Hydrochemical characteristics of groundwater and its suitability for drinking and irrigation uses in Makutupora Sub-basin, Tanzania

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Hydrochemical Characteristics of Groundwater and its Suitability for Drinking and Irrigation Uses in Makutupora Sub-basin, Tanzania

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Abstract. The focus of this study was to assess the suitability of groundwater for drinking and irrigation uses in Dodoma Municipality. Hydrochemical investigations was conducted in Dodoma urban where twenty water samples were collected from boreholes/wells to monitor physico-chemical quality. Groundwater samples were measured for pH, Chloride, Nitrate, Electric Conductivity, Total Dissolved Solids and Temperature in situ while major ions (Na^{+}, Ca^{2+}, K^{+}, Mg^{2+}, NO^{3-}, Cl^{-}, $SO4^{2-}$ and HCO^{3-}) were analyzed in the laboratory. It was found that the physico-chemical properties of the groundwater varies from fresh to brackish and it is slightly acidic to alkaline. The Na^{+} and Mg^{2+} were dominant cations while Cl^{-} and HCO^{3-} were dominant anions. Furthermore, the results show that for most groundwater quality parameters in Dodoma Municipality are suitable for drinking and irrigation uses. As for Chloride, the average concentration of about 1568.21mg/l seems to be unpalatable for drinking. However, for the Chloride which was found at a range of 710-960mg/l in few boreholes can be used for grapes irrigation, the main crop in the area, and 180-600 mg/l that was found in only one borehole is suitable for stone fruits irrigation. The Nitrate concentration complies with the Tanzania Bureau of Standards (TBS) and the World Health Organisation (WHO) limits for drinking purposes since its concentration was below 50 mg/l. Several groundwater management strategies and recommendations were proposed to control the quality of the groundwater and to get rid of groundwater problems. Furthermore, the study recommends frequent groundwater quality monitoring and integration of groundwater into the water resources management for the benefit of all of Dodoma Municipal people.
Keywords : *Hydrochemical characteristics; Semi-arid region; Groundwater; Domestic and Irrigation uses; Sodium Adsorption Ratio*

INTRODUCTION

The global population growth, technological and socio-economic development, and climatic changes have tremendously increased the demand for fresh water [1]. The groundwater is mostly used for drinking, irrigation and industrial purposes in arid and semi-arid areas. The Central Tanzania is semi-arid area, which mainly depends on groundwater [2, 3]. The poor quality water may lead to negative impacts to human and environmental health [4]. Furthermore, irrigation with poor quality water affects the soil physical properties and consequently crop yield [5]. However, the physicochemical quality of the groundwater in Central Tanzania remains poorly understood. Therefore, this calls for studying groundwater quality in this part of the country.

In Tanzania water plays a central role and impacts all sectors of the economy including domestic, agriculture, livestock, industry, and recreation. Majority of rural population depend on groundwater from shallow wells and recently the use of groundwater has expanded in urban areas having inadequate surface water resources. The water supply coverage in most Tanzania rural and urban areas is around 54% and 73% respectively [6]. Conversely, the shortage of surface water sources has made groundwater to be the only source of water in semi-arid regions of Tanzania including Dodoma Region [2, 7, 8]. The Dodoma region falls within the semi-arid climate, with a population

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of about half a million people. The main source of groundwater in Dodoma Municipality is from Makutupora well field. This study was therefore, carried out with the aim of assessing the physico-chemical characteristics of groundwater in Dodoma and asses its suitability for domestic and irrigation purposes.

METHODOLOGY

Description of the Study Area

This study was undertaken in Dodoma Municipality (Fig. 1) which is located between Latitudes 6.00º and 6.30º South, and Longitude 35.30º and 36.02º East. The Municipality covers an area of 2,669 km^2 where the urbanized is 625 km^2 [9]. According to 2012 National Census [9], the population of Dodoma Municipality is 410,956 people.

