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Research Article

Water Quality Assessment of Groundwater Using Multivariate Statistical Techniques: A Case Study of Mogadishu, Banadir Region, Somalia

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Abstract

This study was carried out to assess the groundwater quality around the Mogadishu area, Banadir region, Somalia. Multivariate statistical techniques such as factor analysis (FA), principal component analysis (PCA) and cluster analysis (CA)were applied to 22 groundwater samples collected from boreholes and dug wells in the coastal line districts namely: Wadajir, Kaxda and Dharkinley districts of Banadir region, Somalia. Correlations among 14 hydrochemical parameters were statistically examined. A two-factor model is suggested and explains over 82.4% of the total groundwater quality variation. Factor Analysis (FA) revealed significant variables including electrical conductivity (EC), pH value and other parameters such as K^+, Ca^{2+}, Mg^{2+}, Na^+, SO_4^{2-} and hardness expressed as $CaCO_3$, Chlorine, Fluoride, B, S, Si, and NO_3 which are responsible for variations in groundwater quality and affect water chemistry. The results were compared with the World Health Organization (WHO) standard guidelines. Geographic Information System (GIS) was used to create the spatial distribution maps of water quality parameters. Cluster Analysis (CA) grouped all sites into three zones based on spatial similarities and dissimilarities of physiochemical properties. The pH value and Boron, fluoride calcium, magnesium, sulfide, potassium, and Silica are well within the desirable limit at all locations. However, the concentration of conductivity chloride, hardness as $CaCO_3$, sulfate, nitrate, and Sodium in all samples exceeded the desirable WHO maximum permissible limit. The study reveals that the groundwater quality changed due to anthropogenic and natural influences such as natural weathering processes. As a result of this the qualities of the boreholes and dug well water samples were therefore not suitable for human consumption without adequate treatment. Regular monitoring of groundwater quality, abolishing unhealthy waste disposal practices, and introducing modern techniques are recommended.

Keywords

Multivariate Statistical Techniques, Groundwater Quality, Mogadishu, Somalia

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1. Introduction

As a matter of fact, water is an essential natural resource for the sustainability of life among all organisms, plants, and higher-order animals, including man [5, 12]. It has been proven that while humans can go for several weeks without food, this is impossible without water, which is a vital element for replenishing body fluids lost through physiological processes [15]. Moreover, Water plays a crucial role in the body's ability to eliminate pollutants. [6]. Therefore, the lack of an adequate supply of clean water is a serious challenge in developing countries [21], especially in Somalia. The quality of water can vary from one rock type to another and within aquifers along groundwater flow paths and differs markedly from various geological environments [13]. The composition of groundwater is influenced by many processes, including wet and dry depositions of atmospheric salts, evapotranspiration, and water–soil, and water–rock interactions [18]. The concentrations of naturally occurring chemicals, such as chloride, Silicon, Magnesium, Calcium, and sodium, etc. are not of health concern at levels but may affect drinking water's acceptability [5]. World Health Organization (WHO) published guidelines for drinking water to protect public health [21]. The main sources of drinking water in Somalia are primarily rivers, groundwater such as boreholes, and wells which are largely untreated and may be associated with various health risks. Furthermore, the neglect of the water sector in Somalia, in terms of basic infrastructures such as sanitation facilities exposes the communities to various health-related problems such as water–borne diseases [6, 22]. Therefore, the health concern of the water is necessary for public health policy formulation [2].

The application of different multivariate statistical techniques, such as principal component analysis (PCA), factor analysis (FA) and cluster analysis (CA) helps in the interpretation of complex data matrices to better understand the groundwater quality and allows the identification of possible factors/ sources that influence water systems and offers a valuable tool for reliable management of water resources as well as rapid solution to pollution problems [1, 5, 7, 18-20]. Therefore, this study assesses the levels of some physical and chemical water quality parameters in Boreholes and dug wells located in three Districts alongside coastal areas in west of Mogadishu city, Banadir region, Somalia. Multivariate statistical techniques were also used to identify the possible cause of groundwater salinization in the coastal aquifer of Banadir region.

2. Materials and Method

2.1. Study Area

As the capital, Mogadishu is in the south of Somalia bordering the Indian Ocean, in northern latitude of 2°4′ and east longitude of 45°22′, and it is the eastern most city in African continent. Due to Somalia's location on the equator, there is relatively little seasonal variation in climate. The weather is hot throughout the year, with mean maximum temperatures of 30–40 °C (86–104 °F) except at higher elevations and along the Indian Ocean coast. Mean daily minimums usually vary from about 15 ℃ to 30 ℃ (60 ℉-85 ℉). The research was conducted within Mogadishu particularly three districts namely: Wadajir, Kaxda and Dharkinley districts, Their coordinates of the sampling points. were highlighted in *Table 1*.

