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The Influence of Structures and Lithology on Groundwater Quality: A Case Study of Baringo County in the Central Kenyan Rift Valley

Patrick Kirita Gevera[1*], Kevin Kibet Ngeno[2] & Ednah Kwamboka Onyari[1]
[1]Department of Civil Engineering, University of South Africa, [Florida science campus], Cnr Christian de Wet Road and Pioneer Avenue, Johannesburg, South Africa.
[2]Geothermal Energy Training Institute (GeTRI), Dedan Kimathi University of Technology,
Nyeri, Kenya; [*]geverpk@unisa.ac.za

Abstract - Baringo County is located in the central Kenyan Rift Valley, a region adversely affected by variations in surface and groundwater chemical constituents, affecting human health. This paper reports the influence of geology and structures on the spatial distribution of the physico-chemical parameters in groundwater from data from 55 boreholes used for drinking water in the county. This was achieved using geochemical analysis and ArcGIS tools. The results show that, among the parameters analysed, the concentrations of fluoride, hardness, and turbidity were higher than their recommended values in drinking water by the Kenyan Bureau of Standards (KEBS) and the World Health Organization (WHO) in up to 33% of the sampled boreholes. This could result in health complications such as dental/skeletal fluorosis from high fluoride and unpalatability due to high turbidity and hardness. The spatial distribution of these parameters showed the highest concentrations in the eastern and southern regions, making these areas undesirable for drinking water abstraction. Rock-water interaction and evaporation were the dominant processes controlling groundwater chemistry in the area. The spatial distribution pattern correlated positively with the structural density map, indicating that dense linear structures act as conduits for groundwater, increasing the water-rock interaction time and, therefore, increasing mineral solubility. There was no correlation between the spatial distribution of these parameters and borehole depth or specific rock type. This was due to the interconnected nature of the rocks and aquifers in the Rift Valley. These findings suggest that the structures significantly influence the physicochemical parameters of the groundwater in most parts of the Kenyan Rift Valley.

***Keywords*:** Groundwater quality, Baringo County, Fluoride contamination, structural control of groundwater quality

1. Introduction

Water is an essential natural resource for developing any economy, and providing clean water is one of the United Nations' sustainable development goals [1]. However, to reap its benefits, every country must ensure that its water resources are sufficient and have the recommended limits of physico-chemical parameters for its various intended uses [2]. Achieving this feat is still a challenge in most countries [3], especially in sub-Saharan Africa, where factors such as climate change, mismanagement of water resources, agricultural and industrial activities, increased population, and natural factors have undesirable the available water resources [4]. This has resulted in several water-related health complications affecting most communities.

In Kenya, groundwater resources face challenges such as aquifer depletion due to rapid abstraction in developing urban areas and contamination from natural, agricultural and industrial sources [5], [6]. To curb the water quality issue, studies are being carried out to understand the source and movement of contaminants in groundwater using different methods such as geological, geochemical, structural, Geographic Information Systems (GIS), statistical, geotechnical, and machine learning tools [7], [8], [9], [10].

Structures have been used in groundwater studies in several parts of the world, such as in mapping the flow of natural contaminants such as salinity and those from mining and industrial activities [11], [12], [13]. In the current study, the use of geological structures, which include faults, joints and fractures, which act as conduits for groundwater, and lithology are employed to determine their influence on the spatial distribution of the physico-chemical parameters of groundwater in Baringo County in the central Kenya Rift Valley. Borehole data, including the physico-chemical parameters and borehole logging of 55 boreholes from Baringo County, was used to determine the physical and chemical properties of groundwater in the area and correlate it with the recommended values in drinking water. The spatial distribution of these parameters was associated with the structural density and geological map to determine the latter's influence on the groundwater quality in the county.

