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Assessment of Groundwater Stability Using Corrosion and Scaling Tendency Indices on Selected Springs in the Manga Region in Nyamira County, Kenya

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Abstract

We present the result of groundwater stability assessment on three major springs in the Manga region in Nyamira County found in Kenya in 2018. These springs are Kiangoso (SP1), Kerongo (SP2) and Tetema (SP3). The corrosion and scaling tendency indices were obtained using the Langelier saturation index (LSI), Ryznar stability index (RSI), and Puckorius scaling index (PSI). The LSI values obtained for SP1, SP2, and SP3 are −3.93, −4.71, and −4.17, respectively, while using RSI, the values obtained for SP1, SP2, and SP3 are 14.15, 14.53, and 13.74, respectively. Using PSI, the values of SP1, SP2, and SP3 are 5.58, 5.45, and 5.58, respectively. From the interpretation of the indices, the groundwater from the three springs in the Manga region using LSI and RSI showed intolerable corrosion; hence, it is unlikely to scale as obtained from PSI.

Keywords

Langelier Saturation Index, Ryznar Stability Index, Puckorius Scaling Index

1. Introduction

Water is an essential commodity in human life. Much research has been carried out worldwide to determine water quality and ascertain water source safety [1]-[9]. Much attention has been paid to the quality of water which is influenced by the physical, chemical and biological properties of the water [10] [11] [12] [13] [14]. However it is important to note that water safety relies not only on the sources but also on how water reaches the final consumer. Moreover, much of the water is not used or consumed at these sources; it is either piped, channeled, or even fetched to the final user in homes, industries, hospitals, and other places for storage and last usage. For this reason, water stability is looked at in this study.

Water stability, being the ability of water to deposit or dissolve minerals [15], is a public health concern and an economic issue. Water stability is looked at in terms of either corrosion or scaling. Corrosive water weakens and dissolves metals in plumbing systems, causing the increase in concentration of metals hence contaminating households' water systems and leading to health issues such as digestive and respiratory tract problems as well as skin and eyes issues [16]. In severe cases, it may cause leakages, hence the financial implications of replacing an already damaged system. On the other hand, mineral deposition causes blockage and leakage in the plumbing systems and reduces the efficiency of hot water appliances, especially heaters.

Corrosion or scaling is an inherent groundwater property that has been studied across the world [17]-[26] using mathematical indices. Langelier saturation index (LSI), proposed by R. Langelier in 1936 [27], and the Ryznar stability index (RSI), proposed by Ryznar in 1944 [28], are among the mathematical indices majorly used in evaluating the potential of water to be corrosive or scale [20]. Other mathematical indices used include Larson-Skoldindex (LS), aggressive index (AI), and Puckorius scaling index (PSI) [18] [29] [30].

Langelier saturation index (LSI) and Ryznar stability index (RSI) use chemical properties such as alkalinity, total dissolved solids (TDS), pH, and calcium. Physical properties such as temperature are also considered when finding corrosivity and scaling using the indices above. In this assessment, LSI, RSI and PSI have been used.

2. Materials and Methods

2.1. Study Area

Figure 1 shows the location of the springs in the area map.

The three springs in the study are located in the Manga region in Nyamira county in Kenya [31]. The position and elevation, however, are shown in **Table 1**.

According to [31], the three springs are sources of safe water for drinking. In addition, the water quality index (WQI) and the water quality status (WQS) obtained for the three springs in the year 2018 are shown in **Table 2**.

2.2. Sample Collection

Sample collection was done between 12.00 noon and 5.00 pm (East African Standard Time) during the rainy season in November 2018. A 1.0-litre capacity bottle washed with distilled water and rinsed with water from respective springs was used to collect samples from each spring.

2.3. Sample Analysis

2.3.1. On-Site Analysis

The on-site analysis was done for two parameters in this study. This includes pH

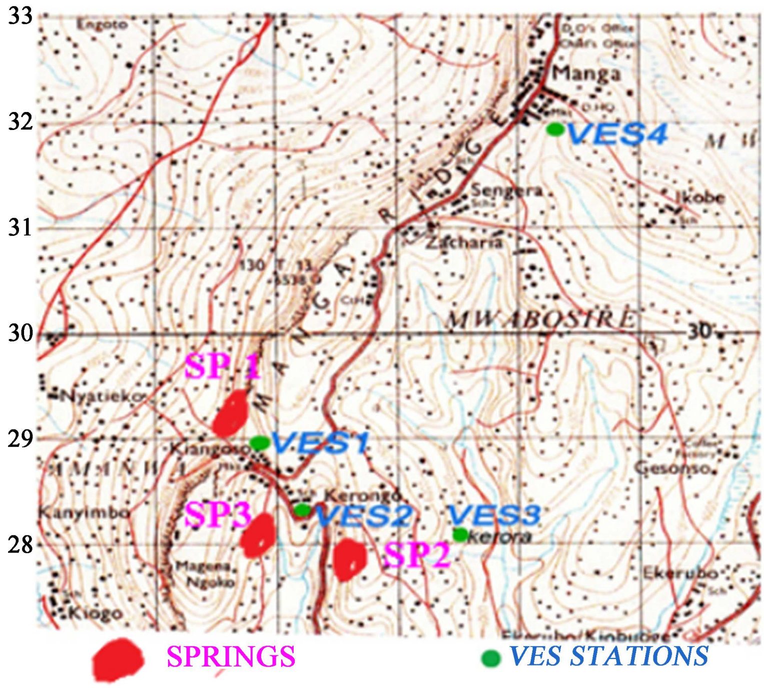

Figure 1. Location of the springs.