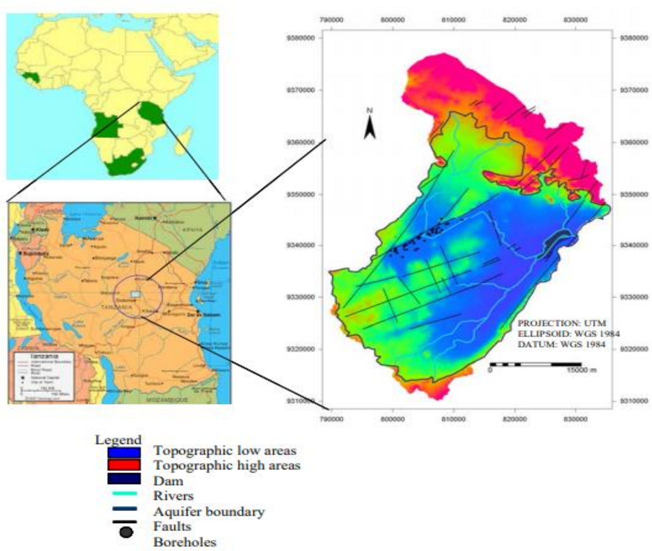

FIGURE 1. *A map of study area [2]*

The climate of Dodoma region is semi-arid with relatively warm temperatures all over the year. The average maximum temperature of the region (26°C) are somewhat consistent throughout the year, the average minimum temperature is around 21 °C [2]. The study area has a single rainfall season which starts on December to March while other months remaining practically dry. The region has low mean annual rainfall is 550 mm and high evapotranspiration of 2000 mm [2]. Geologically, the study area is underlain by crystalline basement formations predominantly granites gneiss, schists and amphiboles [7, 10]. The formation belongs to the Dodoman craton, the oldest formation. The weathered granitic basement zone stores sandy materials, which form a regolith of about 50 m. These geological formations store substantial amount of groundwater mainly through fractures [10].

Sample Collection and Analysis

Twenty (20) water samples were collected in May 2020 just after the end of wet season using prewashed polyethylene bottles after well purging. Two samples were taken from each well, one for determining anions, the other for determining cations. The water samples for cations determination were filtered and acidified with supra pure nitric acid to pH<2 then refrigerated at 4ºC prior to analysis at laboratory. The physical parameters (pH, temperature, electrical conductivity (EC) and total dissolved solids (TDS)) were measured at sampling points using a multimeter Model Eijkelkamp 18.52.SA pH/mV/EC/T/Sal/TDS/DO. The NO_3^- and SO_4^{2-} were determined calourimetrically using HACH spectrophotometer (Model DR/2400, USA). Carbonate, bicarbonate and chloride were analysed by titration method using digital titrator (HACH) (Model 16900). The cations (Na^+, K^+, Ca^{2+} and Mg^{2+} Fe and Mn were analysed using ICP-OES by direct aspiration of water samples into the plasma.

Suitability of groundwater for drinking was assessed based on local and international [11] standards and guidelines. While, the suitability for irrigation was determined by using EC, TDS, total hardness (TH), SAR, Na% and residual sodium carbonate (RSC) values [12, 13]. STATISTICA™ StatSoft 8.0 was used for all statistical analyses. The range, mean, median and standard deviation were calculated for different parameters, and factor analyses were performed.

RESULTS AND DISCUSSION

Descriptive statistical summary of physico-chemical properties of groundwater in the study area presented in Table 1. The pH of sampled groundwater ranged from 5.6 to 8.2 (slight acidic to alkaline) with an average value of 7.4 and median of 7.4 indicating that most samples are alkaline. Most groundwater samples had their pH within 6.5 and 8.5, the range recommended for drinking water [11, 14]. The EC ranged between 527 and 2710 µS/cm with average of 962 µS/cm and median of 796 µS/cm. Correspondingly, TDS ranged between 870 and 3400 mg/l with average of 1329 mg/l and median of 1085 mg/l. The groundwater can be classified as desirable for drinking if the TDS value is less than 500 mg/l while above this value to 1000 mg/l the water is permissible for drinking [11, 15]. In the study area 55% of water sources had TDS above 1000 mg/l, the WHO maximum allowable values for drinking water.

TABLE 1. *Descriptive statistics of chemical analyses of groundwater examined in this study*

Parameter	Minimum	Maximum	Average	Median	Standard deviation
EC (µS/cm)	527	2710	962	796	521
TDS (mg/l)	870	3400	1329	1085	633
pH	5.6	8.2	7.4	7.4	0.7
Na^+ (mg/l)	46	486	111	75	101
K^+ (mg/l)	30	130	50	42	26
Ca^{2+} (mg/l)	2.2	13.0	4.7	3.5	2.6
Mg^{2+} (mg/l)	56.5	276.0	114.5	79.1	59.9
Fe^{2+} (mg/l)	bd	0.500	0.095	0.100	0.110
Mn^{2+} (mg/l)	0.002	2.458	0.191	0.019	0.540
Cl^- (mg/l)	71	4757	1568	1127	1173
SO_4^{2-} (mg/l)	17	145	77	76	32
NO_3^- (mg/l)	0.26	5.94	2.91	3.46	1.94
HCO_3^- (mg/l)	92	580	328	320	125
F (mg/l)	0.10	0.80	0.35	0.30	0.22
TH (Mg/l)	237	1155	477	332	254
SAR	1.02	6.21	2.09	1.80	1.20
$\%Na^+$	23.4	51.0	38.0	39.9	8.1
RSC	-21.67	2.94	-4.27	-2.10	6.31