2. Materials and Methods

2.1 Study Area

Baringo County is located in the central part of the Kenyan Rift Valley, about 270km to the northwest of Nairobi, the capital of Kenya, as shown in **Fig. 1**. Most parts of the county are arid covered with shrubs and grassland where pastoralism of the dominant activity while in the other regions, subsistence farming and fishing, as well as limited commercial tea and coffee farming, are practised. Surface water has been the County's main domestic and livestock use source for decades [14]. However, this water source has been diminishing in the county and other parts of the Rift Valley, partly due to climate change, population increase and mismanagement of the resource, resorting to alternative sources of water such as groundwater [14]. The Baringo County government resolves this by drilling boreholes and water pans, as well as rehabilitating old water supply schemes and improving piped water coverage.

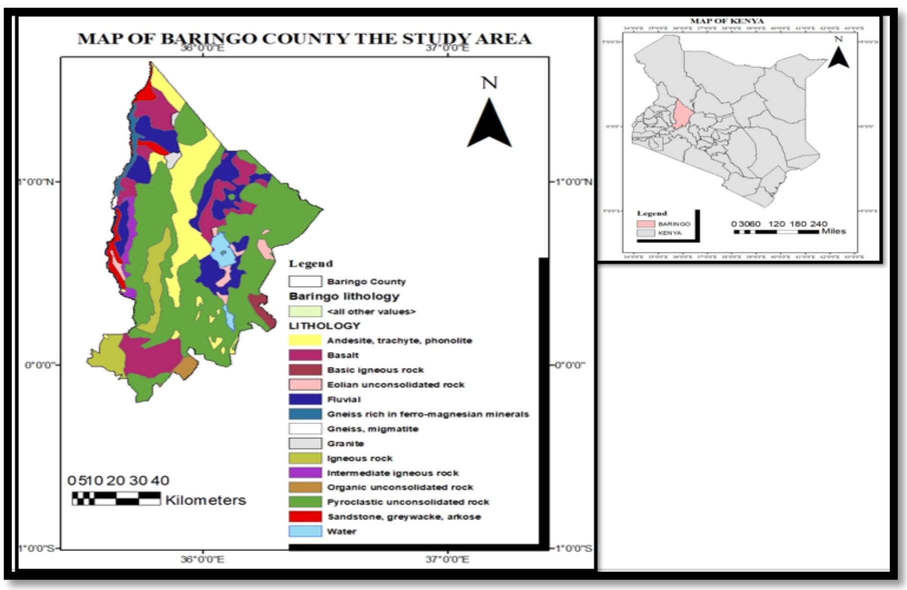

Fig. 1 A map of Baringo County showing the geology and location of the county in Kenya. (Digitised from a shapefile from https://data.humdata.org/dataset/47-counties-of-kenya)

2.2 Geology and Hydrogeology

The geology of Baringo County is predominantly volcanic rocks of the East African Rift Valley. The county is bounded by Elgeiyo and Laikipia escarpments to the west and east, respectively, with the highest point being the Tugen hills, which separate the lower parts of the Baringo basin and Kerio Valley in the Rift Valley floor [15]. The dominant rocks include Tertiary Volcanic (tuffs and lavas) overlying the Precambrian Mozambique Mobile Belt (MMB) gneisses. In Baringo County, similar to other regions in the Rift Valley, most productive aquifers are located in the rift floor hosted in fractured volcanics or volcano-sediments, while the escarpments act as recharge zones [14], [16]. Most aquifers appear to be interconnected, where shallow aquifers below 50 meters are preferred to deeper ones due to the potential of interaction with geothermal fluids in deeper aquifers resulting in saline waters [14].

2.3 Data collection

Water sample analysis

Borehole drilling data and physico-chemical parameters of the water sample used in this paper were obtained from Central Rift Valley Water Works and Development agency located in Nakuru County, which collected and analysed the water samples following the United States Environmental Protection Agency (USEPA) procedure for drinking water samples collection [17]. The water samples were analysed for pH, EC, TDS, Cl^-, F^-, turbidity, total hardness (TH), Ca and Na as outlined here:

The physico-chemical parameters (pH, turbidity, and EC) and Ca were measured at the borehole sites with a Hydrolab field testing kit. Samples for lab analysis were filtered and stored in 1L polyethylene bottles, chilled in a cooler box and transported to the lab. The TDS analysis was conducted using the evaporation method. The TH was analysed using a volumetric titration test, where a reagent (disodium ethylene-diamine-tetra-acetic acid) was added to the sample until a colour change was observed, indicating the presence of a certain level of hardness. Chloride was analysed using volumetric titration using Potassium Chromate(K_2CrO_4) and silver nitrate ($AgNO_3$). Fluoride was analysed using absorption spectrometry. Calcium was analysed using the field test kit, which contained a solution of Calcium Chloride ($CaCl_2$) and Sulphuric acid(H_2SO_4) that reacts with Ca, causing a colour change used to determine the amount of calcium present in the sample. Sodium was analysed using flame photometry. All analysis procedures were conducted in accredited laboratories with qualified staff, using analytical grade calibration standards and reference materials.

Data analysis and interpretation

Data on the physico-chemical parameters were recorded and analysed using the Microsoft Excel program. The concentrations of physico-chemical parameters of the borehole water were compared to the recommended standards by the Kenyan Bureau of Standards (KEBS) and the World Health Organization (WHO) [18], [19] to establish their suitability for human consumption. The spatial distribution maps of the parameters were generated by ArcGIS software's geostatistical spatial interpolation tool using the Inverse Distance Weighted (IDW) method. The geological map of the county was obtained from the lithology shapefiles from the USGS website. The structural data were obtained from Digital Elevation Model (DEM) data from the USGS using ArcGIS software. Several hillshade combinations of the DEM were produced and overlaid upon each other to show the lineaments. Using the ArcGIS editor tool, the lineaments were edited and saved as a shapefile showing the structural density map of Baringo County.

3.0 Results

3.1 Physico-chemical characteristics of the groundwater and spatial distribution

The statistical summary of the physico-chemical parameters of the 55 analysed boreholes, with their recommended drinking water standard values set by KEBS and WHO, are presented in **Table 1**. Spatial distribution maps of the individual parameters were also generated showing areas with higher concentrations and lower concentrations and compared to the structures, lithology and land use pattern of the area. The characteristics of the parameters were as follows:

Table 1 The statistical summary of physico-chemical parameters in Baringo County boreholes relating to their recommended values in drinking water by KEBS and WHO and the % of boreholes exceeding the recommended values.

Parameters	Range	mean	Standard Deviation	KEBS limit	% above limit	WHO limit	% above limit
Physical Parameters							
pH	5.3-9	7.5	0.8	8.5	3.6	8.5	3.6
EC (µS/cm) 25ºC	104.3-1581.2	631.8	367.8	-	-	2500	0

Turbidity (NTU)	0.1-17	5.5	4.3	5	32.7	5	32.7
TDS (Mg/l)	50-800	310	201.6	1000	0	1500	0
TH (Mg/l) (mgCaCO3/L)	10.7-460	140.5	124.7	300	14.5	500	0
Chemical parameters (Mg/l)							
Na	9.75-231	95	55.5	200	3.6	200	3.6
Ca	12.6-187.4	63.3	36.6	150	3.6	100	10.9
F	0.1-2.9	1.1	0.7	1.5	23.6	1.5	23.6
Cl	5-200	44.1	49.2	250	0	250	0

Among the analysed parameters, turbidity (32.7%), calcium (10.9%) and fluoride (23.6%) were higher than the recommended values in drinking water in more than 10% of the analysed boreholes, while the other parameters were within the allowable amount as shown in Figures 2-4. High turbidity suggests the mixing of sediments with the groundwater and can affect the organoleptic properties of the water sources, making them undesirable for drinking. High fluoride in the Rift Valley's volcanic rocks has been attributed to the dissolution of minerals such as muscovite and cordierite, as well as in volcanic glass [20]. These high fluoride concentrations in the area can cause dental and skeletal fluorosis which have been reported in other regions of the Kenyan Rift Valley [21], [22].

The spatial distribution maps show their highest values in the southern (turbidity, fluoride and calcium) and northeastern (turbidity).

