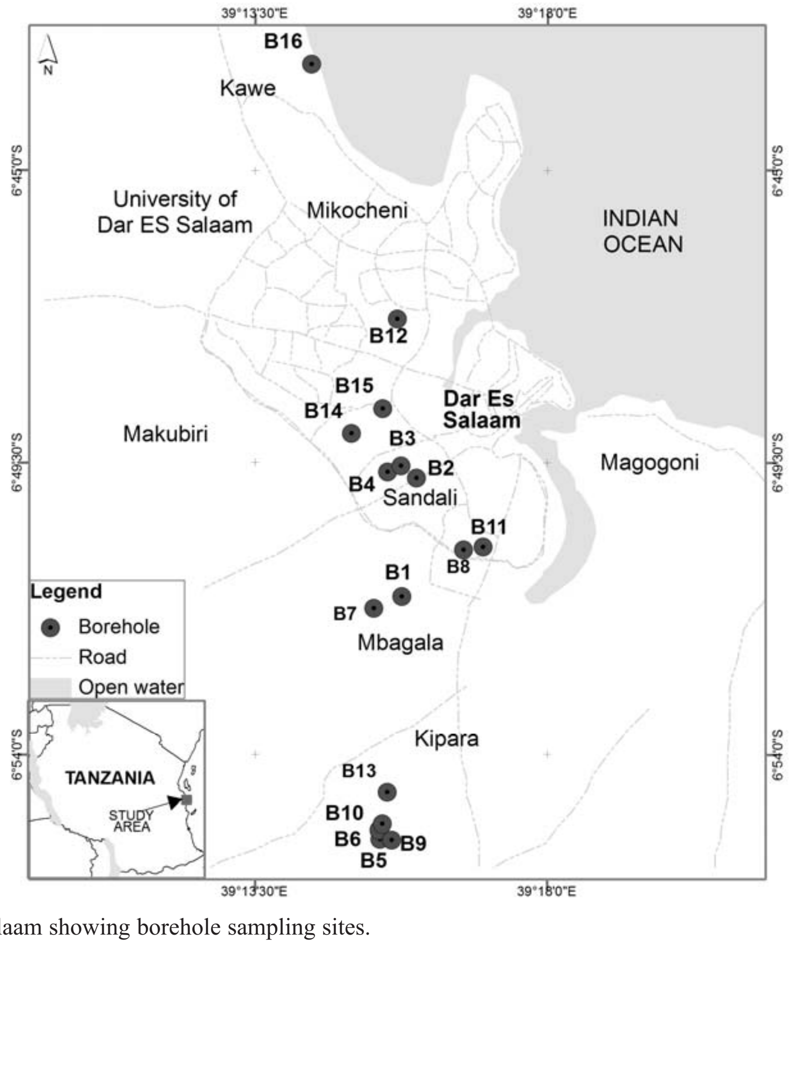

Fig. 1. Map of Dar es Salaam showing borehole sampling sites.

Table 1. Description of the study sites for the borehole water.

Location	Code	GPS Coordinates		Activity/Establishment
		Easting	Northing	
Temeke hospital	B1	529021	9241776	Residential and hospital
Shauri Moyo	B2	529437	9245142	Residential
Amana Ilala	B3	528619	9245314	Residential and commercial
Ilala Boma	B4	528999	9245488	Residential and market
Nzasa III	B5	528402	9234890	Residential and slum
Nzasa I	B6	528380	9235144	Residential and slum
Tandika Mabatini	B7	528227	9241446	Residential
Polisi Farasi	B8	531329	9243184	Residential
Nzasa IV	B9	528733	9234866	Residential and slum
Nzasa II	B10	528466	9235318	Residential and slum
Chang'ombe teacher college	B11	530778	9243110	Residential and university
Kinondoni primary school	B12	528891	9249662	Residential and primary school
Mbagara Kiburugwa	B13	528611	9236212	Residential and slum
Kigogo primary school	B14	527599	9246408	Residential, slum and primary school
Mzimuni primary school	B15	528478	9247116	Residential and primary school
Msimbazi Mseto	B16	526376	9256918	Residential and slum

The wells derive water from shallow Neogene and Holocene formations [7] consisting mainly of sands and reefal limestone. The Kimbiji aquifer may present a sustainable source of water greater than that demanded by the city at present [8]. The aquifer system is susceptible to cross-flow between aquifer sources and surface flow pollution. Water quality issues of underground and surface water resources in Tanzania arise from geological characteristics, terrigenous influx, and anthropogenic effects [9-14]. While most people in urban cities of developing countries have access to piped water, several others still rely on wells, boreholes, and river water.