bd = below detection

Hydrogen-ion concentration: pH

The pH in the study area ranges between 5.6 and 8.2 with median and average of 7.4 as shown in Table 1. According to the World Health Organisation [11] lower and upper limits for quality of drinking water are 6.5 and 9.2 respectively. This does not appear to be a big problem in the study area where the samples from almost all boreholes/wells were within the range pH 6.6 – 8.2 (mildly acidic to neutral), except for borehole number 13 S/W in which its pH was out of the range i.e. 5.6 (Table 2). This low pH at borehole number 13 S/W is probably associated with products from the reaction of the dissolving of the feldspathic mineral known as “albite”, little calcite dissolution, and human activities taking place around this borehole.

TABLE 2. *Physical-Chemical parameter of groundwater samples measured in the study area*

S/N	Sample Id	EC (µS/cm)	TDS (mg/l)	pH	Na^+ (mg/l)	K^+ (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Fe^{2+} (mg/l)	Mn^{2+} (mg/l)	Cl^- (mg/l)	SO_4^{2-} (mg/l)	F (mg/l)	HCO_3^- (mg/l)	NO_3^- (mg/l)
1	Mzakwe B/H 147/78	686	910	7.90	67	36	3.3	76	0.10	0.02	1118	83	0.50	427	1.45
2	Mzakwe B/H 117/75	640	990	8.00	84	42	3.6	75	bd	0.01	870	94	0.50	427	0.26
3	Mzakwe B/H C1	635	920	8.00	78	42	2.8	80	bd	0.01	763	105	0.60	549	1.01
4	Mzakwe B/H C3	548	910	8.00	74	43	3.2	62	bd	bd	621	112	0.70	366	0.26
5	Mzakwe B/H C5	527	870	8.20	82	56	3.4	78	0.10	0.02	497	76	0.80	580	0.44
6	Mzakwe B/H C8	633	900	7.90	83	49	3.4	74	0.10	0.23	1651	66	0.50	247	0.48
7	Mzakwe B/H C9	570	900	8.00	62	35	3.2	72	0.10	0.20	728	102	0.50	397	1.50
8	Mzakwe Tank No 2	709	970	7.90	72	30	3.0	74	0.10	0.01	763	57	0.60	458	1.12
9	St.Gabriel Veyula B/H Do. 114/94	776	1060	7.80	47	34	3.9	95	0.10	0.01	71	62	0.20	363	3.39
10	Miyuji Hon.Shekif B/H	1302	1730	6.90	110	112	6.1	199	0.10	0.17	2503	25	0.10	275	5.10
1	Tumaini Center	987	1350	7.30	76	51	4.9	177	bd	0.01	1828	75	0.20	336	3.65
12	Miyuji CPPS B/H	975	1390	6.70	75	37	5.6	163	0.10	0.16	1775	40	0.10	305	5.06
13	Chang'ombe-Mazengo Omary Kimwaga S/W	2710	3400	5.60	240	130	13.0	153	bd	2.46	4757	145	0.10	153	5.94
14	Sister of Mary Nzuguni B/H	817	1110	6.90	74	66	4.0	87	bd	0.16	941	95	0.30	305	3.52
15	Chinangali West: Mama Omari S/Well	698	950	6.60	69	48	2.2	57	0.50	0.22	1012	51	0.10	214	4.80
16	Makole: Kijogoo Garage S/Well	1640	2200	7.00	204	32	6.8	163	0.10	0.09	3621	56	0.30	366	3.78
17	Chuo cha Mipango B/H	816	1110	7.00	71	47	3.3	77	0.20	0.01	1136	121	0.20	275	4.80
18	Rasilimali za maji B/H	1515	2100	7.30	486	41	9.2	276	0.10	0.01	3053	73	0.10	92	3.92
19	Wakapochini Miyuji B/H	826	1130	6.90	46	34	3.4	78	0.10	0.03	1296	17	0.20	183	5.28
20	Kisasa Martin Luther B/H	1232	1680	7.50	115	42	5.0	177	0.10	0.01	2361	92	0.30	244	2.42

bd =below detection

Total Dissolved Solids and Electrical Conductivity

The TDS from the study area ranges from 870-3400mg/L and Electrical Conductivity values are in the range of 527-2710 μS/cm (Table 1). The water with a TDS level less than 500 mg/L is good and palatable for drinking [11]. Drinking water supplies with TDS levels greater than 1200 mg/L are unpalatable for drinking and this was found in samples from boreholes/wells number 10, 11, 12, 13, 16, 18 and 20 (Table 2) while neither of the rest boreholes has TDS levels less than 500mg/l.