Table 1. *Coordinates and Depths of the Sampling Points in selected Districts.*

Sampling area	Site code	District	Latitude	Longitude
Timacade	W1	Wadajir	2.023308	45.28498
Timacade	W2	Wadajir	2.019378	45.28799
Timacade	W3	Wadajir	2.0145	45.28376
Timacade	W4	Wadajir	2.016731	45.28244
Tarbush	W5	Wadajir	2.008944	45.28039
Halane	W6	Wadajir	2.016624	45.28654
Waaxda janaraal da'uud	W7	Wadajir	2.020485	45.29191
Waaxda janaraal da’auud	W8	Wadajir	2.02229	45.29022
Halane	W9	Wadajir	2.015493	45.30131
Halane	W10	Wadajir	2.015502	45.3013
Abaadir	K1	Kaxda	2.022505	45.24252

Sampling area	Site code	District	Latitude	Longitude
Cumar firaagero	K2	Kaxda	2.06531	45.23893
Cumar fiyaasko	K3	Kaxda	2.066551	45.23236
Indhoolaqaala	K4	Kaxds	2.02449	45.23737
2 Abaadir	K5	Kaxda	2.03792	45.2365
Waaxda 2aad xanaano bulsho	D1	dharkenleey	2.031998	45.28413
Waaxda 2aad xanaano bulsho	D2	dharkenleey	2.035029	45.27894
Waaxda 1aad. Washkax	D3	dharkenleey	2.020074	45.27891
Boocle	D4	dharkenleey	2.023504	45.28065
Kaabo Godeey	D5	dharkenleey	2.016628	45.27009
Cali jareere	D6	dharkenleey	2.017184	45.27778
Waxda 3aad	D7	dharkenleey	2.013614	45.27571

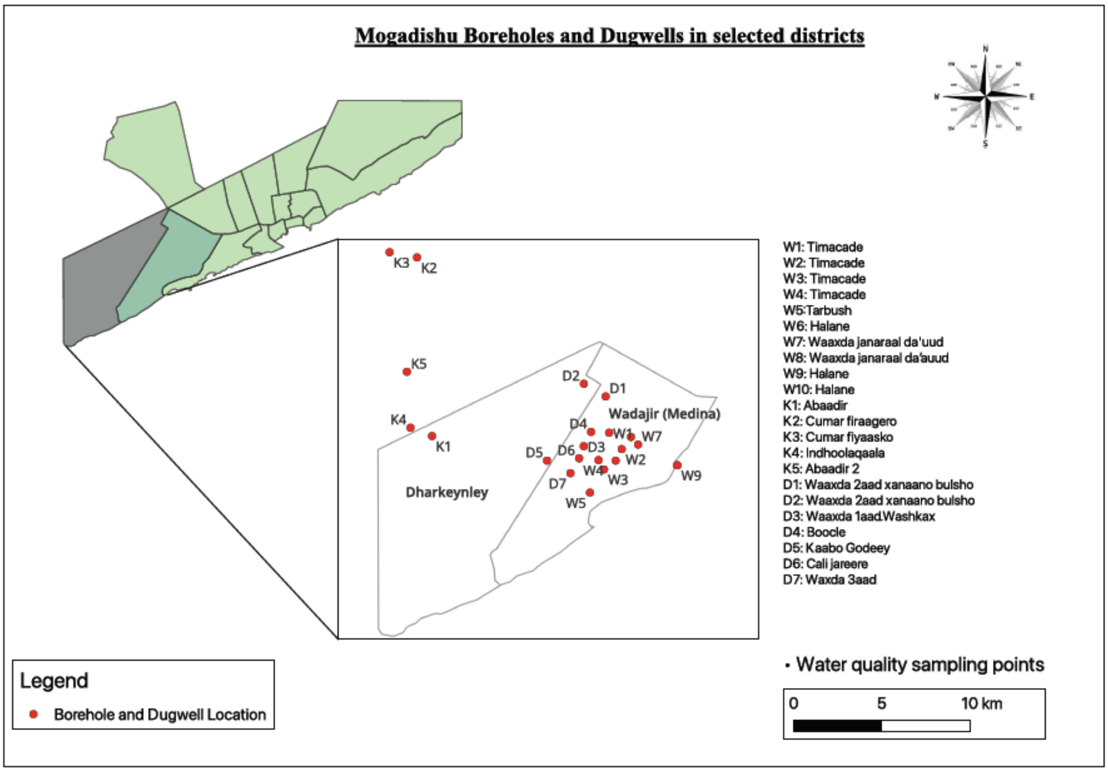

Figure 1. Map of the study area and sampling locations for 22 groundwater samples chosen for analysis. These samples were taken from dug wells and boreholes in the Wadajir, Kaxda, and Dharkinley districts along with coastal area, Mogadishu, Somalia.