3.3 Influence of Structures on Groundwater Quality

The highest structural density was in the southern and central regions, while the other regions had low structural density as shown in **Fig. 5**. The structures in the southern region were mostly linear and trended in the N-S and NE-SW direction. From the structural maps, it is evident that the study area has a high concentration of structures. The high structural density in the southern and central regions of the study area correlated positively with the spatial distribution maps of turbidity, pH, hardness, fluoride and chloride and negatively with EC, TDS, Na, and Calcium, thus influencing their concentration in the region. Geological structures, including faults, joints and fractures, provide permeable zones through which groundwater flows and accumulates to form aquifers [13]. Permeable zones allow rock-water interaction, which promotes mineral dissolution in the aquifer, releasing different elements in the water. These areas with more water-rock interaction time result in higher dissolution of minerals thus higher concentrations of parameters as seen in the study area. Therefore the high structural density in the central and southern regions aids in groundwater percolation which increases mineral dissolution.

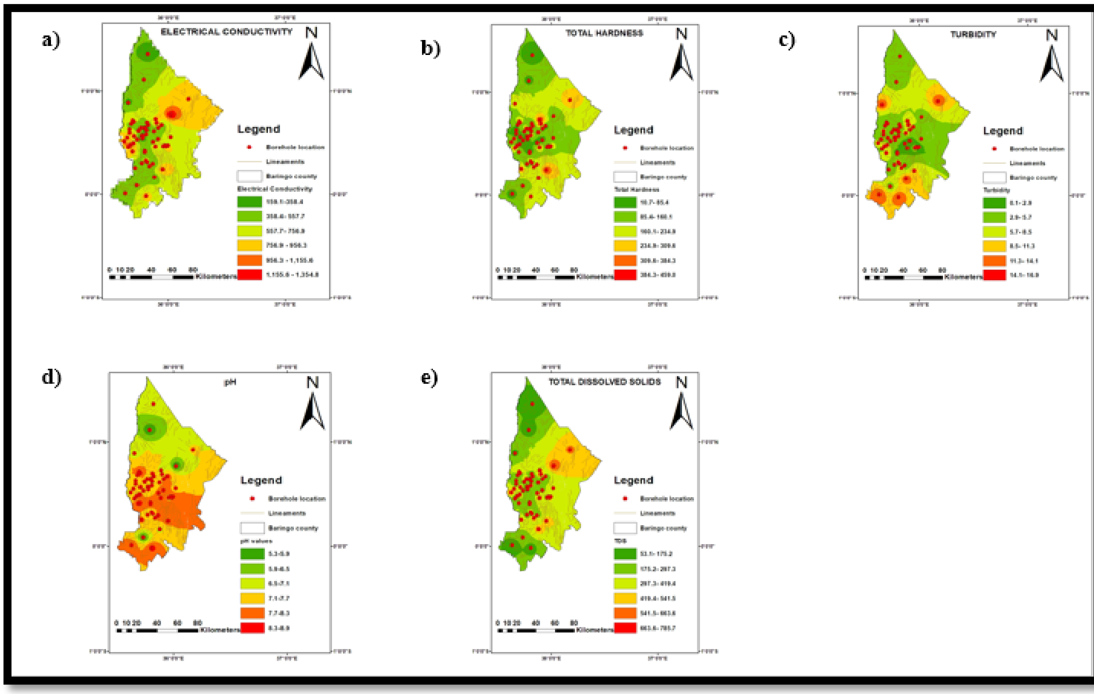

Fig. 2 The spatial distribution maps of the physical parameters of the studied boreholes in Baringo County.