The objectives of this work were:

(1) to establish possible sources that influence borehole potable water quality

(2) to determine water quality status of borehole water sources in Dar es Salaam city in Tanzania.

Materials and Methods

Study Area

Dar es Salaam is the major industrial and commercial centre of Tanzania, located along the coast. Dar es Salaam city covers an area of 1,393 km^2, with a population of 2,497,940, (Tanzanian Population and Housing Census, 2002). The city is situated on latitude 6° 45' and longitude 39° 18' (Fig. 1). The study covered three districts that include Kinondoni, Ilala, and Temeke. The three districts have 73 wards, but only 25 wards located within the primary network were covered. The main sources of water in the study area are boreholes, wells, piped water, water reservoirs, and rivers. The area receives a bimodal type of rainfall in the month of October to December and March to May, with rainfall ranging between 800 and 1,300 mm annually.

Water Sampling

Samples were collected from 16 boreholes using 500 ml polyethylene bottles for physical and chemical analysis of water quality characteristics. Water samples were purposely collected. Electrical conductivity (Ec), pH, total dissolved solids (TDS), temperature (T), chloride (Cl^-), turbidity (Td), color (Col), nitrates (NO_3), ammonia (NH_3), total hardness (TH), aluminium (Al), manganese (Mn), iron (Fe), calcium (Ca), total coliform (Tc), and faecal coliform (Fc) were analyzed. Water samples for microbiological examination were collected using 250 ml bottles. Sampling was done twice a week for four months. Sample bottles were initially washed using deionized water and double-rinsed with the water to be sampled. Bottles were wrapped in aluminium foil and transported in an ice box at 4ºC to Dar es Salaam Water and Sewerage Corporation central laboratory for analysis.

Determination of Physical and Chemical Characteristics of Water

Water quality characteristics such as pH, EC, TDS, and temperature were determined directly on site using portable meters. Other parameters such as turbidity and color were analyzed using the Palintest system. Chemical parameters were analyzed using a photometer model 5000 at different wavelengths using specific tablet reagents, as described in the Palintest system.

Microbiological Examination

Total coliform and faecal coliform were determined using the multiple tube fermentation test method (as recommended by [15]) to establish the bacteriological quality of borehole water. Faecal coliform were streaked onto plates of MacConkey and Levine's Eosin Methylene Blue agar and incubated at 35ºC for 24 h for confirmation and/or to isolate indicator organism in the water sample. Coliform densities were calculated.

Statistical Analysis

Correlation Analysis

Pearson correlation was adopted to analyze and establish inter-metal, bacterial, and physico-chemical relationships of the borehole water.

Cluster Analysis (CA) and Factor Analysis (FA)

CA was performed to classify variables of different sources on the basis of their similarities using dendrograms and to identify relatively homogeneous groups of variables with similar properties for purposes of source apportionment. FA was employed on the variables that are correlated to isolate or determine specific factors that are associated with such groupings of physico-chemical characteristics so as to establish their origin. The data was standardized to give a normal distribution.