2.2. Water Sampling

Water samples were collected between November 2018 and January 2019 from Three different districts namely Wadajir, Kaxda and Dharkenley districts, Mogadishu, Banadir region Somalia (*Figure 1*). All samples were collected, preserved, and stored for analysis as outlined in the Standard Methods for the examinations of Water and Wastewater [1, 3]. One and two litter poly- ethylene bottles were used to determine the chemical properties of the water. The bottles were kept at 4 ℃ and were analyzed within 24 h [5]. All sampling bottles were washed with de-ionized water and again with filtered sample water. A total of 22 boreholes and dug wells were sampled for chemical analyses, each sample being analyzed for the parameters listed in *Tables 2 and 3* Parameters that were measured and recorded at the time of sampling were electrical conductivity (EC), pH value. Other parameters such as K^+,

Ca^{2+}, Mg^{2+}, Na^{+}, $SO_4^{2-}$and hardness expressed as $CaCO_3$, Chlorine, Fluoride, B, S, Si and NO_3 were analyzed in the laboratory. Quantum Geographic Information System (QGIS) was used to create the spatial distribution maps of sampling points and the version 3.3 server was used to identify and collect samples from wells and boreholes for geospatial data.

2.3. Statistical Methods

Multivariate statistical technique was used to evaluate the ground water quality of the boreholes and dug wells of the target area [4]. The data sets were analyzed and evaluated statistically using IBM SPSS.20 Software.

2.3.1. Factor Analysis

Factor analysis, a multivariate statistical method, yields the general relationship between measured chemical variables by showing multivariate patterns that may be helping to classify the original data. It enables the geographical distribution of the resulting factors to be determined [3, 17]. The geological interpretation of factors yields insight into the main processes, which may govern the distribution of hydrochemical variables [8, 10, 11].

2.3.2. Principal Component Analysis (PCA)

Principal Component Analysis (PCA) is One of the methods frequently used to explain the variance of a large dataset of inter-correlated variables with a smaller set of independent variables [20, 22]. The objective of the PCA was to determine the unobserved factors responsible for the data structure when the whole data set is considered (all sites, all parameters). In this way a comparison of the factor's role could be made on a large scale (all sites together) or on a local scale (separate sites) [10, 21]. Kaisere-Meyere-Olkin (KMO) and Bartlett's test were performed. KMO is a measure of sampling adequacy that indicates the proportion of variance, which is common variance, i.e., which might be caused by underlying factors [16]. High value (close to 1) generally indicates that principal component/ factor analysis may be useful, which is the case in this study: KMO= 0.87. Bartlett's test of sphericity indicates whether correlation matrix is an identity matrix, which would indicate that variables are unrelated. The significance level which is 0 in this study (less than 0.05) indicates that there are significant relationships among variables [12].

2.3.3. Cluster Analysis (CA)

The goal of the Cluster Analysis (CA) was to find natural groupings of samples such that samples within a group are more like each other, generally than samples, in different sites and times. The resulting clusters of objects should then exhibit high internal (within-cluster) homogeneity and high external (between clusters) heterogeneity [16]. Hierarchical agglomerative clustering provides intuitive similarity relationships between any one sample and the entire data set and is typically illustrated by a dendrogram [12].

3. Result and Discussion

3.1. Physicochemical Parameters

The physical–chemical parameters from twenty-two sampling points alongside three districts namely: Wadajir, Kaxda, and Dharkinley Districts are given in *Tables 2 and 3*.

