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Evaluation of Groundwater Quality Utilizing the Water Quality Index: Case Study of Selected Springs in Kipkelion West Subcounty, Kericho County, Kenya

Kiptoo Edmon[*], Peter Kuria Ndiba[**], Damaris Oyaro[***]
[**] ORCID: https://orcid.org/ 0000-0003-4563-4333
Department of Civil Engineering, University of Nairobi
[***] ORCID: https://orcid.org/ 0000-0002-5977-0195
Department of Civil Engineering, University of Nairobi

Abstract*- Water resources are under threat of contamination from anthropogenic and natural factors a scenario that is exacerbated by water scarcity. Communities such as the Kipkelion West Subcounty residents that heavily rely on springs for drinking water require a safeguard from gastrointestinal illness that are caused by consumption of contaminated spring water. The study evaluated groundwater quality from six select springs; namely, Chuboit, Sugutek and Kaplaba, Lelechwet, Siret and Kipmologit. The location of the springs was mapped by the use of a handheld GPS and QGIS. Water samples were analysed and the results used to develop Water Quality Indices. R software used to develop a predictive model. The average and range for the six springs for the physical parameters of turbidity was 3.45 NTU (±1.39) and 1.67-5.67 mg/L. pH was 7.88 (±0.45) and 7.33-8.50 while nitrates was 16.7 (±17.92) and 0.6-38.33 mg/L. Fluorides, total iron and calcium were 1.29 (±17.92) and 0.5- 1.57 mg/L, 0.16 (±0.09) and 0.03-0.29 mg/L, 29.1(±5.06) and 24-35.33 mg/L, respectively. Total hardness and total alkalinity were 322.61(±164.02) and 66-500.67 mg/L, 233.94 (±77.49) and 181.67-382.67 mg/L. Chlorides, sulphates and total viable count were 169.6 (±119.55) and 11.33-365.33 mg/L, 77.06 (±94.64) and 18-264.67 mg/L, 1.56 (±2.88) and 0-7.33 cfus/100 ml respectively. The Water Quality Indices provided Water Quality Status ranging from 'excellent' quality at Kipmologit spring to 'very poor' quality at Sugutek and Lelechwet springs. The residual vs. fitted graphical representation of the developed model showed a random distribution of the points, which is a requirement of a good model hence can be applied in predicting the water quality of the springs. The study recommends investigation of runoff pathways and implementation of springs' protection through fencing and good drainage and periodic testing of the water from the springs.

***Index Terms*- Groundwater quality, water quality index, water quality status,**

I. INTRODUCTION

Water as a resource is vital for the sustenance of human life and socio-economic development [1]. However, water resources are at risk of contamination from both anthropogenic and natural factors such as urban and agricultural runoff, leaching, rock weathering, improper disposal of waste and domestic and industrial effluents, amongst others [1] [2]. Drinking of contaminated water can cause gastrointestinal illness [3] [4]. The critical role that water plays in people's livelihoods requires its protection from contamination.
Globally, renewable freshwater availability of 1000 m^3/capita/day is recognized as the threshold below which a nation experiences water scarcity. Kenya is considered to be a water-scarce country because its water supply that stands at 693 m^3/person annually falls short of the threshold value [5]. Scarcity of water in Kenya is primarily caused by factors such as urbanization and climate change impacts that have exacerbated droughts [6]. The challenges of inadequate investment in water infrastructure and management leaves some populations with little or limited water access [7]. The little or limited access causes communities in peri-urban and rural areas to rely on water obtained directly from streams and rivers. However, these sources are susceptible to pollution emanating from untreated waste, agricultural runoff and human activities, which pose significant health risks.
Water Quality Index is a crucial tool in water quality assessment. It entails evaluation of physico-chemical and biological parameters and converting it into a standard value and then comparing it to a single value rated based on quality [8]. Springs in Kipkelion West Subcounty in Kericho county, form a crucial source of drinking water for the subcounty residents. However, the quality of water from the springs is under threat from of anthropogenic activities such as agriculture, improper waste disposal and deforestation. Groundwater contamination has also been reported to be caused by other factors such as the use of unlined pit latrines, leaching of contaminants, infiltration of contaminants and weathering of mineral-bearing rocks. Contaminated water intake pose significant health concerns, with studies establishing them as critical causes of gastrointestinal illness. Despite the springs' importance as water sources in the area, capturing the quality of the springs, for example, using single indices is limited. Therefore, there was a need for groundwater quality assessment and modelling springs within Kipkelion West Subcounty, using using single indexes such as WQI. This study applied WQI in water quality assessment of six select-springs in Kipkelion West Subcounty namely; Chuboit, Sugutek, Kaplaba, Lelechwet, Siret and Kipmologit. A model for predicting water quality of the springs was developed.