Results

Bacterial Counts and Physic-Chemical Characteristics of Borehole Water

Results of bacterial counts, metal, and physic-chemical characteristics are shown in Table 2. Faecal coliform counts ranged between 0 and 1, whereas total coliform ranged between 0 and 3. They exceeded the maximum permissible limits of 0/100 ml [16] at Shauri Moyo and Kigog primary school for faecal coliform, and 1/100 ml Tanzanian guidelines at Temeke hospital, Shauri Moyo, Nzasa I and Polici Farasi for total coliform. Boreholes at site 1B, 2B, 6B, and B8 had total coliform above the Tanzanian and NEMA limits for potable water. Electrical conductivity ranged between 262.95 and 1,241.5 (us/cm) with a mean value of 625.03 us/cm, and exceeded the maximum permissible limit of 400 (us/cm) [16] at most of the sites. Water color ranged between 10 and 16.25 Hazens and exceeded the maximum permissible limit of 15 Hazens at Nsaza IV [16]. Borehole water at sites 4, 5, 10, and 12 were below WHO maximum permissible limits and the Tanzanian target limit of potable water for all measured parameters. Also, water color was above [16] maximum permissible limits and the Tanzanian target limit of 15 hazens of potable water at site 9. Sites 2 and 14 are associated with feacal coliform and with high concentrations of Ca. The pH of borehole ranged between 6.38 and 7.68, with a mean value of 6.915, therefore regarded as near neutral. These values are within the [16] permissible limits of potable/drinking water. Such pH values that are near neutral may suggest unpolluted borehole water. Temperature at all sites exceeded the [16] maximum permissible limit of 12 for potable water. Turbidity ranged between 1.51 and 2.97 NTU at B11 and B14 respectively. Total dissolve solids values ranged between 97.33 and 285.58 mg/l. Turbidity and total dissolved solids of the borehole water were within the range of potable water ($\leq$ 5 NTU and $\leq$ 1000 mg/l, respectively) of [16] and [17] and Tanzanian ($\leq$ 10 NTU and $\leq$ 1000 mg/l, respectively). Total hardness of borehole water ranged between 40.75 and 215.38 Hazens with a mean value of 140.62 Hazens [18] classified potable water based on the hardness values as:

i) Soft (0-60 mg/l)
ii) Moderately hard (61-120 mg/l)
iii) Hard (212-160 mg/l)
iv) Very hard (> 160 mg/l)

Borehole water at site B1 is classified as moderately hard (> 160 mg/l) and moderately hard for sites B5, B7, B8, B9, B10, and B11, and the rest were very hard (TH > 160 mg/l). The sources of hardness in the borehole water were mainly due to calcium attributed to anthropogenic activities, terrigenous influx, and/or natural processes within the aquifers. Aluminium concentrations ranged between 0.02 and 0.23 mg/l and exceeded the [16] maximum permissible limits of 0.1 mg/l at sites B1, B7, B11, B14, and B16. The chloride concentration values ranged between 47.0 and 188.1 mg/l. The highest value of chloride was observed at site B2, which was attributed to entry of sewage from pit latrines, bathing activities, runoff, and organic matter into the underground water. Most of the borehole sites apart from 4, 5, 10, and 12 are unfit as drinking water sources. The major contaminants are aluminium and calcium derived geochemically/naturally and/or anthropogenically, and faecal coliform, attributed to terrigenous influx in runoff and anthropogenic sources such as sewage from pit latrines and/or organic matter.

Source Apportionment of Contaminants in Borehole Water

Results on Pearson correlation analysis are presented in Table 3. A significant correlation between Tc/Fc (r=0.564), Ec/TDS (r=0.672), Ca/Ec (r=0.624), Ca/TDS (r=0.627), TH/Ec (r=0.650), TH/Ca (r=0.881), and Cl^-/Alk (r=0.987) in the underground water was observed and the rest of the

Table 2. Bacterial counts and metal and physicochemical characteristics in borehole portable water in Dar es Salaam.