The pH values ranged from 7.39 to 8.01. all Sampling points recorded pH values which are below the World Health Organization (WHO) recommendation for both drinking water (6.5–8.5). The electrical conductivity values ranged from 1.42 to 7.09 µs/cm. Water ability to conduct electric current is referred to as electrical conductivity and serves as parameter to assess the purity of water depending on the presence of ions, their total concentration, mobility, valence, relative concentrations, and temperature [13]. The electrical conductivity values at all sampling points were above the WHO guidelines for domestic water (0.25 µs/cm). This might be attributed to dissolved bicarbonate, sodium, sulfate, magnesium, and calcium salts in addition to other anions such as chlorides and fluorides (*Tables 2 and 3*). Generally, this is a measure of the dissolved ionic components in water and hence the electrical behavior of the water [13]. The hardness of water indicates water quality mainly in terms of Ca 2+ and Mg 2+ expressed as $CaCO_3$ because it consists mainly calcium and carbonates the most dissolved ions in hard water. According to World Health Organization (WHO), hardness of water should be 200 mg/L. In this study, hardness ranges from 372-1470 mg/l in all locations. These values were found to be above the WHO limits. The main sources of calcium in natural water are various types of rocks, industrial wastes, and sewage. Health studies indicate that hardness in water has no known adverse health effects.

Table 2. *Analytical data for the groundwater samples from the study area.*

Physicochemical parameters,	Sampling points										
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	WHO standards
pH	7.45	7.39	7.58	7.74	7.7	7.62	7.44	7.39	7.76	7.75	6.5-8.5
EC	6	6.59	4.91	3.53	6.12	3.91	4.92	7.09	4.7	1.42	0.25

Physicochemical parameters,	Sampling points										
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	WHO standards
NO3	217	384	125	55.3	22.5	33.5	12.3	405	174	5.8	50
K	11	20.7	13.8	11.3	15.9	12	13.7	27.2	16.9	4.76	N/A
Ca	244	238	189	195	217	243	280	284	146	73	200
Mg	184	188	110	92.8	143	92.9	189	174	115	46.3	100
S	329	331	231	188	239	195	250	230	148	92.2	N/A
SO4	986	992	692	563	716	584	749	689	443	276	400
B	1.42	1.6	1.49	0.84	1.25	0.77	0.47	1.93	1.57	0.26	2.4
Na	823	967	730	460	895	475	537	960	685	151	200
Cl	1210	1400	1020	677	1570	857	1160	1810	1070	142	250
F	0.28	0.41	0.47	0.34	0.52	0.24	0.34	0.53	0.74	0.38	1.5
Si	23.8	25.4	25.6	25.2	24.9	26.5	22.9	27.5	27.9	23	N/A
CaCO3 (mg/L)	1360	1370	924	868	1130	988	1470	1420	837	372	200 __

*W= Wadajir, * N/A= Not available
*Units: pH (standard units), electrical conductivity (µS/cm), ion concentrations K, Ca, Mg, Na, SO_4 and hardness expressed as $CaCO_3$, Chlorine, Fluoride, B, S, Si and NO_3 (mg/L)

***Table 3**. Analytical data for the groundwater samples from the study area.*

Physicochemical parameters	Sampling points												
	K1	K2	K3	K4	K5	D1	D2	D3	D4	D5	D6	D7	WHO standards
pH	7.67	7.98	8.01	7.73	7.96	7.52	7.67	7.82	7.72	7.75	7.89	7.68	6.5-8.5
EC	1.83	2.41	2.82	2.06	1.58	4.81	3.35	6.36	3.06	6.76	5.99	5.78	0.25
NO3	2.61	1.51	2.88	2.08	4.03	169	10.2	239	13.3	167	94.3	181	50
K	7.19	5.96	6.67	5.02	2.72	20.1	14.5	11.3	7.75	10.8	9.62	11.8	N/A
Ca	123	174	185	174	129	288	219	269	185	253	195	215	200
Mg	87.4	123	144	140	79	155	106	156	72.9	164	118	144	100
S	173	238	260	192	146	261	194	346	162	256	273	273	N/A
SO4	518	713	779	575	437	782	581	1040	485	767	818	818	400
B	0.41	0.36	0.46	0.2	0.11	0.96	0.65	1.56	0.61	1.58	1	1.38	2.4
Na	199	207	266	53	87	627	396	966	315	900	726	916	200
Cl	164	281	394	203	136	996	665	1390	601	1720	1430	1330	250
F	0.35	0.3	0.22	0.23	0.39	0.29	0.3	0.38	0.31	0.6	0.5	0.44	1.5
Si	23	22.6	24.5	22.6	20.9	29.4	28.8	27.8	26.9	26.3	24.6	29.5	N/A
$CaCO_3$	666	939	1050	1010	646	1360	982	1310	761	1300	971	1130	200

*K = Kaxda, *D = Dharkinley, * N/A= Not available*Units: pH (standard units), electrical conductivity (µS/cm), ion concentrations K, Ca, Mg, Na, SO_4 and hardness expressed as $CaCO_3$, Chlorine, Fluoride, B, S, Si and NO_3 (mg/L).