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II. METHODOLOGY

A. Description of the Study Area

Kipkelion West Subcounty is located in Kericho County between 0°11' S and 0°39' S latitude and 35°22' E and 35°47' E longitude. The population of the subcounty was enumerated in 2019 national census as 122,530 (KNBS, 2019). The subcounty covers 350 km^2 with a population density of 350 people/km^2. The subcounty is characterized by a hilly terrain with an altitude range of 1800-2300 m above sea level. It experiences moderate temperatures within the range of 16-24°C with an annual rainfall range of 1200-1800 mm. Kipkelion West Subcounty has numerous natural springs that supply water for domestic and agricultural use. It is also dependent on aquifers within the volcanic and metamorphic rock formations [9]. The rivers and streams that originate from the nearby highlands contribute to Kipkelion's west hydrology.

B. Sampling and Mapping of Selected Springs

Purposive/selective sampling focused on the judgment of the researcher about the springs that provided the most relevant information was utilized in the selection of the six springs. The water quality was assessed for springs whose water is utilized for domestic applications. The springs are also easily accessible and have a high usage level.

A handheld GPS was used in collecting the coordinates of the six springs within Kipkelion Sub County. The coordinates were recorded and input into the QGIS software for the development of a map for visual representation of the springs.

C. Determination of Physico-chemical Water Quality

Water samples from the six springs were collected between 8 am and 5 pm (in the months of July and August 2025), which was a dry season. The sampling months were designed to represent the period when residents collect water from the springs during dry seasons; harvest water is used during rainy seasons. Plastic bottles of 1-litre were used in collecting the water samples. Distilled water was used to wash the bottles before sample collection. The samples were labelled before being transported to the Central Rift Water Works Development Agency (CRWWDA) water quality testing laboratory for analysis.

The tests were carried out in the aforementioned water quality testing laboratory. Table 1 below indicates the testing methods that were used in determination of the parameters. A comparison was made with the WHO standards to determine their conformity.

Table 1: Methods used for determining water quality parameters

Parameter	**Instrument/Method** [10]	**Units**
pH	pH	None
Nitrates	Cadmium reduction method	mg/L NO_3^--N
Turbidity	Absorptometric method	Formazine Attenuation Units (FAUs)
Fluorides	Direct ISE method	mg/l Fe^-
Iron	USEPA FerroVer method	mg/L Fe
Calcium	Titration method with ETDA	mg/L Ca^{2+}
Total hardness	Titration method with EDTA	mg/L Ca as $CaCO_3$
Total alkalinity	Digital reactor	mg/L $CaCO_3$
Chlorides	Silver nitrate method	mg/L Cl^-
Sulphates	USEPA SulfaVer 4 method	mg/L SO_4^{2-}
Total Viable Count	Pour plate method (ISO 8199)	CFUs/ml

D. Development of Water Quality Indices

The procedure for the calculation of the index was a modification of procedures used by [11] [12] [13]. The modification was done to inform the study objectives, considering the specific water parameters analyzed. It also ensured the index accurately reflected the water quality characteristics of the study area while maintaining consistency with established WQI calculation approaches. Each parameter was given a unit weight (Wu) on 1 - 5 scale where 1 indicated least health effect while 5 indicated critical health effect when the parameter is ingested in water. A unit weight (Wn) for every parameter was determined by:

$$\mathrm{Wn} = \mathrm{K}/\mathrm{Sn} \qquad \text{Eqn. 1}$$

Where: Wn-Unit weight of n^{th} water quality parameter, Sn-Recommended WHO standards of n^{th} parameter

K represents proportionality constant

$$\mathrm{K} = \frac{1}{\Sigma(\frac{1}{\mathrm{Sn}})} \qquad \text{Eqn. 2}$$

The quality rating of every parameter was determined using Equation 3

$$\mathrm{Qn} = 100\left[\frac{\mathrm{Vn}-\mathrm{V1}}{\mathrm{Sn}-\mathrm{V1}}\right] \qquad \text{Eqn. 3}$$

Where: Vn- Observed value of n^{th} parameter, Sn- Recommended WHO standard value of the n^{th} parameter, V_1- Ideal value of the n^{th} parameter

Finally, the final WQI value for every respective stream was determined using Equation 4.

$$\mathrm{WQI} = \sum \mathrm{Wn\ Qn} / \sum \mathrm{Wn} \qquad \text{Eqn. 4}$$

WQI results underwent a comparison with Water Quality Status (WQS) from Table 2:

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Table 2: WQS for Comparison with WQI

WQI	WQS	Possible use
>100	Not suitable for drinking	Requires proper treatment before use
76≤ 100	Very poor	Irrigation
51≤ 75	Poor	Irrigation and industrial use
26≤ 50	Good	Irrigation, drinking and industrial use
0≤ 25	Excellent	Irrigation, drinking and industrial use

E. Development of a Prediction Model for Selected Springs

R software was utilized in developing a prediction model for springs within Kipkelion West Subcounty. A coding script was developed in the R software to import, clean and analyze the water quality data set. The script was used to fit the prediction model and evaluate its performance. Water quality parameters were the independent variables while the WQI was the dependent variable.