Sites	Fc	Tc	Ec	Col	pH	Temp.	Td	TDS	Al	Fe	Mn	NH_4	NO_3	Cl^-	Ca	Alk	TH
								mg/l									
B1	0	**2**	262.95	11.25	7.11	**29.2**	2.29	97.33	**0.22**	0.01	0.01	0.04	1.31	107.75	88	64	123.25
B2	**1**	**3**	**713.25**	12.75	7.1	**30.3**	2.2	196.76	0.09	0.04	0.04	0.56	4.77	188	**148.25**	106.25	197
B3	0	0	**812**	12.23	6.91	**30.55**	2.48	285.58	0.05	0.05	0.01	0.02	0.19	144.5	**153.5**	207.5	192
B4	0	1	**691.5**	12.25	7.19	**29.7**	2.53	186.75	0.02	0.01	0.01	0.14	0.71	61.88	**167.25**	288.4	191.15
B5	0	0	346.5	13	6.4	**30.25**	1.81	108.15	0.09	0.05	0.06	0.01	2.27	175.38	29.5	109.5	40.75
B6	0	**3**	276.88	10	6.45	**30.35**	1.9	105.2	0.09	0.03	0.01	0.01	2.85	41.93	**51.5**	72.25	53.75
B7	0	0	**829.75**	11.5	6.42	**29.9**	1.88	189.13	**0.18**	0.02	0.02	**1.46**	0.96	134	**132**	18	159.95
B8	0	**2**	**703.78**	14.25	7.12	**30.9**	1.97	150.6	0.13	0.03	0.08	0.92	0.26	74	**145.75**	143.75	142.5
B9	0	0	**449.9**	**16.3**	6.38	**30.65**	1.62	150.28	0.07	0.01	0.01	0.05	1.69	58.2	44.25	92.53	60.1
B10	0	0	**455.5**	12	6.49	**30.4**	2	152.8	0.11	0.14	0.01	0.01	0.59	47	46.25	23.75	82.75
B11	0	0	**444.25**	11.75	6.68	**30.23**	1.51	156.93	**0.16**	0.02	0.01	0.02	3.26	119.5	**113.75**	221.25	156
B12	0	0	**583.25**	12.5	7.03	**30.85**	2.05	219.6	0.02	0.04	0.01	0.06	14.74	51.9	**210**	210	210
B13	0	0	**643.5**	11.25	7.19	**30.2**	2.45	279.4	0.1	0.03	0.01	0.1	5.22	82.25	84.5	62.4	65.75
B14	**1**	1	**1023.5**	14	7.06	**30.83**	2.97	255.58	**0.19**	0.03	0.02	0.31	1.7	151.63	**206.25**	136.8	178.65
B15	0	0	**1241.5**	13	7.68	**30**	2.26	145.45	0.08	0.02	0.03	0.18	5.08	151.18	94	188.5	215.38
B16	0	0	**522.5**	10.5	7.43	**33.15**	1.78	222.75	**0.23**	0.04	0.01	0.04	0.4	134.5	101	189.5	181
Mean Value			**625.03**	**12.41**	**6.92**	**30.47**	**2.11**	**181.39**	**0.11**	**0.04**	**0.02**	**0.25**	**2.88**	**107.73**	**113.48**	**133.40**	**140.62**
*Tanzania (2005)	**0**	**1**	**400**	**15**	**6.5-8.5**		**5**	**1000**	**0.2**	**0.3**	**0.1**	**0.5**	**30**	**200**	**75**	**600**	**500**
**[17]	**0**	**0**		**10**	**6.5-8.5**		**10**	**500**	**0.1**	**0.3**	**0.1**		**10**	**250**	**75**		
***[16]	**0**		**400**	**15**	**6.5-9.2**	**12**	**5**	**1000**	**0.1**	**0.3**	**0.4**	**1.5**	**50**	**250**	**100**		**500**

*Tanzania (2005) maximum permissible limits for drinking water;
**[17] maximum permissible limits for drinking water; Fc – Faecal coliform;
***[16] maximum permissible limits for drinking water;
Tc – total coliform, Ec – electrical conductivity (us/cm), Temp. – Temperature (OC), Td – Turbidity (NTU), TDS – total dissolved solids (mg/l), Alk – alkalinity; TH – total hardness, Col – color (Hazen)

Table 3. Pearson correlation matrix of bacteria, metals, and physico-chemical characteristics of the borehole water in Dar es Salaam.