Table 1. Descriptive location and elevation of the study springs.

S/N	Spring name	Description	Position		Elevation (m)
			Latitude	Longitude	
1	Kiangoso	SP1	000˚38'42.5"S	034˚48'45.0"E	1785
2	Kerongo	SP2	000˚39'03.7"S	034˚49'08.7"E	1844
3	Tetema	SP3	000˚39'08.4"S	034˚48'55.4"E	1823

Table 2. Water quality index and water quality status of the springs as adapted from [31].

Spring	WQI	WQS
SP1	21.32	Excellent
SP2	29.66	Good
SP3	25.64	Good

and total dissolved solids (TDS) using the Hanna Combo H198129 water tester.

2.3.2. Laboratory Analysis

Other parameters of importance in this study were total alkalinity and calcium, which were characterized in the laboratory in Kisumu by the examination standards established in 2005 for water and wastewater [32]. For instance, the titration method was used in characterizing calcium parameters. This characterization was also inferred from World Health Organization (WHO) standards [33] as well as Kenyan standards by the Kenya Bureau of Standards (KEBS) [34].

2.4. Calculation of Langelier Saturation Index

The Langelier saturation index calculation was based on a modification made by Carrier to Professor W. F. Langelier's work. In this case, the Langelier Saturation Index (LSI) is given by

$$\text{LSI} = \text{pH} - \text{pHst} \tag{1}$$

[12] [13] LSI is the Langelier Saturation Index, pH is the measured pH, and pH is the theoretical pH at saturation of chemical and physical parameters of water. The parameters in this case include total dissolved solids, temperature, calcium, and total alkalinity.

$$\text{pHst} = (9.3 + A + B) - (C + D) \tag{2}$$

Equation (2) involves calcium carbonate saturation points, calculated based on the assumption that the pH ranges between 6 and 9.

Where

$$A = \frac{\text{Log}_{10}(\text{TDS}) - 1}{10} \tag{3}$$

$$B = -13.12 \times \text{Log}_{10}(^{\circ}\text{C} + 273) + 34.55 \tag{4}$$

$$C = \text{Log}_{10}(\text{Ca}^{2+}) - 0.4 \tag{5}$$

$$D = \text{Log}_{10}(\text{Alkalinity}) \tag{6}$$

2.5. Calculation of Ryznar Stability Index (RSI)

The Ryznar Stability index is calculated by

$$\text{RSI} = 2\text{pHst} - \text{pH} \tag{7}$$

where pH is the measured pH while pHst is the theoretical saturation pH as obtained in Equation (2).

2.6. Calculation of Puckorius Scaling Index (PSI)

The Puckorius scaling index was calculated by

$$\text{PSI} = 2\text{pHeq} - \text{pHst} \tag{8}$$

where

$$\text{pHeq} = 1.465 \times \text{Log}(\text{Alkalinity}) + 4.54 \tag{9}$$

and

$$\text{pHst} = 1.465 + \text{Log}(\text{Alkalinity}) + 4.54 \tag{10}$$

3. Results and Discussion

3.1. Physical Parameters

The results of parameters essential in this study are given in **Table 3** alongside their respective standards recommended by either KEBS or WHO.

From **Table 3**, the values of pH range are 5.1 to 5.7 while their standard values range from 6.5 to 8.5.

Table 3. Characterized parameters.

parameter	unit	SP1	SP2	SP3	Standard	Reference agency
pH	pH scale	5.7	5.1	5.4	6.5 - 8.5	WHO/KEBS
Calcium	mg/l	8	6	9	Max 150	KEBS
Total alkalinity	$mgCaCO_3/l$	20	17	20	Max 500	WHO
TDS	mg/l	25	22	23	Max 100	KEBS

These values are within the acidic region of the pH scale as shown in **Table 4**.

The value of Calcium, on the other hand, ranges between 6 mg/l and nine mg/l, with the KEBS standard at a maximum of 150 mg/l.

Total alkalinity is 17 mg $CaCO_3/l$ at SP2, which is lower compared to SP1 and SP3 at the same level, 20 mg $CaCO_3/l$.

TDS values are 25 mg/l, 22 mg/l and 23 mg/l for SP1, SP2 and SP3 respectively.

Table 4. Descriptive Statistical analysis of the parameters.