III. FINDINGS

A. Location of Select Springs

The coordinates of the six select springs within Kikelion West Sub County (Chuboit, Sugutek, Kaplaba, Lelechwet, Siret and Kipmologit springs) were collected using a handheld GPS. The coordinates were input in QGIS software for the development of a map to give a visual interpretation of the selected six springs, as shown in Figure 1.

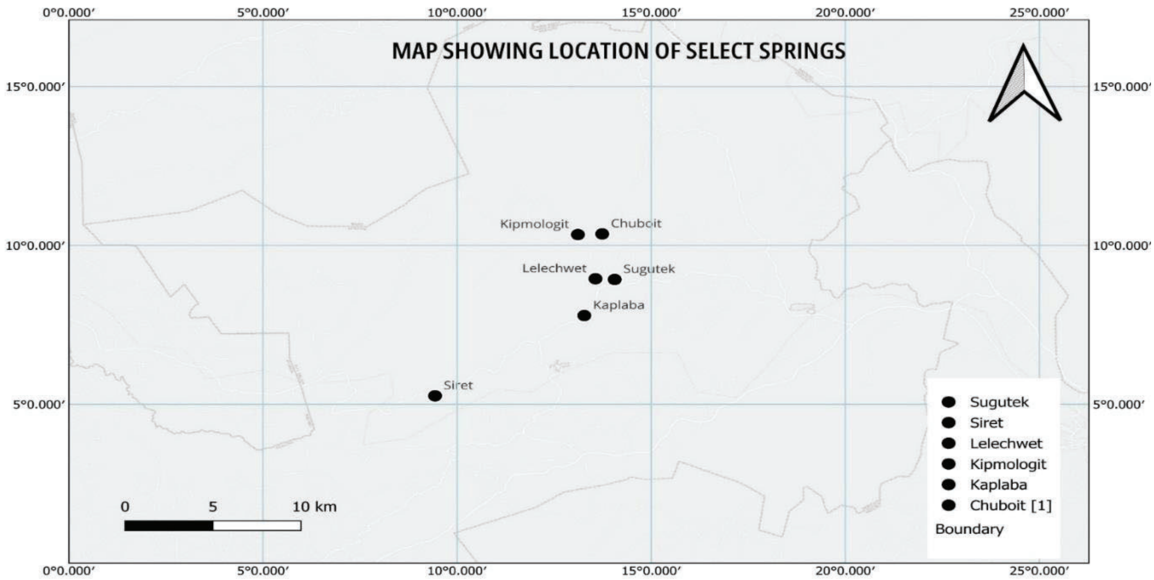

Figure 1: Map showing Location of the Six Select Springs

B. Physico-chemical and Biological Characteristics of Spring Water

The water quality parameters levels and their statistical analysis are presented in Table 3.

Table 3: Statistical parameters of the water quality characteristics

Spring	pH	Turbidity	Nit	F	Total Iron	Ca	Total hardness	Total alkalinity	C^{l-}	SO^{3-}	Total Viable Count
WHO standard	**6.5-8.5**	**<5**	**<50**	**<1.5**	**<0.3**	**20-30**	**<500**	**<200**	**<250**	**<250**	**0**
Units	**0-14**	**NTUs**	**Mg/l**	**Mg/l**	**Mg/l**	**Mg/l**	**Mg/l**	**Mg/l**	**Mg/l**	**Mg/l**	**CFUs/ 100ml**
Chuboit	7.33	3.33	1.07	0.50	0.14	28.67	66.00	181.67	11.33	64.33	0.67
Sugutek	7.89	2.33	26.00	1.47	0.29	35.33	500.67	184.33	130.00	18.00	1.33
Kaplaba	8.50	1.67	38.33	1.57	0.19	24.00	498.67	184.33	104.67	23.67	0.00
Lelechwet	8.31	3.67	33.67	1.50	0.22	35.00	326.00	224.33	209.67	264.67	7.33