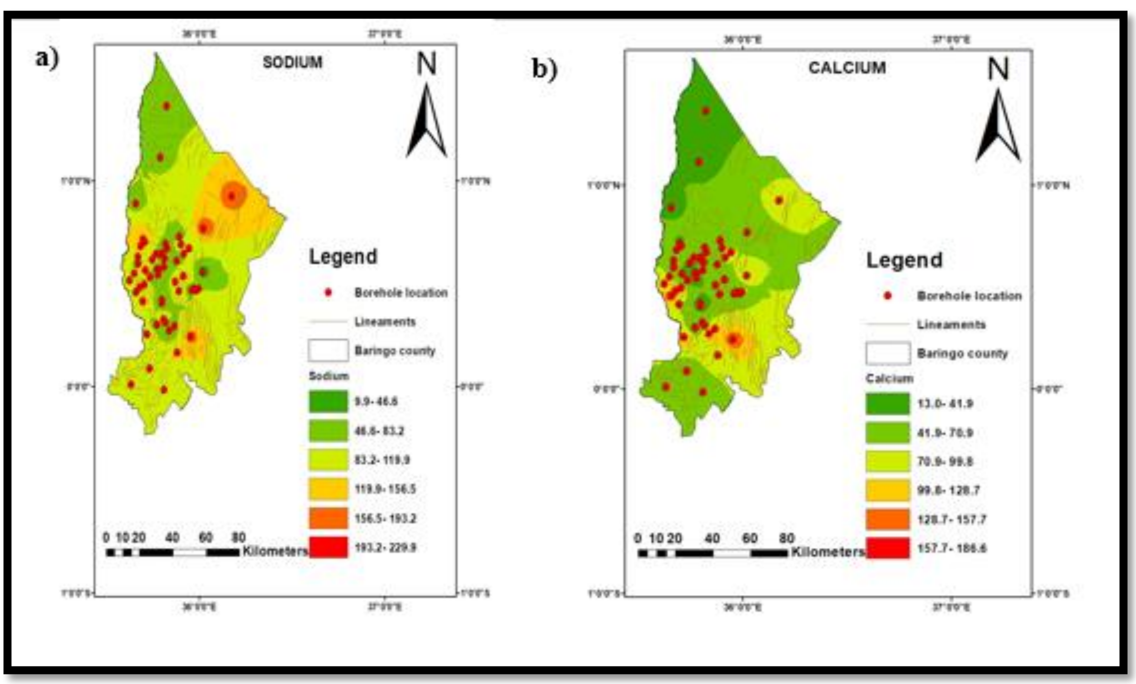

Fig. 3 The spatial distribution maps of cations in the studied boreholes in Baringo County.

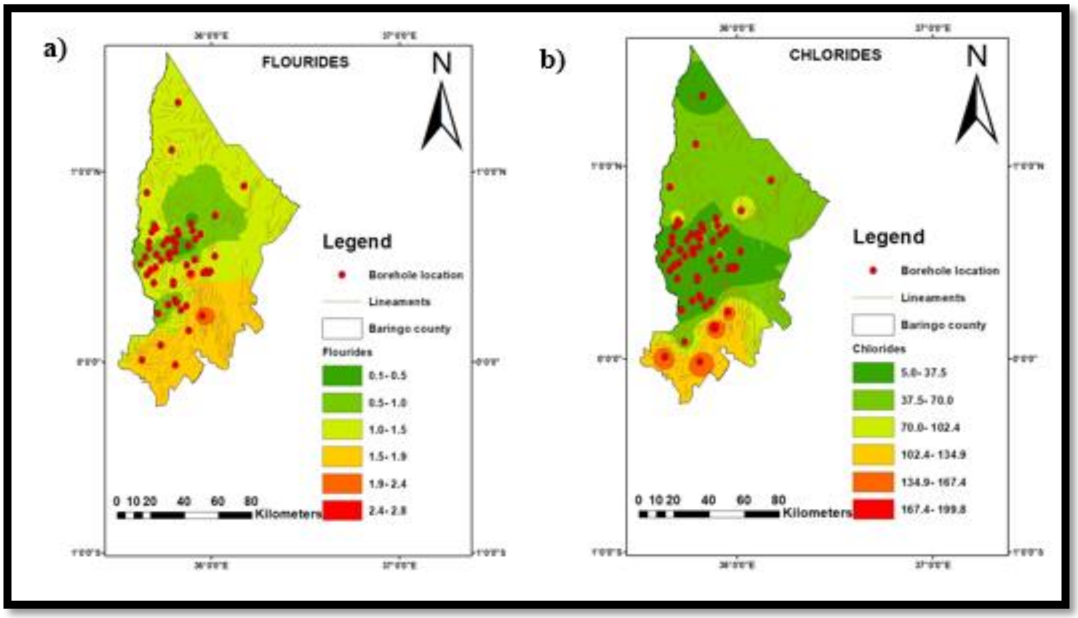

Fig. 4 The spatial distribution maps of anions in the studied boreholes in Baringo County.