Parameter	min	max	range	mean	Std deviation	C.I of mean	KS distance	KS prob	SWilk w	SWilk prob
pH	5.1	5.7	0.60	5.4	0.30	0.745	0.175	0.654	1.00	1.00
TDS	22.0	25.0	3.00	19.00	1.000	3.795	0.253	0.487	0.964	0.637
Calcium	6.00	9.00	3.00	7.667	0.882	3.795	0.253	0.487	0.964	0.637
Alkalinity	17.0	20.0	3.00	19.00	1.000	4.303	0.385	0.089	0.750	<0.001

3.2. Langelier Saturation Index (LSI) and Ryznar Stability Index

Table 5 shows the calculated values of quantities that are used to obtain LSI in Equation (1), RSI in Equation (7).

Table 5. Calculated values of quantities in Equation (1) and Equation (7).

Spring	pH	*A*	*B*	*C*	*D*	pHst	LSI	RSI
SP1	5.7	0.040	2.09	0.503	1.301	9.626	−3.93	14.15
SP2	5.1	0.034	2.09	0.380	1.230	9.814	−4.71	14.53
SP3	5.4	0.036	2.09	0.554	1.301	9.571	−4.17	13.74

From **Table 5**, the LSI of SP1, SP2, and SP3 are −3.93, −4.71, and −4.17, respectively. It is, therefore, evident that all LSI values are negative. According to [19] [20], LSI values can be negative, zero, or positive. In this case, the negative values mean that the water in the study area is not saturated and requires more metals to dissolve to achieve stability. As a result, it has the potential to cause corrosion. Similar results of LSI less than −4.0 have been obtained previously by

Dr. B.S Shankar [35] in sample numbers 10, 11, and 20 in a groundwater study in India.

Table 6. Interpretation of LSI as adapted from [35].

LSI	Tendency of water
LSI < −2	Intolerable corrosion
−2.0 < LSI < −0.5	Serious corrosion
−0.5 < LSI < 0	Slightly corrosive and nonscaling
LSI = 0	Balanced
0 < LSI < 0.5	Slightly scale forming and corrosive
0.5 < LSI < 2	Noncorrosive but scale-forming

Moreover, all the LSI values are less than −2; according to [30], as interpreted in **Table 6**, the tendency of the water from the three springs to cause corrosion is intolerable.

Table 7. Interpretation of RSI as adapted from [35].

RSI	Tendency
4.0 - 5.0	Heavy scaling
5.0 - 6.0	Light scaling
6.0 - 7.0	Little scaling or corrosion
7.0 - 7.5	Corrosion significant
7.5 - 9.0	Heavy corrosion
>9.0	Intolerable corrosion

The RSIs of SP1, SP2, and SP3 are 14.15, 14.53, and 13.74, respectively, as shown in **Table 5**. In addition, the average value is 14.14, and maximum value is 14.53 while the minimum is 13.74 as shown in **Table 9**. Moreover, these values are more significant than 9; hence, from the interpretation by B. S. Shankar [35] in **Table 7**, the tendency of the water from the three springs to corrosion is intolerable.

3.3. Puckorius Scaling Index (PSI)

Table 8 shows PSI values obtained using Equation (8).

Table 8. Calculated PSI values.

SPRING	PSI
SP1	5.58
SP2	5.45
SP3	5.58

PSI of SP1, SP2, and SP3 are 5.58, 5.45, and 5.58, respectively, as shown in **Table 8**. In addition, the average value is 5.54, and maximum value is 5.58 while the minimum is 5.45 as shown in **Table 9**. It is also evident that these values are less than 6 for all the three springs. A comparison to Alipour *et al.* [18] in their evaluation of corrosion and scaling tendency research shows that scaling is unlikely to occur when using the water from the three springs.

Table 9. Descriptive statistical analysis of LSI, RSI, and PSI.

SPRING	LSI	RSI	PSI
SP1	−3.93	14.15	5.58
SP2	−4.71	14.53	5.45
SP3	−4.17	13.74	5.58
Mean	−4.27	14.14	5.54
Min	−4.71	13.74	5.45
Max	−3.93	14.53	5.58
SD	0.3995	0.3951	0.0751

Table 9 shows the descriptive statistical analysis of the LSI, RSI, and PSI of the groundwater obtained from the three springs in the Manga region. From the interpretation of the indices, it is evident that the water during the study period was corrosive and was unlikely to scale.

Similarly, results of groundwater having an intolerable corrosion tendency have been obtained previously by researchers worldwide. For instance, Atasoy*et al.* [36] 2007, *in their research on groundwater from Harran in Türkiye,* noted that the water had an intolerable corrosion tendency. On the other hand, Dr.B.S Shankar [35], in his study on groundwater of the K.R.Puram area in Bangalore, India, found that 40% and 66.67% of water samples using LSI and RSI, respectively, had intolerable corrosion.

4. Conclusion

The groundwater from the three springs in the Manga region using LSI and RSI showed intolerable corrosion and, hence, unlikely to scale as obtained from PSI. This result may be handy in future studies on water management.

Data Availability

The data of this research is available upon request from the corresponding author.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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