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Siret	7.58	5.67	0.60	1.57	0.11	24.00	293.00	246.33	196.33	36.00	0.00
Kipmologit	7.64	4.00	0.60	1.10	0.03	27.67	251.33	382.67	365.33	55.67	0.00
Mean	7.88	3.44	16.71	1.28	0.16	29.11	322.61	233.94	169.56	77.06	1.56
SD	0.45	1.39	17.92	0.42	0.09	5.06	164.02	77.49	119.55	93.64	2.88
Minimum	7.33	1.67	0.60	0.50	0.03	24.00	66.00	181.67	11.33	18.00	0.00
Maximum	8.50	5.67	38.33	1.57	0.29	35.33	500.67	382.67	365.33	264.67	7.33
Range	1.17	4.00	37.73	1.07	0.26	11.33	434.67	201.00	354.00	246.67	7.33
CI of mean	0.48	1.46	18.80	0.44	0.10	5.31	172.13	81.32	125.46	98.27	3.02

The values of the pH for the 6 springs were in range of 7.33 and 8.50 with a mean value of 7.88 (±0.45), indicating slight alkalinity. These findings indicate that the 6 springs in Kipkelion west conformed to the WHO set standards of 6.5-8.5 [14]. Slight alkalinity in groundwater is common in various aquifers, with bicarbonates and carbonates dissolution due to geology composition [15]. The pH that falls within the WHO range pose no significant threat to human health. However, such pH may influence corrosivity and taste of water and affect the treatment efficiency of water when chlorine is used. According to [14], the effectiveness of chlorine in treating water reduces with the increase in pH. A spring such as Kaplaba had a pH of 8.5 which is near the upper limit of the standards, implying that it should be noted when determining the amount of chemical disinfectant too use. Studies about protected springs and other sources of groundwater in East Africa have also reported pH within this range, and attributed the occurrence to geological influence [16] et al., 2019; Haruna et al., 2005). Based on these findings, there is need for routine monitoring of pH at different intervals amongst the springs and to adjust the chlorine dosages for disinfection based on the observed pH values [14].

The mean of the turbidity values for the 6 select springs was 3.45 NTU (±1.39), which was in conformity with the WHO guidelines of 5NTU [14]. However, the Siret spring had a turbidity level of 5.67 NTU, which exceeded the 5 NTU guideline. Turbidity is a representation of the suspended particles in water including microbes, algae, organic matter, soil, amongst others. Therefore, the high turbidity levels in Siret springs may be a reflection of the influence of the local surface, a shallow source of inflow of particulates or lack of spring protection. The lack of protection may influence runoff and human and animal activity around the spring, hence leading to the elevated turbidity levels. Turbidity may not be considered to be a health parameter. However, it has a string association with microbial contaminants because microorganisms attach themselves on particulates in water. Furthermore, the particles may shield the microbes from disinfection [14]. Therefore, the Siret spring needs to be well managed and protected and its water needs to undergo treatment and disinfection before consumption. Studies conducted in Uganda and Kenya on protected water sources and springs have linked the increase in turbidity levels to surface runoff and poor protection [16] [17]. Based on these findings, there is a need to investigate the runoff pathways at Siret and implement the spring protection through fencing and constructing good drainage systems. Filtration and chlorination also need to be provided at the household level before consuming the Siret spring water.

The mean for nitrates in the 6 springs was 16.7 (±17.92) mg/L, which was in conformity of the 50 mg/L standard set by the WHO [14]. The range was 0.6-38.33 mg/L. Therefore, all the target springs were fit for human consumption considering the nitrates parameter alone, without considering all the other parameters. The nitrates in groundwater reflection of can be an indication of sewer leaks, agricultural inputs and animal waste presence in the recharge areas [14]. The higher values of nitrates at Lelechwet, Kaplaba and Sugutek, though still conforming to the set standards, could have been evidence of localized anthropogenic sources such as nearby pit latrines and upland farming. Kericho is a known agricultural hub, and this fact may be a contribution to the present nitrates' levels in the springs [18]. The recommendation by WHO of <50 mg/L of nitrates is to safeguard infants from the risk of contracting methemoglobinemia. Despite all the 6 springs being below this limit, concentration levels of approximately 10 mg/L or more may be an indication of anthropogenic impact which requires protection the water sources [14]. Ondieki et al. [19] and Karianki et al. [20] have also reported nitrates levels in similar ranges to this study, in their studies on water quality in Kisii Town and Njoro Subcounty in Kenya, and attributed the occurrence to agricultural impact. A monitoring plan needs to be developed for springs showing higher nitrate levels, and the land use studied to ensure target specific interventions are made.

The mean value for fluorides was 1.29 (±17.92) mg/L. Its range was 0.5- 1.57 mg/L. Based on these findings, only 2 springs: Siret at 1.57 mg/L, Kaplaba at 1.57 mg/L exceeded the set WHO standard of 1.5 mg/L [14]. The high fluoride levels may be as a result of the water and rocks interaction in the minerals that bear fluorides. The springs with the high fluoride levels are a risk to human health because of its association with skeletal and dental fluorosis [14]. There has to be cite reference seasonal monitoring of the springs that exceeded the WHO guideline. If the high fluoride levels persist with time and the water is to be used for community supply, then defluoridation needs to be done. Public awareness needs to be conducted for such springs so that the community is aware of the health implications it faces if it utilizes the water without treatment. Slightly higher fluoride levels have also been reported in various studies in groundwater, which have attributed the occurrence to the geological composition [21] [22].

