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EVALUATION OF SELECTED DRINKING WATER QUALITY PARAMETERS USING CCME-WQI IN NAKURU MUNICIPALITY, KENYA

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ABSTRACT

Purpose**:** Reliable baseline information on overall quality status of drinking water at spatial and temporal scales is important in drinking water management systems, ensuring access to clean and safe drinking water. The study aimed at determining the suitability of natural and treated water for drinking in Nakuru Municipality, Kenya. An attempt was also made to explore the applicability of CCME-WQI (Canadian Council of Ministers of the Environment Water Quality Index) in evaluation of groundwater quality data for drinking uses.

Methodology**:** The study adopted a stratified random sampling technique that was employed systematically in conjunction with point and line techniques to create stratas/sampling components while ensuring each water cluster was represented through the sampling process. Analytical values of electrical conductivity, pH, selenium, cadmium, chloride and fluoride were used to determine quality status of water sourced from river and boreholes and as input parameters in calculation of index values. The evaluation and characterization of natural borehole water quality for drinking purposes was made using the water quality index (WQI) of the Canadian Council of Ministries of the Environment (CCME).

Results: The quality of natural and treated drinking water was found to be fresh in pH, chloride and electrical conductivity but contaminated in selenium, cadmium and fluoride in line with respective regulatory standards for drinking water. Based on the CCME-WQI, index values for all sampled sites representing natural borehole water were calculated in a range of 29.83 to 37.71 with an average value of 31.05 and ranked as poor.

Unique contribution to theory, practice and policy: Considering the limitations associated with the conventional methods in water quality monitoring, there is need to utilize other scientific based methods that can fill in the gaps to improve the current state of governance and practice of drinking water management systems. The CCME-WQI method as applied in this study can be utilized in evaluation of water quality monitoring data to facilitate water resources operational management and their allocation for different uses.

Keywords: *Water quality, CCME-WQI, river and groundwater, Nakuru Municipality*

1.0 INTRODUCTION

Chemical composition of water is derived from many different sources of solutes (natural and anthropogenic) where their quality are subject to changes in both space and time. In combination with environmental influence, natural and anthropogenic factors can contribute to water contamination and water quality deterioration. However, in regard to natural background conditions, the primary factor controlling the natural chemistry of water resources of a region is geology (Alper & Orhan, 2017). Generally, without human influence, naturally occurring chemical contaminants in drinking water present a risk to public and environmental health after prolonged periods of exposure (WHO, 2011). The fact that safe drinking water is a necessity for human health, reliable information on its overall quality over a range of spatiotemporal scales and changing environmental pressures becomes important (Akter et al., 2016).

Though water quality monitoring is among the highest priorities in water resources protection policy especially in regard to public use and optimal allocation of different water sources according to their uses many significant problems arise in maintenance and protection of protection of water quality (Simeonov et al., 2002; Abbasi & Abbasi, 2012). Traditionally water quality monitoring is limited to conventional methods that do not provide robust historical data for further exploration to extract useful information on overall status of water quality and its time-space dimensions (Cude, 2001). Given this limitations, there is need to explore possible solutions to provide viable alternatives in drinking water quality data evaluation using existing practical methods like Water Quality Indices (WQI) for water quality control and management.

WQI provides a convenient way to express the quality of water resources for consumption. They are considered as models of water quality where the objective is to classify the waters relative to biological, chemical and physical characteristics defining their possible uses and managing their allocations (Khalil et al., 2011). The index summarizes complex data on water quality to facilitate its communication to the public and can provide a distinct picture of overall water quality status over an area based on important water quality parameters (Abbasi & Abbasi, 2012). Around the world, the importance of the water quality index method has emerged through providing acceptable information on water quality conditions of water bodies and in determination of intervention priorities. A number of water quality indices have been developed by individuals, organizations and agencies to determine the overall water quality status of surface water and groundwater systems globally since the 1960s. Globally, the CCME-WQI is one of the critical indices present till now being used to estimate the quality of water (Lai, 2011). The index simplifies the interpretation and evaluation of water quality data without losing its scientific base which is practicable to use over space and time to the public in an easier manner (CCME, 2001). The index is mainly based on number of selected input water quality variables, size of dataset and objectives or standards used for its development. Also, the selection of suitable guidelines or objectives is important towards computing the water quality index values.