	Tc	Fc	Ec	TDS	Col	Td	Al	Mn	NH_4	NO_3	Ca	Alk	Cl^-	TH
Tc	1.000													
Fc	**0.564***	1.000												
Ec	-0.226	0.173	1.000											
TDS	-0.348	0.132	**0.672****	1.000										
Col	0.000	0.183	0.348	0.056	1.000									
Td	0.231	0.497	0.492	0.443	0.025	1.000								
Al	0.081	0.304	-0.155	-0.124	-0.275	-0.128	1.000							
Mn	0.278	0.096	0.153	-0.258	0.412	-0.077	0.006	1.000						
NH4	0.228	0.199	0.477	0.138	0.177	0.051	0.237	0.482	1.000					
NO3	-0.072	0.120	0.023	0.026	-0.011	-0.016	-0.350	-0.110	-0.177	1.000				
Ca	0.143	0.351	**0.624****	**0.627****	0.028	0.494	-0.001	-0.061	0.403	0.078	1.000			
Alk	0.017	-0.001	0.223	0.219	0.196	0.127	-0.319	0.075	-0.355	0.149	0.405	1.000		
Cl-	0.014	-0.018	0.182	0.192	0.169	0.092	-0.332	0.026	-0.385	0.197	0.348	**0.987****	1.000	
TH	0.005	0.278	**0.650****	0.486	0.008	0.347	0.063	-0.087	0.320	0.002	**0.881****	0.427	0.378	1.000

*Correlation significant at p=0.05; **Correlation significant at p=0.01 (2-tailed); Fc – faecal coliform, Tc – total coliform, Ec – electrical conductivity, Td – turbidity, TDS – total dissolved solids, Alk – alkalinity, TH – total hardness, Cl^- – chlorides

pairs were not significantly correlated. Calcium (Ca^{2+}) is correlated with total dissolved solids, turbidity, total hardness, alkalinity, and ammonia. Total dissolved solids comprise some organic matter and inorganic salts such as calcium, aluminium, chlorides, manganese, and carbonates.

In this study, the association of electrical conductivity, total dissolved solids, and total hardness with Ca suggest its influence on the quality of underground water. The main constituent of total dissolved solids was Ca. Total dissolved solids in water affects the taste of potable water when it is above [16] permissible limits. However, all other variables did not correlate with total coliform and feacal coliform, counts as an attribute of good water quality.

The relationship between calcium and total hardness is shown in Fig. 2. Calcium is linearly correlated with electrical conductivity, total dissolved solids, and total hardness, suggesting water hardness contribution in regulation of cationic-metal discharges in the underground water. Cationic metals are released into water geochemically by ionic exchange reactions and weathering of minerals in rocks or aquifers influencing electrical conductivity. High water hardness was attributed to high amounts of dissolved calcium in water derived geochemically and/or from anthropogenic sources. Conductivity and calcium at most sites were above the WHO maximum permissible limit of 400 µs/cm for conductivity and 100 mg/l for Ca in drinking water, but are within the range for Tanzanian and upper limits of 400-1500 µs/cm for conductivity and 75-200 mg/l for Ca.

Cluster analysis was performed on the data using Ward linkage and correlation coefficient distance. Results of cluster analysis are shown in Fig. 3. Five Factors with eigenvalues > 1 were extracted in the analysis. Water quality variables were fused into cluster because of their physicochemical association and similarity of coefficients. Group I contained total and faecal coliform. Group II contained aluminium. Group III contained manganese, ammonia, and water color. Group IV contained electrical conductivity, total dissolved solids, calcium, total hardness and turbidity. Group V contained alkalinity and chlorides.

The biplot of elemental, physicochemical parameters, bacteria, and sites suggests that total dissolved solids (TDS), turbidity (Td), electric conductivity (Ec), calcium (Ca), and total hardness (TH) are high and are associated with sites 2, 3, 13, 14, and 15. Total coliform was associated with sites 1, 6, 5, and 9. Faecal coliform was associated with sites 2 and 14 as well as turbidity, ammonia, total dissolved solids, electrical conductivity, total hardness, and water color.