The mean for total iron was 0.16 (±0.09) mg/L with a range of 0.03-0.29 mg/L. These values were in conformity with the WHO set standard of 0.3 mg/L for total iron levels in surface water. The low iron content is a common phenomenon in shallow springs that are well oxygenated. Higher iron content occurs when iron-bearing minerals are present or when there are reducing conditions The low iron content in the 6 springs are unlikely to cause taste problems or staining. However, if spike levels get noticed later, it will be prudent to consider treating the water before consumption, especially aeration, settling and filtration processes which have proven to be effective and low-cost in water treatment [14].

Total hardness in water is always linked to presence of calcium and magnesium ions. Hence, tying them together is prudent in order to understand how they complement each other. The mean values for the 6 springs for calcium and total hardness were 29.1(±5.06) mg/L and 322.61(±164.02) mg/L, respectively. The range for calcium and total hardness for the 6 springs were 24-35.33 and 181.67-382.67 mg/L. Two springs exceeded the WHO recommendation for calcium level of surface water of 20-30 mg/L (Sugutek-35.33 mg/L and Lelechwet-35 mg/L) [14]. Sugutek spring also exceeded the WHO limit of total hardness of <500 mg/L, with a value of 500.67 mg/L [14]. Hardness is controlled by Mg^{2+} and Ca^{2+} that emanate from dissolution of carbonates [23]. The high hardness in Lelechwet and Sugutek springs is an indication of a calcareous geology and longer residence time of water, which enables it to dissolve these ions. Hardness levels that exceed 300 mg/L has the ability of scaling appliances and pipes [24]. Hard water presents aesthetic concerns unlike having a direct implication on health. However, calcium and total hardness can influence acceptability and taste of water. Furthermore, hardness can complicate the water treatment process in that the coagulant demand becomes high, hence increasing the costs. Source protection is therefore important to avoid any additional minerals and ions inputs that influence calcium and total hardness levels through anthropogenic activities.

The mean for the total alkalinity for the 6 springs was 233.94 (±77.49) mg/L, which exceeded the WHO standard value of <200 mg/L [14]. The springs of Lelechwet, Siret and Kipmologit had high values of total alkalinity of 224, 246 and 382 mg/L, respectively, which were all above the <200 mg/L threshold. The high alkalinity levels is an indication of carbonate and bicarbonate buffering, which typically takes place in concurrence with high total hardness. The elevated alkalinity buffers pH, and leads to a reduction in the immediate effect caused by acidification. However, it complicates water treatment processes, specifically increasing the coagulant dosage at coagulation and the chlorine demand at disinfection. Periodic monitoring needs to be done for total alkalinity to inform any on-point water treatment processes, especially at the 3 springs (Lelechwet, Siret and Kipmologit).

The average value of chlorides for the 6 springs was 169.6 (±119.55) mg/L which was below the <250 mg/L standard [14]. The range for chloride levels was 11.33-365.33 mg/L, with only Kipmologit Spring exceeding the WHO standard. The elevated chloride levels in Kipmologit Spring may be as a result of saline intrusion, weathering of rocks, contamination from animal and human waste and runoff having chloride ions. The high levels of chlorides at the spring is also a suggestion of a local geologic source. High chloride levels implicate taste and aesthetic issues, as they can lead to the corrosion of metallic pipes. Despite chlorides not being a specific health hazard for people, they indicate geologic processes and contamination [25]. Therefore, it is important to monitor the land use and asses the local geology around Kipmologit, and if anthropogenic sources are established, source protection measures need to be implemented.

The average value of the sulphates levels for the 6 springs was 77.06 (±94.64) mg/L with a range of 18-264.67 mg/L. The standard threshold for the sulphates in surface water is <250 mg/L [14]. Lelechwet Spring exceed this threshold with a sulphates value of 264.67 mg/L. This elevated value is an indication of anthropogenic inputs and gypsum dissolution at the Lelechwet Spring. The high sulphates values implicate taste issues, especially to the sensitive consumers. There is a need for periodic sampling of sulphates, and if spikes are noted, the water needs to be treated before consumption.