River and groundwater are the primary sources of drinking water in Nakuru Municipality. The water sources are located in the larger Lake Nakuru basin where geological factors control the natural water chemistry resulting to highly mineralized waters and soils (Olago, 2018). The underlying condition can alter or influence the natural composition of water and pose a risk to the quality especially for drinking uses among other uses. The area is also characterized by limited availability of clean and safe drinking water (Madadi et al., 2017). The primary issue of concern is lack of robust information that can represent the overall composition of drinking water sources in an integrated way due to the limitations associated with the conventional methods of water quality monitoring hence the motivation of this study. The study aims in filling the gap. The CCME-WQI (2001) model has been adopted in this study as an alternative quantitative measurement tool to evaluate and classify the areas drinking water quality status from selected sources based on pH, electrical conductivity, fluoride, cadmium and selenium. Published work on application of CCME-WQI technologies in evaluating suitability of groundwater for drinking uses using key chemical drinking water quality parameters in the area does not exist. The objectives of the study were to; (i) determine drinking suitability of natural and treated river and groundwater in Nakuru Municipality, (ii) evaluate and characterize the quality of natural borehole water for drinking uses based on the CCME-WQI model, (iii) assess the variation of the calculated WQI values between the sampled sites.

2.0 RESEARCH METHODOLOGY 2.1 Study area location

Nakuru municipality/town is located in Nakuru County which lies in the central rift valley, in Kenya. The Municipality has an area of about 300 km^2 where its boundary lies at latitude $0^0$15’30” and $0^0$30’15” South and longitude 36^0 0’ and $36^0$10’0” East (Figure 1.1). The area experiences two rainy seasons that occur in April, May to August (long rains) and October to December (short rains). Rainfall has a tri-modal distribution with peaks centered in April, August and November. April peak being highest followed by August and November respectively.