The results of the FA based on the correlation matrix of water quality variables are expressed in Table 4. The first five factors account for 84.8% of the total variance or inertia in the data set. Factor 1 contributed 26.7% of the total variance and contained conductivity, calcium, total hardness, total dissolved solids, ammonia, and turbidity with high variable loadings, and corresponds with group IV in cluster analysis. This factor seems to be attributed to geochemical and/or anthropogenic sources. High levels of total hardness were attributed to entry of sewage and soil from anthropogenic sources containing calcium into the ground water [19]. Conductivity is attributed to dissolved ions and substances in water such as calcium, total dissolved solids, and aluminium, which in turn affects water quality [14]. However, turbidity is a measure of water quality and may

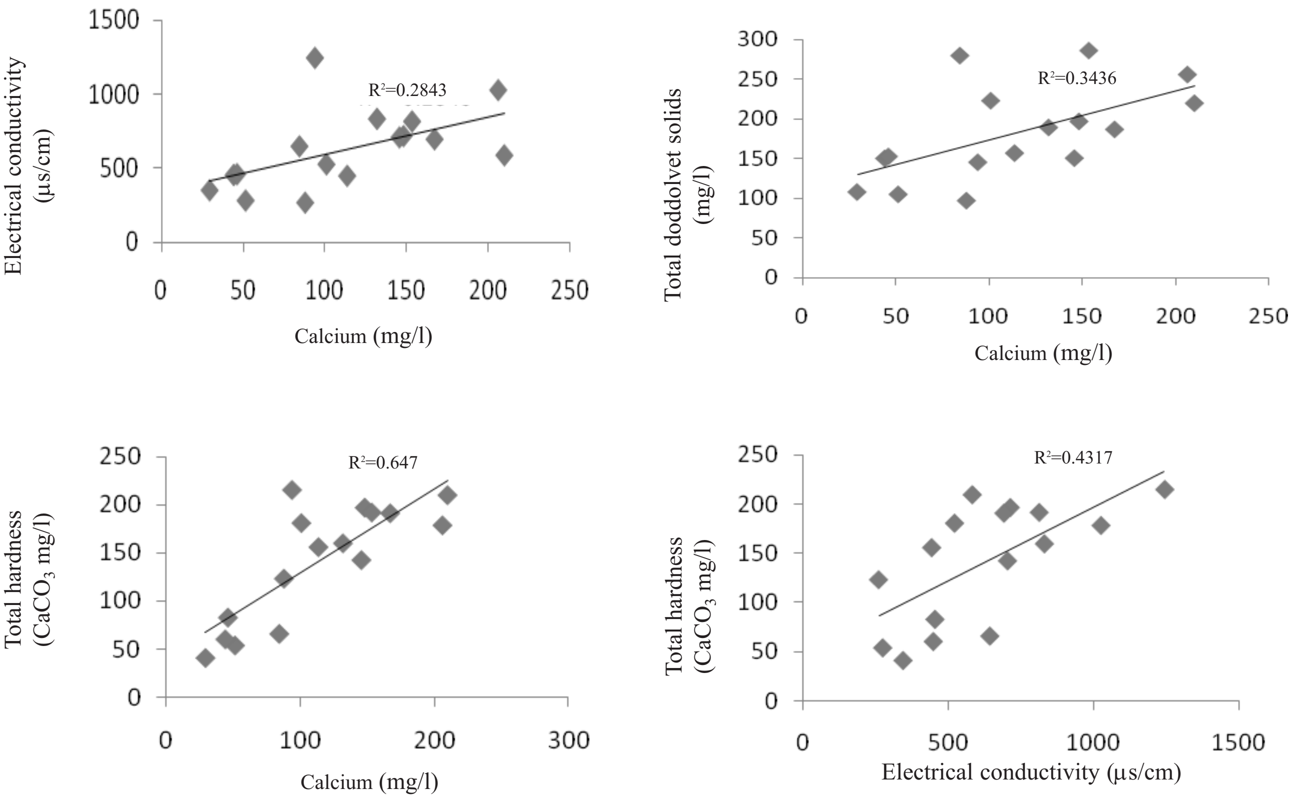

Fig. 2. Scatter plots of physico-chemical characteristics of borehole portable water.

suggest seepage of sewage or organic matter into the underground water as an anthropogenic source. Factor 2 accounts for 18.0% of the variance and contains alkalinity and chloride with high variable loadings and corresponds with group V of the cluster analysis. Chloride and alkalinity may be attributed to organic decomposition, domestic sewage and/or geochemical processes in underground water.