For the case of irrigation, usually crop yield is independent of salt concentration when salinity is below some threshold level then yield gradually decreases to zero as the salt concentration increases to the level which cannot be tolerated by a given crop. The groundwater with TDS value of 450mg/l is suitable for irrigation of all types of crops [16]. In one hand, the TDS concentration between 450 and 2000 mg/l slightly to moderately restricted to some crops. In the other hand, TDS concentration of more than 2000 mg/l is severe restricted for irrigation. The samples taken from the boreholes/wells that are used for irrigation in the study area were all within the range of slight to moderate restrictions except boreholes/wells number 13, 16 and 18 (Table 2) having TDS of more than 2000mg/l that require severe restriction.

Nitrate Concentration

Nitrate concentration decrease away from Dodoma town as shown in Fig. 2. The concentration of nitrate in Dodoma town might be as a result of poor sewage systems for the collection of wastewater, fertilizers use, domestic wastes and petroleum products. Previously nitrate concentration was high about 31.87mg/l in Mkutupora well field; this was a result of human activities around Makutupora well field (i.e. septic tanks and animal dungs). But now the concentration has been dropped to 1.5mg/l. This is because of resettlement done in the area. Outside Makutupora well field the concentration at St Gabriel Veyula borehole in 2008 was 150mg/l [2] while now it is about 6 mg/l (Table 2). The total-nitrate levels were low in all boreholes/wells i.e. ranges from 0.26 to 0 5.94 mg/l with an average of 2.9 mg/l therefore were below the usual range for irrigation and domestic use (Table 1). The usual range for nitrate-nitrogen in irrigation and domestic use of water is 0 – 10 mg/l [16].

Chloride Concentration

The World Health Organisation [11] standard limit for chloride concentration in water is 200 mg/L. The Chloride concentration in the study area is 99% out of the range and only St. Gabriel Veyula borehole which is 71 mg/l was below the range (Table 3). Higher chloride concentration might be due to the disintegration of chloride rich rocks, together with human activities that generate chloride to groundwater. Therefore, groundwater in the study area is not suitable for drinking. Also for the case irrigation purpose the average range chloride concentration of about 710-960 mg/l suitable for grapes it occurs at boreholes number 3, 7, 8, 14 (Table 2). Again, the range of about 180-600 suitable for stone fruits occurs only at borehole number 5.

Factor Analysis

The PCA performed on 14 water quality variables yielded 14 principal components (PC) (Fig. 2(a)). Nevertheless, only 3 PCs with eigenvalue greater than 1 (Fig. 2) were considered to be the most important. Such most important PCs with eigenvalue greater than one cumulatively accounted for 79.63% of the total variance of the water quality parameters in the study area. Therefore, the first three PCs were used to yield rotated factors (Table 3) after varimax rotation.

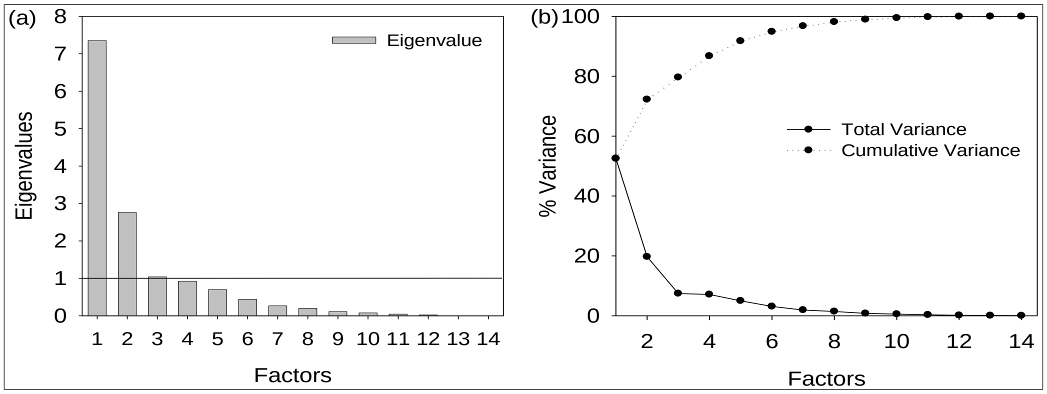

FIGURE 2. *(a) Scree plot of factors in and (b) variance of principle components*