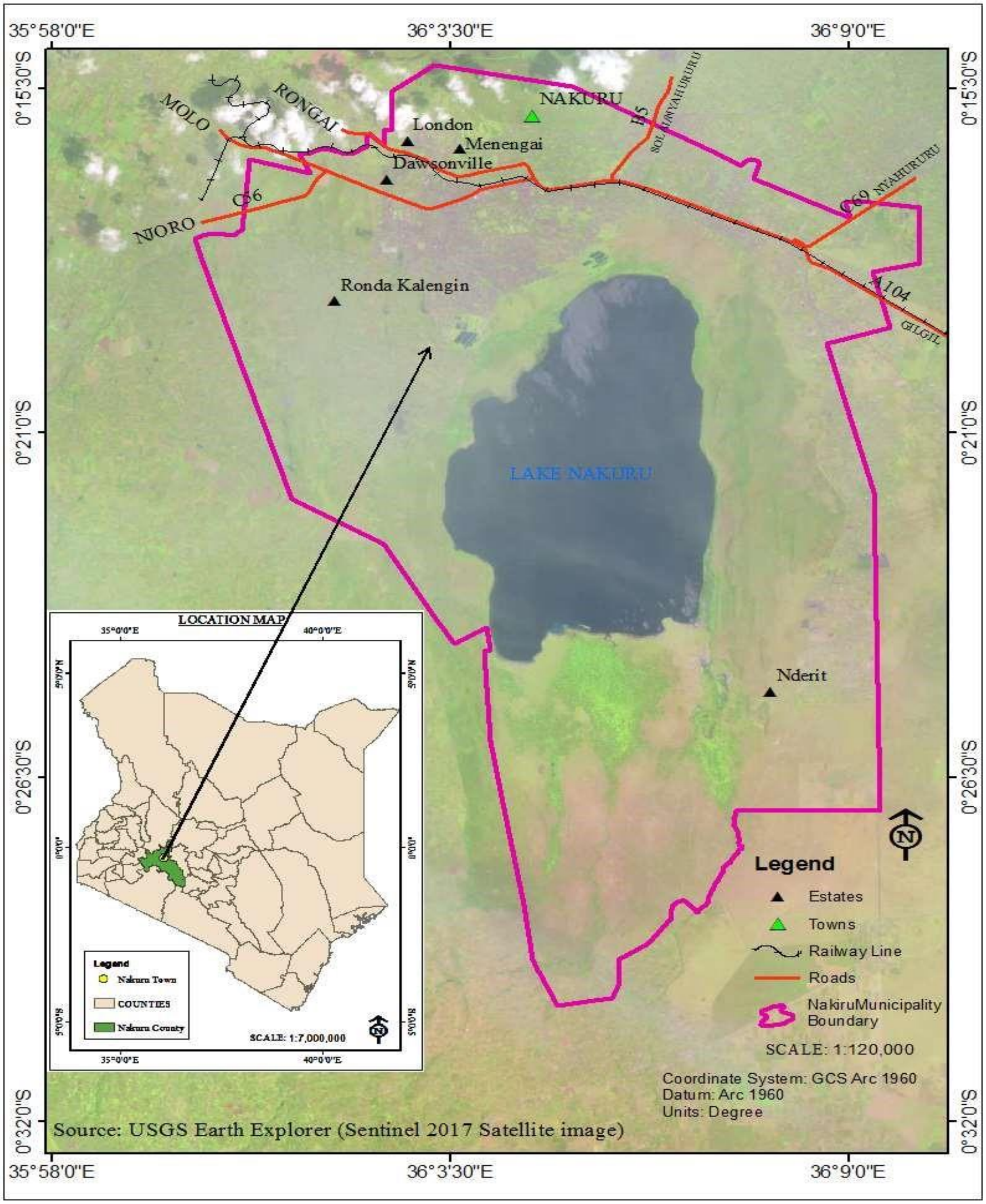

Figure 1: Location of the study area

2.2 Geology, hydrogeology and soils

The geology of Nakuru area comprises mainly of volcanic rocks (lava and pyroclastics) of Tertiary – Quaternary age, that have been affected by a series of faulting and are overlain by recent sediments (Thompson and Dodson, 1963).

The areas hydrogeology is controlled by the local geology, tectonic processes, topography and climate (Clarke et al., 1990; McCall, 2007). Groundwater recharge is mainly through seepage from the bottom of lakes, rivers and streams. Recharge of lakes and rivers is through groundwater inflow, runoff and direct rainfall. The recharge varies with rainfall (altitude) and geological variations. Secondary phenomena include structures/cavities, soil, vegetation type, rock mineralogy and degree per end product of weathering. Soils are of volcanic origin, young, poorly developed, porous, light and poorly structured.

2.3 Drinking water sources

Natural and treated piped water from rivers and boreholes are mainly the primary drinking water sources in Nakuru Municipality. Other water supply sources include rainwater, several springs, water pans and shallow wells where the drinking suitability of the water cannot be ascertained (Olago, 2018). The municipalities examined drinking water supply sources were from 38 points where some are located in the larger Lake Nakuru basin which has a catchment area of 1800 km^2 and others in the lower Baringo basin in a sub basin area of 6.25 km^2. 28 sites represented natural river and groundwater types while 10 points represented tap and piped treated water. The geographical co-ordinates of the sampling points were taken using hand held GPS (Global Positioning System)-Garmin etrex-10 GPS and the data processed using ArcView 10.1 software. The data was imported in GIS platform and exported in Bitmap format to create map of the locations of the sampling points (Figure 2 and 3).

2.4 Datasets

Three groups of water quality datasets covering three hydrological periods were generated by analyzing 240 river water and 320 groundwater samples at 38 sampling points. Each dataset consisted of six selected water quality parameters (pH, electrical conductivity, chloride, cadmium, selenium and fluoride).

Twenty three groundwater and five river water sampling points represented water sources (untreated) covering the study area. All the sampling points formed 84 groups. Nine sampling points represented piped and chlorinated water (treated water) while one sampling point represented river treated water forming 30 groups.