Factor 3 accounts for 14.9% of the variance and contains total coliform and faecal coliform, as well as turbidity, and corresponds with group I of the cluster analysis. The association of faecal coliform with turbidity suggests the entry of sewage form pit latrines/septic tanks, soil and/or organic matter into the underground water. Classification of Turbidity under Factor 1 and 3 suggest dual sources of contaminants from sewage and soil/organic matter at sites B2, B13, and B14. Total coliform and faecal coliform suggest the presence of pathogenic disease-causing bacteria or viruses in such water [20, 21]. Factor 4 accounts for 14.2 % of the total variance and contains water color, manganese, and ammonia with high variable loadings, and corresponds with group III of the cluster analysis. This may suggest the influence of manganese on the color of the borehole water. The presence of ammonia is an indication of organic waste attributed to domestic sewage. Ammonia in water is an indicator of possible bacterial, sewage, and animal waste pollution [16]. Factor 5 accounts for 11.0% of the total vari-

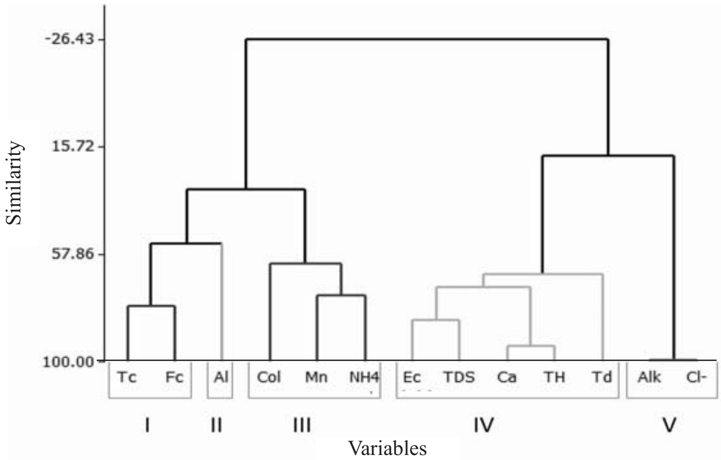

Fig. 3. Dendrogram of bacteria, metals, and physico-chemical characteristics in drinking water samples at different borehole sites (n=16).

Table 4. Varimax rotated factor loadings and communalities of chemical variables of borehole drinking water in Dar es Salaam (n=16).

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Communality
Total Coliform (Tc)	-0.243	-0.102	**0.828**	-0.233	-0.182	0.843
Faecal Coliform (Fc)	0.218	0.056	**0.859**	-0.069	-0.075	0.799
Electrical conductivity (Ec)	**0.878**	-0.008	-0.029	-0.278	0.229	0.902
Total Dissolved Solids (TDS)	**0.838**	-0.011	-0.083	0.228	0.208	0.804
Colour (Col)	0.095	-0.085	0.052	**-0.621**	0.557	0.715
Turbidity (Td)	**0.526**	0.05	**0.615**	0.225	0.339	0.822
Aluminium (Al)	-0.012	0.268	0.141	-0.001	**-0.77**	0.684
Manganese (Mn)	-0.12	-0.05	0.109	**-0.885**	0.027	0.814
Ammonia (NH_3)	**0.444**	0.407	0.097	**-0.662**	-0.313	0.909
Calcium (Ca)	**0.838**	-0.304	0.263	-0.035	-0.197	0.904
Alkalinity (Alk)	0.188	**-0.961**	0.013	-0.019	0.151	0.982
Chloride (Cl^-)	0.141	**-0.961**	-0.001	0.019	0.157	0.969
Total hardness (TH)	**0.799**	-0.368	0.116	-0.042	-0.295	0.877
Variance	3.4743	2.3391	1.9365	1.8506	1.4238	11.0244
% Var	**0.267**	**0.18**	**0.149**	**0.142**	**0.11**	**0.848**