According to WHO [14], there should be no detection of faecal indicators in drinking water. From the findings of this study, only 3 springs meet this criterion (Kaplaba, Siret and Kipmologit). The other 3 springs had their water samples detected with faecal matter indicators (Lelechwet- 7.33, Sugutek- 1.33 and Chuboit- 0.67 cfus/100ml). Detection of fecal matter in any water sample from the springs is an indication of either post-collection contamination or poor protection of water sources. Their presence is an indication of a public health risk. For example, Lelechwet spring is of concern because apart from the exceedance in TVC, it also had elevated values of turbidity, alkalinity and sulphates. Even low TVC indicate the presence of pathogens, and hence the water needs to be treated before consumption. Studies have shown that protected springs exhibit intermittent contamination of pathogens because of surface runoff, animals, and proximity to unlined pit latrines [16] [26]. Priority needs to be given to microbiological testing for the 3 flagged springs. Point-of-use disinfection needs to be done and source protection measures such as fencing need to be adopted.

C. Development of unit weights (Wn), quality ratings (Qn) and WQIs

Table 4 shows the determined values of the unit weights, from calculations done using equations 1 and 2 presented in the methodology section. The recommended WHO values (Sn) utilized in the determination of the unit weight (Wn) are also presented. In most cases, the development of WQI models entails using between 8-26 parameters, while some researchers have applied 8-11 parameters [27] [28]. For this case, the 11 target parameters were in agreement with what the aforementioned work.

Table 4: Unit weights of the target parameters

No	Parameters	Sn	1/Sn	Unit weight (Wn)
1	pH	8.5	0.117647	0.02670168
2	Turbidity	5	0.2	0.04539285
3	Nitrates	50	0.02	0.00453928
4	Fluorides	1.5	0.666667	0.15130949

5	Total iron	0.3	3.333333	0.75654747
6	Calcium	30	0.033333	0.00756547
7	Total hardness	500	0.002	0.00045393
8	Total alkalinity	200	0.005	0.00113482
9	Chlorides	250	0.004	0.00090786
10	Sulphates	250	0.004	0.00090786
11	Total Viable Count	50	0.02	0.00453928
		Sum (1/Sn)	4.40598	1
		K	0.226964	

The constant of proportionality (K) was determined by:

$$K = \frac{1}{\sum(\frac{1}{Sn})}$$

K= 1/4.40598 = 0.226964

The quality rating of the nth parameter indicates a relative value of each of the respective parameters in the water sample when compared to the recommended water quality standards. In this case, the water quality standards are the relative values based on the WHO recommended standards.

The ideal values for the water quality target parameters were assumed to be 0 for this study, except for pH which is always 7 in normal neutral water pH practice. The same assumptions were made by other researchers in the development of the WQI models [29] [13]. Equation 3 in the methodology section was used in the determination of the Qn values, as presented in Table 5. The Qn, Wn and WnQn results are presented in Table 5.

Table 5: Wn, Qn and WnQn values for the target water quality parameters

Spring name	Parameter	pH	Turbidity	NO_3^-	F^-	Fe	Ca	TH	TA	Cl^-	SO_4^{2-}	TVC	Sum
	Standard value	8.50	5.00	50.00	1.50	0.30	30.00	500.00	200.00	250.00	250.00	50.00	
	Wn	0.03	0.05	0.00	0.15	0.76	0.01	0.00	0.00	0.00	0.00	0.00	∑Wn 1.00
Chuboit	Observed value	7.33	3.33	1.07	0.50	0.14	28.67	66.00	181.67	11.33	64.33	0.67	
	Quality rating Qn	22.22	66.67	2.13	33.33	47.78	95.56	13.20	90.83	4.53	25.73	1.33	
	WnQn	0.59	3.03	0.01	5.04	36.15	0.72	0.01	0.10	0.00	0.02	0.01	∑WnQn 45.68
Sugutek	Observed value	7.89	2.33	26.00	1.47	0.29	35.33	500.67	184.33	130.00	18.00	1.33	
	Quality rating Qn	59.56	46.67	52.00	97.78	95.56	117.78	100.13	92.17	52.00	7.20	2.67	
	WnQn	1.59	2.12	0.24	14.79	72.29	0.89	0.05	0.10	0.05	0.01	0.01	∑WnQn 92.14
Kaplaba	Observed value	8.50	1.67	38.33	1.57	0.19	24.00	498.67	184.33	104.67	23.67	0.00	
	Quality rating Qn	100.22	33.33	76.67	104.44	63.33	80.00	99.73	92.17	41.87	9.47	0.00	
	WnQn	2.68	1.51	0.35	15.80	47.91	0.61	0.05	0.10	0.04	0.01	0.00	∑WnQn 69.06
Lelechwet	Observed value	8.31	3.67	33.67	1.50	0.22	35.00	326.00	224.33	209.67	264.67	7.33	
	Quality rating Qn	87.56	73.33	67.33	100.00	73.33	116.67	65.20	112.17	83.87	105.87	14.67	
	WnQn	2.34	3.33	0.31	15.13	55.48	0.88	0.03	0.13	0.08	0.10	0.07	∑WnQn 77.86
Siret	Observed value	7.58	5.67	0.60	1.57	0.11	24.00	293.00	246.33	196.33	36.00	0.00	
	Quality rating Qn	38.67	113.33	1.20	104.44	35.56	80.00	58.60	123.17	78.53	14.40	0.00	
	WnQn	1.03	5.14	0.01	15.80	26.90	0.61	0.03	0.14	0.07	0.01	0.00	∑WnQn 49.74
Kipmologit	Observed value	7.64	4.00	0.60	1.10	0.03	27.67	251.33	382.67	365.33	55.67	0.00	∑WnQn 23.68