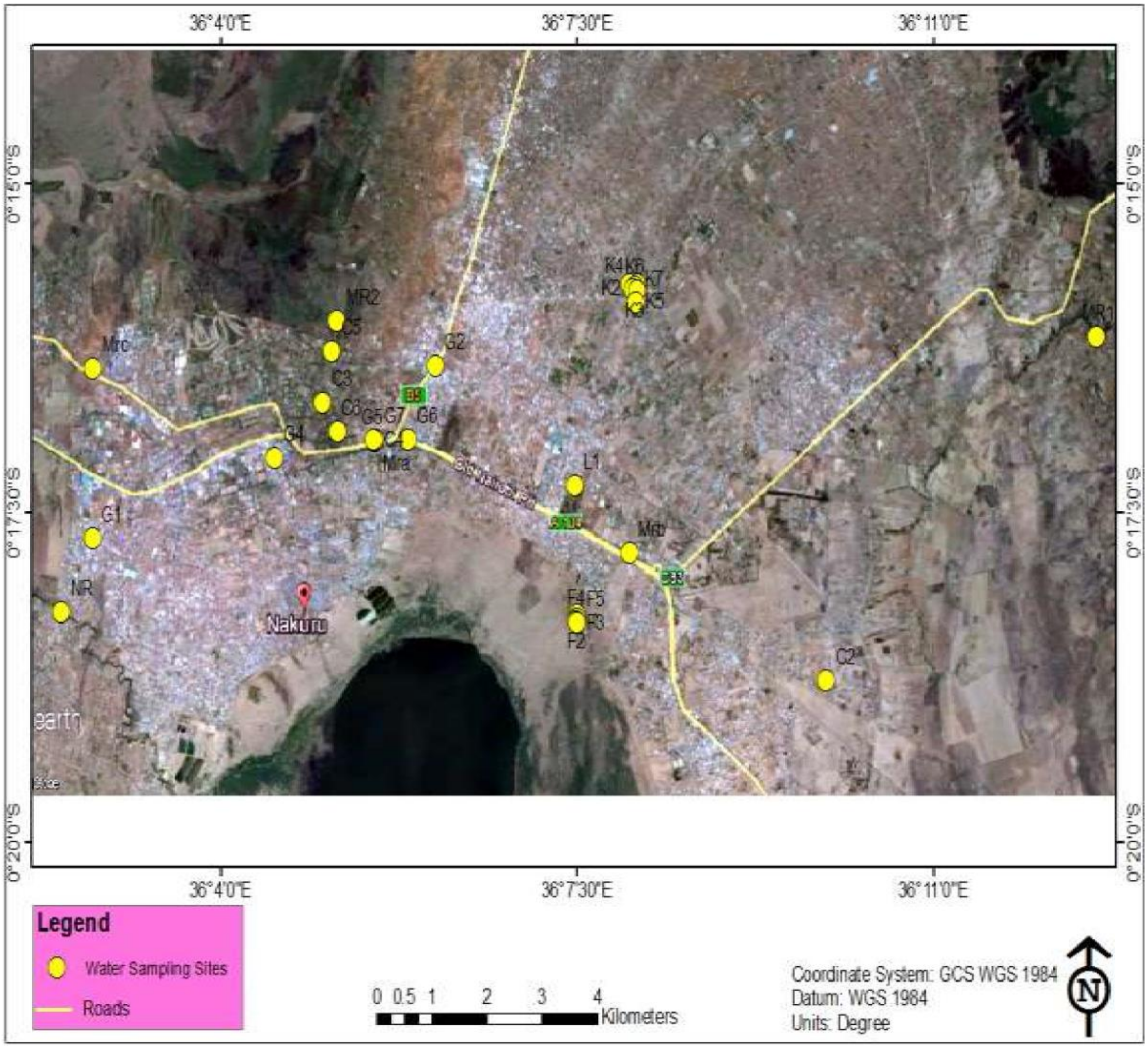

Figure 2: Location map of sampling points representing river and groundwater sources in Nakuru Municipality

Source: Author's field work (2014 to 2015)