The concentration of fluorides in all sample collection sites ranged between 0.22 and 0.74 mg/L. These values were considerably below the WHO recommended guideline for drinking water set at 1.5 mg/L [23]. Drinking water rich in fluoride concentration has deleterious effects on human health and the worst-case scenario, skeletal problems [3]. Luckily the data predict that people around these three districts areas are safe from risks associated with skeletal fluorosis. In this study, the levels of sulfates ranged from 276 to 1040 mg/L. These levels were found to be above the WHO limits of 400 mg/L [23]. Except Location W10 which was recorded 276 mg/L which is below the WHO limits. All sampling points were believed to receive effluents from domestic waste and recorded the highest concentration of sulfates (*Tables 2 and 3). No health-based guideline is proposed for sulfate. However, drinking water with sulfate concentrations above 200 mg/L may also lead to gastrointestinal irritation and bowel discomfort [23]. All sampling locations in this study had Sulfide levels that ranged from 92.2 to 346 mg/L there is no recommended limit of Sulfide in water. All sites located in Wadajir and Kaxda were found to have nitrate values lower than (50 mg/l) recommended by WHO for safe drinking water except for four sites located in Wadajir District namely W1, W2, W4, and W8 that were above the permeable WHO level, the concentration of nitrate in these sites was recorded at 217 mg/l, 384 mg/l, 55.3 mg/l, and 405 mg/l respectively. However, all the sites in Dharkinley were found to have high levels of nitrate. Two sites namely: D2 and D4 were found to contain low concentrations of nitrate and were recorded at 10.2 mg/l and 13.3 mg/l. The main sources to nitrate contamination of water could be from animal and human waste, industrial effluent, and pesticides, fertilizers, and silage used in drainage systems. The results considered that the groundwater of the study area, in general, cannot be considered of good quality because its concentration of chloride in all sites was high. Chloride values were above the acceptable WHO limits of 250 mg/l for domestic water. The range of chloride in the water samples was 601 to 1810 mg/l. Except for four sites namely W10, K1, K4, and K5 that were within the permeable WHO level, the concentration of chloride in these sites was recorded at 142 mg/l, 164 mg/l, 203 mg/l, and 136 mg/l respectively. High chloride concentration in water could be due to contamination by the chloride arising from, anthropogenic activities and intrusion of seawater and other saline water. It is widely distributed in nature in form of sodium, phosphate, and calcium salts. There is no health–based guidelines on the values that are recommended for chloride in drinking water; however, chloride concentration in excess of about 250 mg/l can give rise to abhorrent taste in water [23]. Clearly, the concentrations of sodium in all sample sites in Wadajir and Dharkinley District were observed to be high. Its concentration in all the sampling points was above the WHO guideline of 200 mg/l for domestic water. The values ranged between 315 to 967 mg/l. Except for the W10 site which was recorded at 151 mg/l. However, all the sites in the Kaxda district were found to have low levels of Sodium. The values ranged between 53 to 199 mg/l. Two sites namely: K2 and D3 were found to contain high concentrations of Sodium and were recorded at 207 mg/l and 266 mg/l. Studies have shown that high intake of sodium in drinking water may lead to hypertension in pregnant women and serious neurological damage occasioned by high intake of sodium [2,14].The levels of potassium in this study ranged from 2.72 to 27.2 mg/L. Although there is no recommended limit of potassium in water however, increased exposure may result in significant health effects in people with kidney disease or other conditions, such as heart disease and diabetes [9]. All sampling points located in Wadajir and Dharkinley were found to have calcium values higher than WHO (200 mg/l) except for six sites located in Wadajir and Dharkinley Districts namely W3, W4, W9, W10, D4 and D6 that were below the permeable WHO level [23], the concentration of calcium in these sites was recorded at 189 mg/l, 195 mg/l, 146 mg/l, and 73 mg/l 185 mg/L and 195 mg/L respectively. However, all the locations in Kaxda District were found to have low levels of calcium. Calcium is important for good health, and levels between 20 and 30 mg/L are desirable in drinking water. The level of magnesium in all locations reported that was above the WHO limit of 100 mg/L [23] except for six sampling points located in Wadajir, Kaxda and Dharkinley Districts namely W4, W6, W10, K1, K5, and D4 that were below the permeable WHO level [23], the concentration of magnesium in these sites was recorded at 92.8 mg/l, 92.9 mg/l, 46.3 mg/l, 87.4 mg/L, 79 mg/L and 72.9 mg/L respectively. Like calcium magnesium is a major dietary requirement for humans. Its concentration is very significant when considered in conjunction with that of sulfate [23]. Furthermore, the levels of boron in this study were lower than the World Health Organization (WHO)'s recommended limit for boron in groundwater (2.4 mg/L), ranging from 0.11 to 1.93 mg/L for most water sampling regions, boron concentrations in drinking water vary greatly and depend on the surrounding geology. Boron is typically present in groundwater primarily as a result of leaching from rocks and soils containing borates and borosilicates [23]. All sampling locations in this investigation had silicon levels that ranged from 20.9 to 29.5 mg/L (*Tables 2 and 3*). The most common element in rocks is silicon (as silica), therefore natural groundwater will always contain it. However, according to the World Health Organization (WHO), there are no clear health effects of silicon in water.