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	Quality rating Qn	42.44	80.00	1.20	73.33	8.89	92.22	50.27	191.33	146.13	22.27	0.00	
	WnQn	1.13	3.63	0.01	11.10	6.72	0.70	0.02	0.22	0.13	0.02	0.00	

The WQIs for the 6 springs were determined through a combination of the different sub-indices of Wn and Qn [28] [27] [13]. Table 5 shows the WQIs of the springs.

Table 4-5: WQIs of the springs

No.	Name of spring	∑WnQn	∑Wn	WQI= ∑WnQn/∑Wn
1	Chuboit	45.68		45.68
2	Sugutek	92.14		92.14
3	Kaplaba	69.06		69.06
4	Lelechwet	77.86	1.00	77.86
5	Siret	49.74		49.74
6	Kipmologit	23.68		23.68

The assessment of the WQIs shows a range in the water quality status of the 6 springs starting from the excellent quality at Kipmologit spring to very poor quality at Lelechwet and Sugutek springs. Only 1 spring had the 'excellent' standard (16.7%), two springs had the 'good' standard (33.3%), one spring was of 'poor' standard (16.7%) and two springs has the 'very poor' classification (33.3%). This is a representation of heterogeneity in contamination amongst the springs in Kipkelion west subcounty, with some springs negatively impacted while others are relatively protected. The pattern is an indication for the need of adoption of targeted monitoring, protection and interventions in order to safeguard water security and public health at large.

Kipmologit spring had an excellent water quality status with a WQI of 23.7 According to this WQS classification, its water is safe for irrigation, drinking and any small-scale industrial application in the area. Chuboit (45.68) and Siret (49.74) were of good water quality with their water being acceptable for drinking, irrigation and industrial applications. Kaplaba had a WQI of 69.1, which is classified as poor water quality that can only be utilized for irrigation and small-scale industrial applications, but not for drinking without proper treatment. Finally, Sugutek (92.14) and Lelechwet (77.86) had 'very poor' water quality and their water is restricted for irrigation use only. However, when the water undergoes treatment, it can be used for consumption.

Kipmologit spring's low WQI value is an indication of minimal contamination, which is as a result of the source protection and little input from anthropogenic activities. The springs has low loading of microbes, low turbidity and generally good physico-chemical conditions based on the results from its water quality parameters. Similar findings have been reported by Kiwanuka et al. [30], where springs were assessed in peri-urban areas and a shift from 'excellent' to 'good' WQS were reported for the dry and wet seasons, respectively. Kipmologit spring is safe for direct human consumption, though periodic monitoring and protection need to be carried out in order to safeguard it from any degradation in future.

Chuboit spring was in good water quality status with a WQI of 46.68. However, the spring shows some degradation which indicates moderate impact from pollutants. The possible pollutant sources may be livestock and surface runoff when it rains. However, the spring's water can be used for drinking. However, it is important that measures of reducing contamination be implemented in order to maintain or improve its water quality status.

Siret spring had a good water quality status with a WQI of 49.74. Any slight increase in the contaminant loads in Siret spring may push the spring's classification to the 'poor' category as it is very close to the upper limit of the 'good' status. Similar results have been reported in springs in Kampala whose WQI values ranged between 50-58 but the WQS declined during the wet season due to flooding and runoff [31]. Buffer zones need to be implemented to prevent animal and human intrusion. Furthermore, upstream land use has to be considered in the preservation of water quality of the spring.

Kaplaba spring was classified as 'poor' in terms of WQS with a WQI value of 69.06. This spring cannot be relied on as being safe for human consumption if the water is not treated. The high value of WQI is likely to be informed by contamination arising from agricultural runoff, sediment load and organic matter. However, for domestic use, there has to be appropriate treatment. However, for industrial and irrigation use, this water quality may still be acceptable.

Lelechwet spring was established to have 'very poor' WQS because of the WQI value of 77.86. The classification indicates substantial pollution, indicating that there is a compromise on the drinking suitability of the water. It can also bot be used for irrigating sensitive crops. The contamination may also be as a result of livestock presence near the source, garbage and seepage from nearby unlined latrines. The spring needs to be rehabilitated and provision of alternative safe water sources for the residents be provided. The water also needs to undergo treatment before any application.