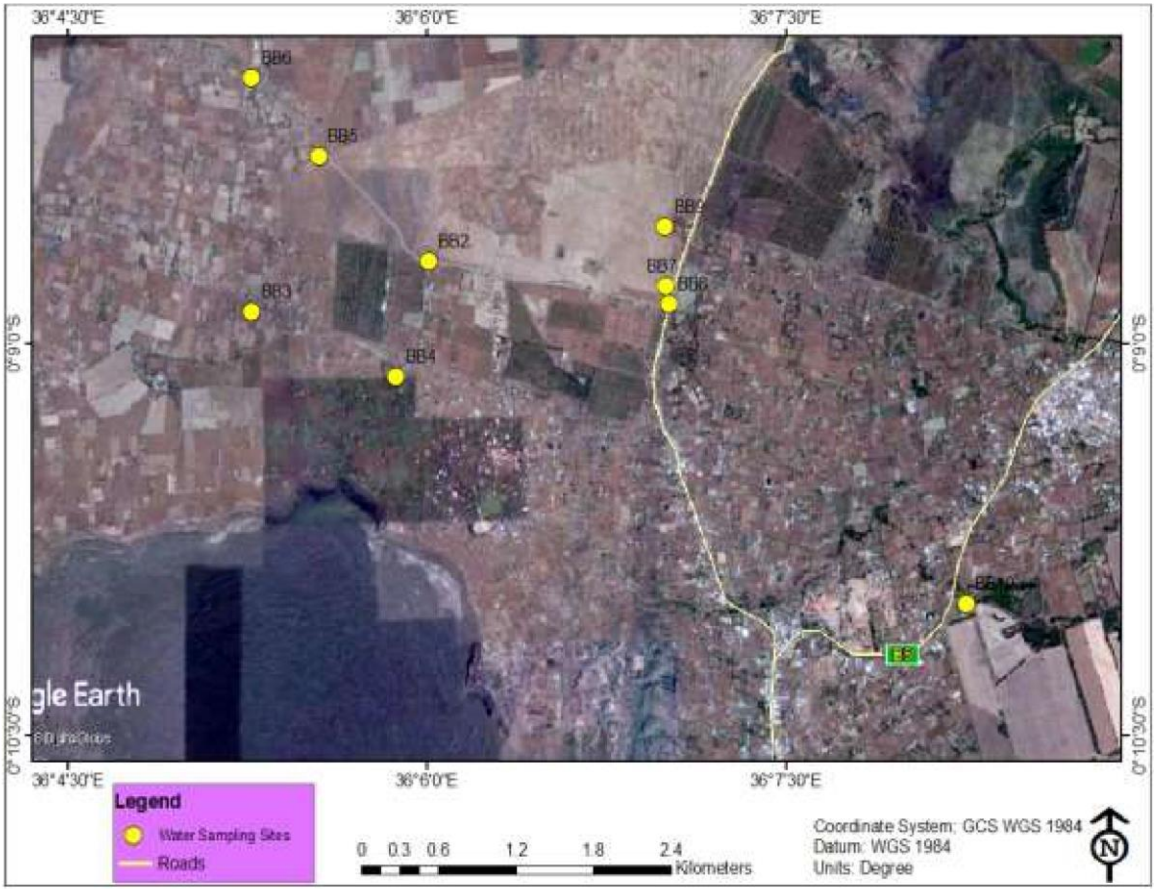

Figure 3: Location map of sampling points representing Olobanita well fields (BB2 to BB10) in Nakuru Municipality

Source: Author's field work (2014 to 2015)

2.5 Sampling Method

Stratified sampling technique was employed systematically in conjunction with point techniques to create stratas/sampling components (Burns 2008). The samples from the selected sources was done in three hydrological/seasonal periods that represented transition period (June, 2014 to September, 2014), short rain period (October, 2014 to December, 2014) and dry period (January to March 2015). Thirty eight (38) sampling points representing river and groundwater were selected. A total of 320 groundwater and 240 river water samples were collected from June 2014 to March 2015. Collection of groundwater samples was done manually on monthly basis where else the river water samples were collected on weekly basis for nine months. The sample collection, preservation and analyzing techniques were in accordance with the standard procedures and standards (APHA 1998). Parameters selected for this study included pH, electrical conductivity, fluoride, chloride, selenium and cadmium. Their selection was based on being; some of the most important water quality variables affected by geology of an area, effective in detecting water quality changes in space and time, some of the conventional variables of special concern from a health standpoint and environmental health, being significant variables that describe the quality of drinking water in terms of its mineral content (Cude, 2001; WHO, 2011; Alper & Orhan, 2017).

2.6. CCME-WQI method

pH, electrical conductivity, fluoride, cadmium and selenium were selected to assess the suitability of natural and treated river and groundwater for drinking.