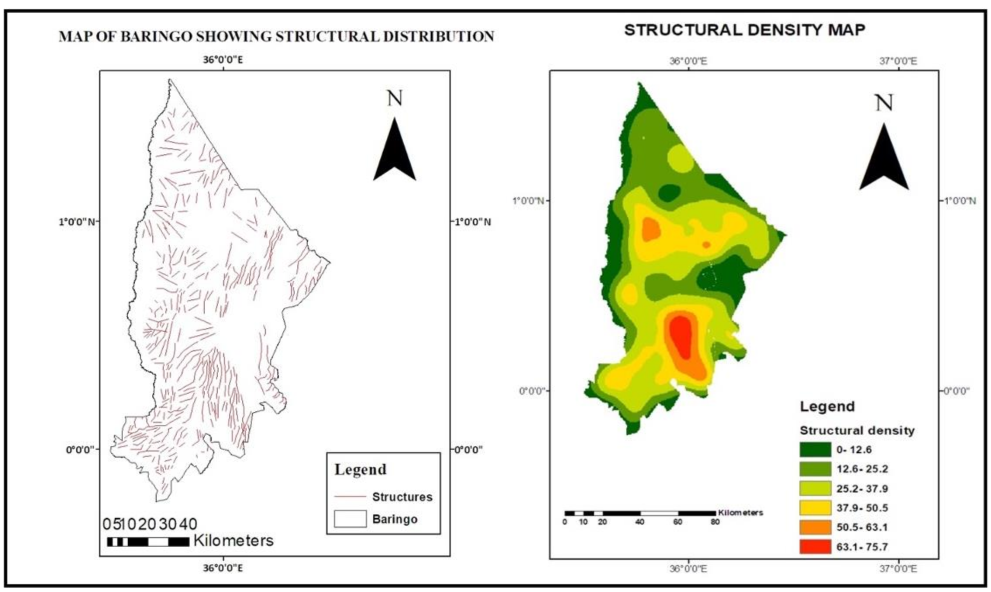

Fig. 5 The structural distribution and density maps of Baringo County.

3.4 Influence of Geology on Groundwater Quality

The spatial distribution map (**Fig. 1**) of the rocks shows the igneous rocks (basalts, andesites, phonolites, trachytes, granites and pyroclasts) in the central part of the study area stretching in the north-south direction. Metamorphic rocks (gneisses and migmatites) majorly occupy the escarpments on the western side of the area. Sediments, mostly greywackes, fluvial deposits, eolian and organic unconsolidated sediments overly most rocks in the central region. The spatial distribution maps of the physico-chemical parameters show that most of the parameters have their highest concentrations in the central and southern regions (such as pH, turbidity, sodium, fluoride and chloride) which are covered by volcanics and volcano-sediments.

4.0 Conclusions And Recommendations

The groundwater quality of Baringo County shows higher concentrations of turbidity, fluoride and chloride than recommended values in drinking water by KEBS and WHO. However, fluoride concentrations were of great concern since they were high in many boreholes (23.6%). The spatial distribution of these parameters showed that the concentrations were highest in the central and southern regions of the area. This distribution pattern correlated positively with the structural density map. Structures increase permeability in rocks/aquifers. Permeable rocks have a long rock-water interaction time, resulting in high dissolution of minerals into groundwater. Based on the current findings, we recommend further detained study of structural characteristics such as the type of structures (faults, fractures, joints), their orientation and influence on groundwater flow pattern, their depth (deep and shallow structures) to understand further how structural characteristics influence groundwater quality.

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