Factor 1 for dry season which explained the largest fraction (50.6%) of the total variance indicated that water quality parameters like EC, TDS and concentrations of Na^+, K^+, Ca^{2+}, Mg^{2+} Mn and Cl^- had high positive loadings while concentrations of NO_3^- and SO_4^{2-} showed the moderate loadings (Table 3). The high positive loading can be attributed to weathering process. Additionally, high evaporation rate in this area, may likely result to accumulation of salts which may be dissolved and leached during rainy season. Similar, the results in Hombolo basin, where concentration of such parameters in groundwater, were linked to dissolution of plagioclase and amphiboles, along with the leaching of surficial and soil salts. Moderate loadings of NO_3^- and SO_4^{2-} were likely a result of decomposition of soil organic matter. The second factor which exhibited 19.7% of the total variance, had high positive loadings of pH, HCO_3^- and F^- and moderate loading of SO_4^{2-} probably attributed to decomposition of organic matter in the wetlands. The third principal component which explained 9.4% of the total variance, had high positive loadings of Fe.

TABLE 3. *Rotated matrix with three components and water quality characteristic variables*

Variable	Factor 1	Factor 2	Factor 3	Communality
EC	0.978	-0.022	0.127	1.083
TDS	0.977	-0.005	0.112	1.084
pH	-0.009	0.719	0.170	0.880
Na^+	0.805	0.061	0.217	1.083
K^+	0.813	0.128	0.085	1.026
Ca^{2+}	0.986	0.008	0.060	1.054
Mg^{2+}	0.776	-0.065	0.259	0.970
Fe	0.205	0.111	0.886	1.203
Mn	0.851	0.082	0.035	0.967
Cl^-	0.939	-0.088	0.126	0.976
SO_4^{2-}	0.528	0.601	-0.190	0.938
F^-	-0.051	0.921	-0.083	0.787
HCO_3^-	-0.038	0.908	0.117	0.987
NO_3^-	0.597	-0.394	0.519	0.722
Explained Variance	7.081	2.756	1.312	
Proportion of Total Variance	0.506	0.197	0.094	

Irrigation Water Quality

Sodium Adsorption Ratio (SAR) is a measure of alkali/sodium hazards to crops and is calculated by using Eq. (1) [13, 14].

$$SAR = \frac{Na^{+}}{\sqrt{\left(Ca^{2+} + Mg^{2+}\right)/2}} \qquad \textbf{(1)}$$

The reported SAR values for the boreholes/wells sampled in Dodoma Municipal were between the range of 6.7 and 40.7. Boreholes number 1, 7-12, 14, 17, 19 and 20 were in the range of 6-12, boreholes number 2-6 and 15 were in the range of 12-20 and boreholes number 13 and 16 were in the range of 20-40 and the SAR for borehole number 18 was more than 40. The FAO guidelines suggest severe restrictions for irrigation water with an EC <2.9 within this range of SAR, which were not recorded in any borehole/well in the study area. The EC values for all boreholes/wells in the Dodoma municipality were <1.3 and the FAO guidelines therefore suggest moderate restrictions (Table 4) and therefore suitable for irrigation.

Determination of SAR is essential for assessing the suitability of water for irrigation because Sodium and Calcium have different effects on the soil. Calcium will flocculate while sodium disperses soil particles. Water with low salinity content (<0.5 dS m^{-1}) leaches the soluble minerals and salts. High salinity water will increase infiltration, whereas low salinity water or water with a high sodium to calcium ratio will decrease infiltration. Therefore, it is important to consider both EC and SAR as well as TDS [12, 16].

TABLE 4. *Guidelines for potential irrigation problems of infiltration rate of water to soil*

	No restriction	Moderate restriction	Severe restriction
SAR		**EC(μS/cm)**	
0-3	>0.7	700-200	<0.2
3-6	>1.2	1200-300	<0.3
6-12	>1.9	1900-1300	<0.5
12-20	>2.0	2900-1300	<1.3
20-40	>5.0	5000-2900	<2.9

Source: [16]

CONCLUSION

Generally, the groundwater quality in the study area is suitable for drinking and irrigation uses in terms of the pH, EC, TDS, SAR and NO_3^-. However, with respect to Chloride concentration the water was found to be unpalatable for drinking use and irrigation for some of plants. Therefore, this study calls for groundwater management strategy which recognizes the groundwater as a vital and strategic resource.

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