Based on the combined influence of the six observed parameters, integration of the three index periods (transition period, short rain period and dry period), WHO (2011) and NEMA (2006) guideline values for drinking water, the CCME-WQI equation and conceptual framework was used in calculation of index values at each sampled site. CCME-WQI designations (2001), WHO (2011) and NEMA (2006) guideline based objectives were used in categorization of the water for drinking uses. The following formula was used to calculate the WQI values at each sampling site.

$$CCME_{-WQI} = 100 - \left(\frac{\sqrt{(F1^2 + F2^2 + F3^2)}}{1.732}\right)$$

The computation method is based on three elements which are measures of variance from selected water quality objectives (F1, F2 and F3). The equation is calculated using the three elements using root mean square aggregation where;

$$F1 = \frac{(\text{Number of failed variables})}{(\text{Total number of variables})} \times 100$$

$$F2 = \frac{(\text{Number of failed tests}) \times 100}{(\text{Total number of variables})}$$

$$F3 = \frac{nse}{0.01nse + 0.01}$$

where F3 is calculated in three steps as follows;

1. where the test value must not fall below the objective:

$$excursion_i = \frac{(Objective_j)}{\text{Failed Test Value}_i)} - 1$$

$$= \frac{(\sum (excursions))}{(\text{Total number of tests})} \quad 2. \quad nse$$

where nse is normalized sum of excursions

The normalized sum of excursions, nse, is the collective amount by which individual tests are out of compliance. F1 describes the scope that is the number of variables which do not meet the objectives at least once during the time period under consideration (“failed variables”), relative to the total number of variables measured:, F2 describes the frequency that is percentage of individual tests that do not meet guideline values and F3 describes the amplitude which represents the amount by which failed test values do not meet their guideline values (CCME 2001). A failed test can be greater or less than its objective.

2.7 Water analysis

The analysis methods were both field (pH and conductivity) and laboratory (selenium, chloride, fluoride and cadmium) based. Field measurement instruments were fully calibrated before starting sampling (pre-field) and again after all the sampling had been completed (postfield).

For pH and electrical conductivity, JENWAY digital portable water analyzer kit with probes for each parameter were used.

For the analysis of selenium and cadmium samples, atomic absorption spectrometry method was used. Procedure involved digestion of the samples to capture all the elements. Six selenium standard solutions were then prepared at concentrations: 0, 2, 4, 6, 8, 10 ppm. For cadmium, concentrations were at 0, 0.25, 0.5, 0.75,1, 2 ppm.

3.0 Results and discussion

Analytical results of examined variables for the three sampling periods representing natural and treated drinking water were descriptively summarized in to minimum, maximum and mean values and presented as compared to WHO (2011) and NEMA (2006) guideline values for drinking water. Mean concentrations values were calculated to assess the quality of treated and natural drinking water by averaging the concentration of each parameter considering all sampled sites at each sampling period and the results presented in Table 1and 2 respectively.

The results show significant variations in examined natural and treated water samples from river and groundwater sources according to chemical characteristics of observed variables indicating that the quality of water considerably varies between the three sampling periods. Range of average concentration levels of all the water quality parameters were generally characterized by small to average to large variations across the three sampling periods. Natural water samples for both river and groundwater had elevated concentration levels as compared to treated water across the sampling periods. The levels of chloride, pH and electrical conductivity remained within the required guideline values for drinking water while fluoride, selenium and cadmium had elevated levels. The overall analytical results shows that the river and groundwater of the area is slightly alkaline and considerably ionized. This can be related to geological factors and anthropogenic activities that prevail in the area.

The results of the present study are in conformity with previous study findings concerning interaction of surface and groundwater with anthropogenic and geological factors of the larger

Nakuru basin where the authors report the areas soils and waters to be highly mineralized and alkanic in nature (Kanda 2010; Oketch, 2012). Physical and chemical contamination of the larger Nakuru area drinking water sources has also been reported (contamination of the larger Nakuru area drinking water sources has also been reported (Ngotho, 2014; Madadi et al., 2017).