3.2. Multivariate Statistical Analysis of Analytical Data

To test the suitability of the data for Factor Analysis (FA), Kaiser-Mayer-Olkin (KMO) and Bartlett's test were employed. As it is highlighted in *Table 4*, in this study, the KMO index was 0.746 and it is greater than the threshold of 0.6, a high value (close to 1) generally indicates that the data are suitable for principal component/factor analysis. Bartlett's test of Sphericity of which it was 711.649 with a degree of freedom of 91 indicates that the physicochemical parameter analysis in this study for water quality assessment of groundwater have enough correlation for factor extractions. In this study, the significance level is less than 0.05 (sig = 0.000), which indicates that there are significant relationships among the variables. Fourteen hydrochemical parameters were considered in the study because of their significance.

Table 4*. KMO and Bartlett's test for Water quality assessment of groundwater.*

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		**.746**
Bartlett's Test of Sphericity	Approx. Chi-Square	711.640
	Df	91
	Sig.	.000

PCA/FA was performed on the normalized data set (14 variables) separated in three districts (Kaxda, Wadajir and Dharkenley) as indicated by the Factor Analysis techniques, to identify the factors influencing each other. There were (14 parameter x 7 boreholes/dug wells) for Dharkinley district, (14 parameters x 10 boreholes/dug wells) for wadajir district and (14 parameters x 5 boreholes/dug wells) Kaxda district. It was performed separate data analysis for each data for Kaxda, Dharkinley and Wadajir sites with Eigenvalues greater than 1, explaining 95.746%, 88.490% and 85.885% of the total variance in respective water quality data sets.

An Eigenvalue gives a measure of the significance of the factor: the factors with the highest Eigenvalues are the most significant. Eigenvalues of 1.0 or greater are considered significant.

For the data set belongs to Kaxda, among 3 factors, Factor 1, Factors 1 has an eigenvalue of 9.463 and illustrates 67.59% of the total variation and has strong positive loading (>0.7) on Calcium (Ca), Magnesium (Mg) and hardness as Calcium Carbonate ($CaCO_3$).

Factor 2 has an eigenvalue of 2.25 and explains 16.073% of the variance has a strong positive loading (>0.7) on Sodium (Na), K, and Silicon (Si). This Factor represents the intrusion effect on groundwater quality, factor 3 has an eigenvalue of 1.692 and illustrates the lowest (12.083%) of the total variation and has strong positive loading (>0.7) on pH only has neither negative nor positive loadings. This factor can be interpreted as pH normal of all sampling sites.

For the data sets representing the Dharkinley district, Factor 1 has an eigenvalue of 8.519, explaining 60.853% of the total variation and has strong positive loading (>0.7) on EC, NO_3, B, Mg, S, SO_4. This factor represents effect of intrusion and human activity on water sampling area.

Factors 2 has an eigenvalue of 3.529 and explaining 27.637% of the total variation and has strong positive loading (>0.7) on K, Si and strong negative loading on pH. This factor represents the geological structure effect on quality of the water.

For the data sets representing Wadajir district, Factors 1 has an eigenvalue of 9.068 and explaining 64.768% of the total variation and has strong positive loading (>0.7) on hardness of water as Calcium Carbonate ($CaCO_3$), Silicon (Si), Sulfate (SO_4), and Magnesium (Mg) and strong negative loading on PH. This factor represents the human and animal activity effect on sampling sites. Factors 2 has an eigenvalue of 2.956 and explaining 21.116% of the total variation and has strong positive loading (>0.7) on Calcium Silicon (Si), B, F and K. This factor represents the rocks, industrial wastes, and sewage effect on the quality of groundwater sampling sites.