Sugutek spring was the most degraded spring as it was classified as 'very poor' with a WQI value of 92.14. The spring is unsuitable for drinking under its current conditions. The source of contamination included heavy microbial contamination, chemical pollutants, turbidity and high nutrients levels. Research has shown that various springs sources in Kenya always exhibit high coliform counts despite being protected, which suggests that microbial contamination is a frequenting problem [32]. There is a need for immediate

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protective measures and water treatment systems to be implemented at the spring. Therefore, in the Kipkelion west subcounty, there is an immediate need to prioritize Sugutek spring for interventions.

Based on these findings, there is a need to implement source protection measures such as fencing of the springs, maintaining buffer zones and restricting animal access. Land use changes uphill need also to be controlled. There needs to be regular inspection and repair of the infrastructure at the springs including masonry and drainage works. Secondly, the springs that do not meet the standards (Sugutek, Lelechwet and Kaplaba) need to implement treatment interventions at points-of-use. Thirdly, it is important to sample and monitor all the springs seasonally for the physic-chemical and biological water quality indicators and trends be tracked over time to detect any improvement or deterioration. Finally, community awareness needs to be done on matters of sanitation, hygiene, water handling and health risks.

D. Statistical regression model

The R software was utilized in the development of a statistical regression predictive model for the WQI of the 6 select springs within Kipkelion west subcounty. A code was generated, which enabled the development of the model with only 5 coefficients. 6 coefficients are missing because of singularities. The following multiple linear regression model was developed.

$$y1 = 117.512 - 15.5472\,x1 + 1.4099\,x2 + 0.5659\,x3 + 11.9736\,x4 + 215.5195\,x5 \qquad \text{Eqn. 4}$$

Where; y1- WQI, x1- pH, x2- Turbidity, x3- Nitrates, x4- Fluorides, x5- Total iron

This means that in any water sample picked from the 6 springs, the pH, turbidity, nitrates, fluorides and total iron levels can be used to perfectly first confirm that the model returns the same WQIs as the WQI formula predict their WQIs. The rest of the water quality indicators had singularities, hence attaining their coefficients lacked applicability. The residuals vs. fitted plot for this model is represented in Figure 2.

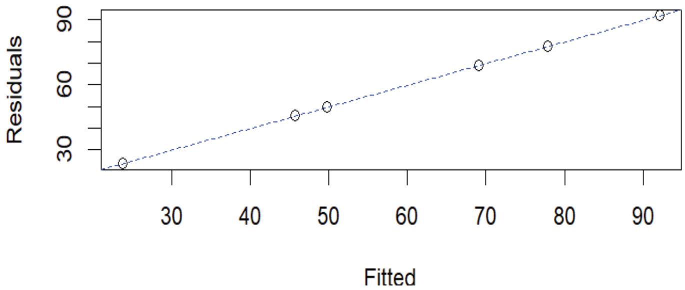

Figure 2: Residuals vs. fitted plot

Figure 2 does not show any identifiable pattern of the points along the blue abline onto which they conform to. This is an indication of a random distribution, which shows that the model is good [33]. Such a graphical outcome of the residuals vs fitted plot coupled with an R^2 value of 1 as determined by the model indicates that it has a high predictive power for the WQI values of the 6 select springs within Kipkelion west subcounty.

IV. CONCLUSION

The study determined the physico-chemical and biological water quality parameters of 6 select springs within Kipkelion west subcounty in Kericho County, Kenya and obtained WQI and developed. The WQIs of springs in the area range from 'excellent' quality at Kipmologit spring to 'very poor' quality at Sugutek and Lelechwet springs. Only 1 spring (16.7%; Kipmologit) had the excellent WQS standard, 2 springs (33.3%; Chuboit and Siret) exhibited the good WQS standard, 1 spring (16.7%; Kaplaba) had the poor standard while 2 springs (33.3%; Lelechwet and Sugutek) showed the very poor classification. A model was successfully developed from a code in the R software. An analysis of the model in terms of the residual vs. fitted graphical representation showed a random distribution of the points with no clear identifiable pattern on the line that they conformed to, which showed that the model can be used to predict the WQIs of the springs. Therefore, all the objectives of the study were achieved.

Based on the findings of this study, the following recommendations were made:

1. The runoff pathways at Siret need to be investigated and implementation of the spring's protection through fencing and constructing good drainage systems be considered due to the determined spiked turbidity levels.
2. Public awareness should be conducted to communities that utilize Siret and Kapba springs because of their slightly high fluoride content, so that they are able to know the public health risk faced when they consume their water without treatment.
3. Microbiological testing for the 3 flagged springs (Lelechwet, Sugutek and Chuboit) b done periodically and point-of-use disinfection be done.

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