Table 1: Statistical summary of levels of water quality parameters of bore hole water for treated and natural samples over the study period

		TP (Transition period)			SRP (Short rain period)			DP (Dry period)			Maximum permissible limits	
Parameter	**Water type**	**MIN**	**MAX**	**MEAN**	**MIN**	**MAX**	**MEAN**	**MIN**	**MAX**	**MEAN**	**WHO (2011)**	**NEMA (2006)**
pH	Natural water	6.66	10.54	**8.60±1.94**	6.43	9.98	**8.21±1.78**	5.97	10.53	**8.25±2.28**	5.5-9.5	6.5-8.5
	Treated water	7.30	9.01	**8.16±0.86**	6.50	9.83	**8.17±1.67**	6.00	10.15	**8.25±2.28**	6.5-8.5	
Electrical conductivity (µS/cm)	Natural water	215	991	**603±388**	300	978	**639±339**	205	994	**599.50±394.50**	2500	-
	Treated water	121	980	**550.50±429.50**	213	872	**542.50±329.50**	212	865	**538.50±326.50**	1500	
Selenium (mg/l)	Natural water	0.09	6.75	**3.42±3.33**	0.50	8.20	**4.35±3.85**	0.064	7.48	**3.77±3.71**	0.01	0.01
	Treated water	0.08	6.55	**3.32±3.24**	0.11	5.70	**2.91±2.80**	0.07	3.49	**1.78±1.71**		
Cadmium (mg/l)	Natural water	0.00	0.30	**0.15±0.15**	0.04	0.29	**0.17±0.13**	0.04	0.35	**0.20±0.16**	0.003	0.01
	Treated water	0.00	0.21	**0.11±0.11**	0.02	0.32	**0.17±0.15**	0.04	0.30	**0.17±0.13**		
Fluoride (mg/l)	Natural water	1.21	9.30	**5.25±4.05**	0.23	14.50	**7.37±7.14**	0.30	14.00	**7.15±6.85**	1.5	1.5
	Treated water	0.11	10.60	**5.36±5.25**	0.30	8.00	**4.15±3.85**	0.60	9.50	**5.05±4.45**		
Chloride (mg/l)	Natural water	14.20	28.40	**21.30±7.10**	14.20	28.40	**21.30±7.10**	14.20	28.40	**21.30±7.10**	250	250
	Treated water	14.20	21.30	**17.75±3.55**	14.20	14.20	**14.20±0**	14.20	21.30	**17.75±3.55**		

Table 2: Statistical summary of water quality parameters of river water for treated and natural samples over the study period

		TP (Transition period)			SRP (Short rain period)			DP (Dry period)			Maximum permissible limits	
Parameter	**Water type**	**MIN**	**MAX**	**MEAN**	**MIN**	**MAX**	**MEAN**	**MIN**	**MAX**	**MEAN**	**WHO (2011)**	**NEMA (2006)**

pH	Natural water	6.74	8.50	**7.62± 0.88**	7.41	8.96	**8.19± 0.78**	6.33	9.50	**7.92± 1.59**	5.5-9.5	6.5-8.5
	Treated water	6.93	7.49	**7.21± 0.28**	6.84	8.04	**7.44± 0.60**	6.94	8.95	**7.95± 1.01**	6.5-8.5	
Electrical conductivity (µS/cm)	Natural water	93.75	180.50	**137.13± 43.38**	90.00	160.75	**125.38 ± 35.38**	127.75	280.50	**204.13± 76.38**	2500	-
	Treated water	91.25	105.00	**98.13 ± 6.88**	111	138.25	**124.63 ± 3.63**	144.50	175.75	**160.13± 15.63**	1500	
Selenium (mg/l)	Natural water	0.01	3.33	**1.67± 1.66**	0.01	3.94	**1.98± 1.97**	0.01	4.37	**2.19± 2.18**	0.01	0.01
	Treated water	0.01	0.03	**0.02± 0.01**	0.01	1.19	**0.60± 0.59**	0.08	0.48	**0.28± 0.20**		
Cadmium (mg/l)	Natural water	0.01	0.22	**0.12± 0.11**	0.02	0.10	**0.06± 0.04**	0.03	0.31	**0.17± 0.14**	0.003	0.01
	Treated water	0.01	0.03	**0.02± 0.01**	0.02	0.06	**0.04± 0.02**	0.08	0.13	**0.11± 0.03**		
Fluoride (mg/l)	Natural water	0.21	4.58	**2.40± 2.19**	0.27	1.63	**0.95± 0.68**	0.40	1.89	**1.15± 0.75**	1.5	1.5
	Treated water	0.13	2.35	**1.24± 1.11**	0.44	0.81	**0.63± 0.19**	0.38	0.63	**0.51± 0.13**		
Chloride (mg/l)	Natural water	12.40	16.00	**14.20 ± 1.80**	10.70	16.80	**13.75± 3.05**	12.40	17.80	**15.10± 2.70**	250	250
	Treated water	14.20	14.20	**14.20 ±0.00**	14.20	14.20	**14.20± 0.00**	14.20	14.20	**14.20± 0.00**		