Table 5*. Kaxda district (three significant principle component).*

Parameters	**Factor 1**	**Factor 2**	**Factor 3**
CaCO3	.983	.162	.081
Mg	.979	.176	.008
Ca	.963	.144	.220
F	-.938	-.212	.086
EC	.738	.597	.313
S	.728	.607	.292
SO4	.728	.607	.292
Cl	.677	.592	.430
NO3	-.599	-.301	.461

Parameters	Factor 1	Factor 2	Factor 3
B	.195	.979	-.051
Na	.055	.948	.308
K	.225	.895	-.385
Si	.526	.788	-.053
pH	.203	.053	.961
Na	.965	-.150	
Eigenvalue	9.463	2.250	1.692
% total variance	67.590	16.073	12.083
Cum % variance	67.590	83.663	95.746
Dharkinley district (three significant principle component)			
EC	.947	-.294	
NO3	.947	.181	
B	.945	-.147	
Mg	.936	.293	
S	.915	.000	
SO4	.914	.000	
Cl	.892	-.385	
CaCO3	.854	.477	
K	.145	.907	
pH	.205	-.903	
Si	-.010	.863	
Ca	.649	.663	
F	.583	-.651	
Eigenvalue	8.519	3.529	
% total variance	60.853	27.637	
Cum % variance	60.853	88.490	
Wadajir district			
Wadajir district (three significant principle component)			
CaCO3	.952	.172	
S	.948	.031	
SO4	.948	.030	
Mg	.929	.207	
pH	-.896	-.061	
Ca	.875	.102	
EC	.805	.569	
Cl	.723	.614	
Na	.702	.654	
Si	-.131	.866	
B	.403	.854	

Parameters	Factor 1	Factor 2	Factor 3
Fl	-.312	.828	
K	.498	.799	
NO3	.511	.648	
Eigenvalue	9.068	2.956	
% total variance	64.768	21.116	
Cum % variance	64.768	85.885	

Spatial CA rendered a dendrogram (*Figure 2*), where all twenty-two sampling sites on the dug wells and boreholes were grouped into two statistically significant clusters at (Dlink/Dmax)×100< 60. Cluster one consisted of groundwater W1, D1, W6, D4, W3, W9, K2, K3, K4, K1, K5 and W10. Cluster two consisted of Groundwater W7, D2, W2, D3, W1, D5, D6, W5, D5 and W8. The group classifications varied with significance level because the sites in these groups had similar characteristic features and natural backgrounds that were affected by similar sources. Sites with modest levels of contamination are under Cluster 1. The locations of the sampling points in Cluster 1's districts are all along the seashore. These stations are contaminated by human activity and the entrance of seawater. Sites that are comparatively heavily contaminated fall under Cluster 2. The sampling locations in Cluster 2 are located at their respective shoreline sites. These sampling locations are impacted by surface runoff from settlements, pollution from anthropogenic activities, and seawater intrusion. A useful classification of the groundwater watercourses in the study area was produced using hierarchical CA, which might be used to create a more cost-effective future spatial monitoring network.