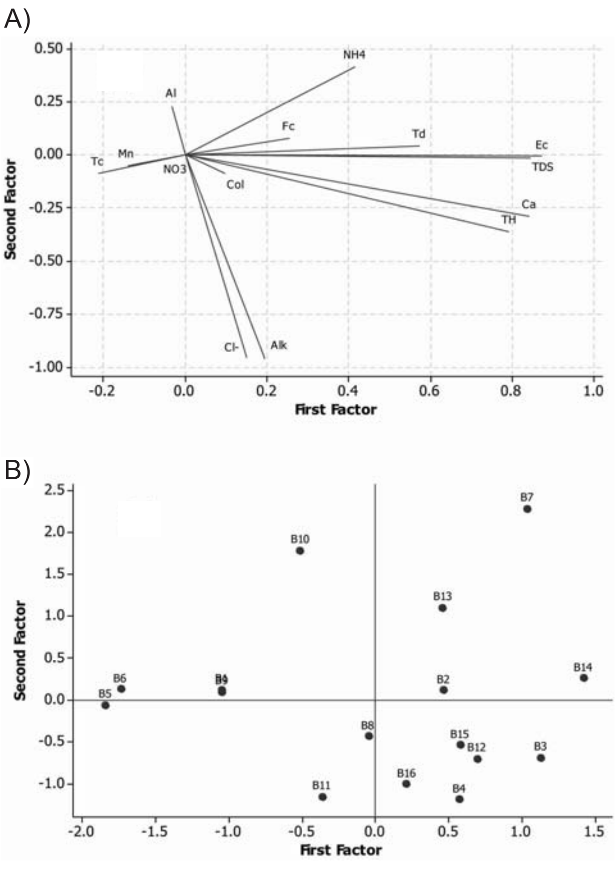

Fig. 4. A biplot of factor analysis (FA) of water quality variables (A) and sampling sites (B) of borehole water (n=16).

ance and contains aluminium with high variable loadings and correspond with group II of cluster analysis. This may suggest the influence of geochemical processes in the rocks or aquifers.

Discussion

Some sites of borehole water were contaminated with faecal coliform and total coliform, and their presence is an indication of bacteriological quality of water [20] due to anthropogenic activities from septic systems and animal sources [4, 19]. Consumption of contaminated drinking water with faecal coliform puts human health at risk [3, 22-24]. This phenomenon of ground water pollution is attributed to urbanism.

The pH of borehole water was described as near neutral. These values are within the [16] permissible limits of potable/drinking water. Such pH values that are near neutral and are therefore within the range of potable water (6.5-9.2) may suggest unpolluted borehole water [25, 26].

Total dissolved solids Turbidity values are within [16] acceptable limits of potable water and may be attributed to natural filtration mechanisms in the aquifers [27]. Borehole water with high turbidity values may amount to a health risk [24].

The highest chloride values in borehole water at some sites is indicative of pollution, especially of animal origin such as entry of sewage from pit latrines, bathing activities, runoff, and organic matter into the underground water [5, 14, 27]. Chloride content in water increases with the level of eutrophication [5, 14]. High chloride concentrations in drinking water are associated with heart and kidney diseases such as kidney stones [28].

Borehole water was generally classified as hard, with a mean value of 140.62 mg/l. The sources of hardness in the borehole water were mainly due to calcium attributed to anthropogenic activities, terrigenous influx in run off, and/or natural processes within the aquifers [14, 19, 27].

Conclusions

Most of the sites studied had good potable water, except for a few that were contaminated by faecal contamination and aluminium, which was attributed to anthropogenic activities such as entry of sewage into the underground water and natural processes. There is a need for water to be treated or boiled before consumption. Water hardness was mainly influenced by calcium in the underground water. Factor analysis generated three sources of pollutants in the underground water:

(1) mixed origin of human wastes and soil in runoff characterized by calcium, total dissolved solids, ammonia and turbidity
(2) dual sources of turbidity characterized by human wastes (Factor 3) and entry of soil/organic matter into the underground water as indicated by ammonia (Factor 1)
(3) natural/geochemical processes in the rocks or aquifers characterized by aluminium and magnesium.

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