3.1 Measurement of natural borehole water quality using CCME-WQI method

For the 23 sampled boreholes, index values by CCME-WQI method were calculated by integrating the three sampling periods (transition, short rain and dry) and combined effect of the examined six water parameters. WQI values for all sampled boreholes ranged from 29.83 to 37.71 with an average value of 31.05 and were ranked poor with conditions of departing from desirable levels in regard to drinking uses (Table 3).

Table 3: Calculated WQI values in groundwater samples

Sampling point	F1	F2	F3	WQI Value	Rank	Description
BB2	50	50	98.73	36.1	Poor	Water quality is almost always threatened or impaired,
BB3	50	50	97.89	30.28	Poor	
BB4	50	50	98.19	30.14	Poor	

BB5	50	50	98.04	30.21	Poor	conditions usually depart from natural or desirable levels
BB6	50	50	97.98	36.49	Poor	
BB7	50	50	98.83	29.84	Poor	
K1	50	50	98.12	20.94	Poor	
K2	50	50	96.47	30.94	Poor	
K3	50	50	98.81	29.85	Poor	
K4	50	50	95.62	37.71	Poor	
K5	50	50	97.01	36.99	Poor	
K6	50	50	96.12	31.11	Poor	
K7	50	50	98.10	30.18	Poor	
L	50	50	98.26	30.1	Poor	
F1	50	50	97.85	30.92	Poor	
F2	50	50	96.82	30.78	Poor	
F3	50	50	98.31	30.04	Poor	
F4	50	50	97.72	30.36	Poor	
F5	50	50	97.25	30.58	Poor	
G2	50	50	97.39	30.51	Poor	
G5	50	50	98.85	29.83	Poor	
G6	50	50	98.34	30.07	Poor	
G7	50	50	98.01	30.20	Poor	

The results of calculated WQI values as given in Table 3 indicate that the quality of borehole water in all sampled sites was poor in regard to CCME-WQI regulatory requirements. Variation of water quality existed across all the sampled boreholes. Levels of selenium, Cadmium and fluoride at all sampled sites were taken as important parameters that contributed to poor drinking water quality. For the study area, there is no published research work to identify the suitability of groundwater for drinking purposes based on the CCME-WQI model therefore it was not possible to compare the findings directly with any other studies. In related studies the reliability of the CCME-WQI in evaluation of water quality index for drinking water in the city of Pogradec, Albania was demonstrated by Damo and Icka, 2013.

4.0 Conclusion

This study has demonstrated the use of CCME-WQI to evaluate and characterize groundwater quality for drinking uses inorder to provide reliable solutions to the limitations associated with the conventional methods.

The results showed that the quality of natural and treated drinking water across the three sampling periods from the examined boreholes as compared to river water is poor as per the standards of drinking water.

Both river and groundwater are slightly to moderately alkaline, fresh in nature of chloride and electrical conductivity but contaminated in respect to fluoride, selenium and cadmium.

Based on CCME-WQIs model, WQI for all examined boreholes is found to vary between 28.83 and 37.71 which indicate that groundwater quality of the area is poor and frequently impaired with conditions usually departing from natural or desirable levels. Also, the results of WQI showed that the quality of water varied from one borehole to another.

Based on the combined influence on the overall water quality parameters, selenium, cadmium and fluoride were taken as important parameters in rating of the water quality as their concentrations exceeded the objective permissible limits for drinking water as per WHO (2011).

Overall, the results of analytical analysis and the calculated WQI values indicate that borehole water as compared to river water from the examined sites is chemically poor, not potable and need proper treatment before use.

In conclusion, natural contamination of the areas drinking water systems is significant therefore the generated data together with other scientific based methods can be considered in the context of improving the current state of its management practices and governance.

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