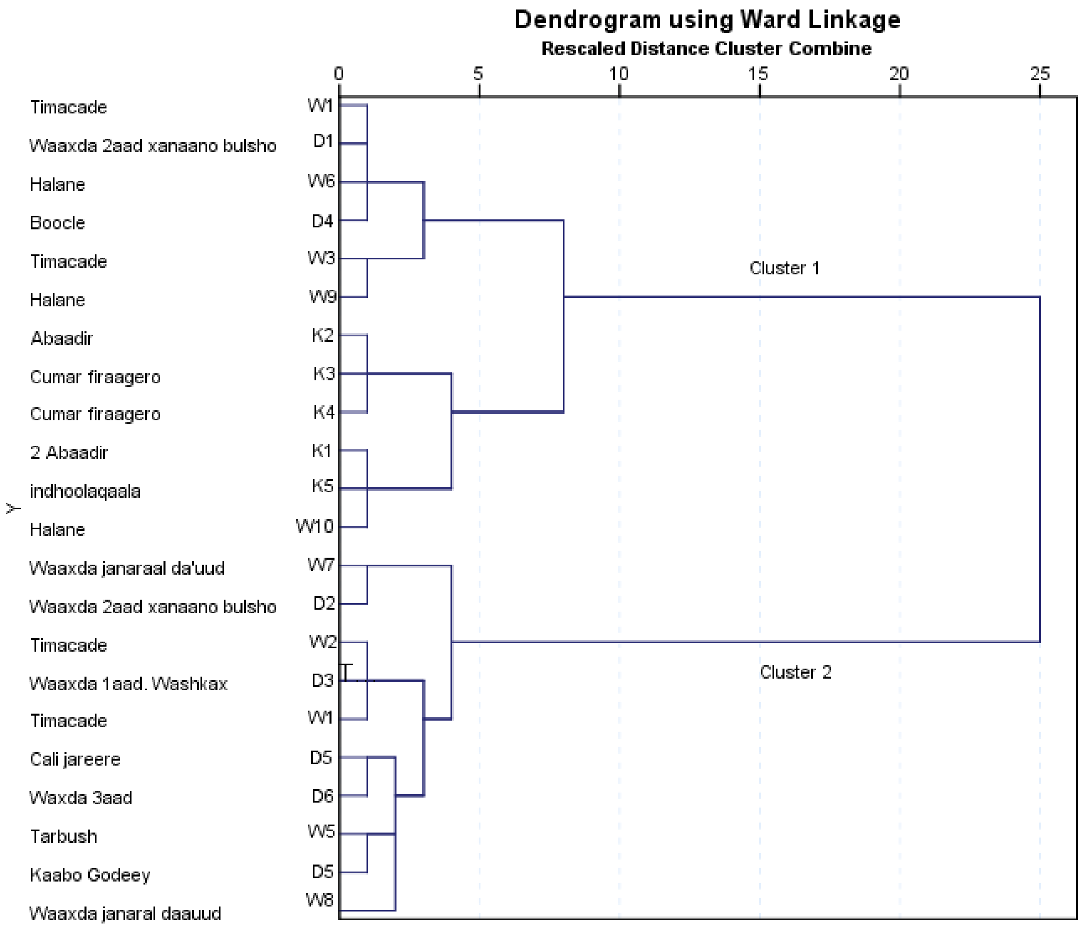

Figure 2. *Dendrogram showing clustering of 22 sampling sites of dug wells and boreholes in the Wadajir, Kaxda, and Dharkinley districts along with coastal area, Mogadishu, Somalia.*

4. Conclusion

Groundwater is one of the main sources of drinking water in and around the Mogadishu city. Its quality is getting deteriorated due to untreated discharge of urban effluent. The urban population relies on dug wells and boreholes for all their groundwater requirements. The uncontrolled disposal of urban wastes and the closeness of these districts to the coastline area are the primary causes of groundwater contamination. The results considered that the groundwater of the study area, in general, cannot be considered of good quality because its concentration of chemical parameters in all sites was high. This study has also demonstrated that some parameters such as pH, fluorides, boron, and silicon values were within WHO limits indicating that water is acceptable as drinking water purposes. On the other hands electrical conductivity, hardness of water, Chloride, sodium, potassium, sulfate, Sulfide, were above the World Health Organization permissible limit. These elevated concentrations may serve as precursors for waterborne diseases. Nitrate level in Dharkinley district was found to be above permeable WHO standard and some locations in Wadajir district as well. For calcium concentration was found that slightly higher that WHO limits especially sampling point located in both Wadajir and Dharkinley districts. However, the Calcium level of locations in kaxda district was found to be within the WHO standard. Most area showed that there is a slightly high concentration of magnesium in water. Therefore, continuous evaluation of ground water quality is very important for public safety and environmental monitoring. Nonetheless, this work has provided a baseline for the categorization of hazardous chemicals potentially affect the quality of natural groundwater. This study also shows the usefulness of Multivariate Statistical Techniques in groundwater quality assessment, and identification of significant parameters to get better information about the source of pollution. The analytical results of sampling sites, monitored in this study irrespective of pollution source, revealed that groundwater from these sites required further purification to ensure its suitability for human consumption. The results of this study stress the need for environmental awareness, adequate regulations, and proper management of waste sites by the local municipal authorities. There is a need to check water pollution by implementing strictly pollution control laws and strict control on the disposable of untreated effluents around the areas close to water supply system needs to be enforced. High concentrations of nitrates and other hazardous substances in the groundwater quality in the country in general and Mogadishu City need to be evaluated.

Abbreviations

WHO: World Health Organization
FAO: Food and Agriculture Organization
QGIS: Quantum Geographic Information System
mg/L: milligrams per liter
µS/cm: Microsiemens Per Centimeter

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Conflicts of Interest

The authors declare no conflicts of interest.

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