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Groundwater Evaluation in a Rain-Fed Likangala Irrigation Scheme in Malawi

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ABSTRACT

The Likangala Irrigation Scheme in Malawi was constructed in 1969 along the coast of Lake Chilwa in Malawi, a saline inland basin lake. Water for irrigation comes from a heavily polluted river which also passes through urban and peri-urban areas of Zomba District. Overpopulation and water scarcity due to climate change have pushed people to have permanent residence within and around the scheme. Groundwater, through boreholes and shallow wells, is the only source of drinking water. The aim of this study was to evaluate the chemistry of groundwater and evaluate its suitability for drinking and irrigation purposes in the Lake Chilwa Basin. WSeven Boreholes and six shallow wells were sampled from the study area. The levels of the abundance of the major ions were found to be in the order Na > Ca > Mg > K and Cl > HCO_3 > CO_3 > SO_4 >NO_3 > F. The study results suggest that the groundwater for the study area is predominantly of sodium-bicarbonate type, due to both silicate weathering, cation exchange and agriculture influence. The Water Quality Index (WQI) showed that 61.5% of the groundwater samples were unsuitable for drinking. Based on irrigation quality index model, there was no sample belonging to a rejection category from irrigation. The study further revealed that 23% of the samples require caution to be used for irrigation. However, there is need for a further studies to examine the soil chemistry of the scheme to identify other crops suitable for the area, besides rice.

Keywords: *Groundwater chemistry, Irrigation water quality, Total Hazard Index, Water Quality Index, Lake Chilwa, Malawi.*

1.0. INTRODUCTION

Global sustainability will not be reached without ensuring the availability of safe water for all consumers(Salehi, 2022). However, the global water resources are highly sensitive to both climate change and climate variation (Ngongondo, 2006). The need for water for sustainable development was recognized by the United Nations by making water as one of the major goals (SDG6) of the UN2030 agenda (UN, 2015). The current water shortage is rapidly growing and impacting an increasing number of residential, commercial, industrial, and agricultural water consumers worldwide. Poor access to water remains one of the most pressing challenges across the world, especially in Sub-Saharan Africa (SSA) (Adams & Smiley, 2018). The Sub-Saharan Africa region suffers from water scarcity mainly due to under-utilization of groundwater (Cobbing, 2020).

In recent years, Malawi has been adversely hit by climatic variability and changes, and the major irrigation schemes in Lake Chilwa basin, which rely mostly on water from rivers, have been negatively affected (Nkhoma & Kayira, 2016). Irrigated agriculture is being promoted in Malawi not only as a way of fostering rural development, but also as means of reducing rural poverty, malnutrition, and disease, and stemming the growing social and economic inequalities between rural and urban areas(Gwiyani-Nkhoma, 2011).Groundwater is the primary source of water supply for the rural populations in Malawi as well as several urban populations (Holm et al., 2018). According to 2018 Malawi Population Census, 74.9% of the Malawian population use boreholes (61.7%) and wells (13.2%) as main source of drinking water during the dry season (NSO, 2019).

The only improved sources of drinking water in communities within and around Likangala irrigation scheme are boreholes and shallow wells. Groundwater contamination can emanate from infiltrating surface water and from dissolution of minerals. Most of the heavy metals easily bind themselves to the soil sediments as a sink. However, tilling of land during farming may facilitate the availability of these heavy metals to sink into the deeper layers. Pollution of these resources occurs because human activities have altered the structure of rural landscapes and increased the quantity of substances that are loaded into the rivers and lake systems (Mussa et al., 2019).

This study was aimed at evaluating the chemistry of groundwater from boreholes and shallow wells used by communities within and around Likangala Irrigation Scheme in the Lake Chilwa Basin in Southern Malawi. This was achived by establishing factors affecting the groundwater chemistry and to assessing the groundwter suitaibility for both drinking and irrigation purposes using modern Integrated Water Quality Index models. Water Quality Indices (WQIs) are useful mathematical tools to assess the overall quality of water for different purposes by integrating a large number of quality data into a unique number (Jamshidzadeh, 2020).

1.1.1. Climate

Likangala Irrigation Scheme (Figure 1) lies along the latitude 15º 20'S and longitude 35º 40'E.Most of the areas within and around the scheme experience floods and drought during the rainy season. The climate of the area has been problematic for the development of irrigation. The area, just like the whole Lake Chilwa basin, has witnessed a long history of drought which left Lake Chilwa dry in years like 1903,1913,1922,1934,1948, 1967, 1973, 1995 and 2012 (Nkhoma & Kayira, 2016).

Likangala irrigation scheme lies along the saline endorheic Lake Chilwa and the riparian communities use water mainly from Likangala river for irrigation. The scheme was constructed by the Government of Malawi (GOM) together with the Taiwanese Agricultural Technical Mission (TATM) in 1969 as a settler scheme. Thus, settlers would stay and farm at the scheme for one or two seasons to raise some money before returning home again. However, settlers started staying longer and built some houses at the scheme and have created permanent settlements and chiefdoms resulting in an increasing demand for water for drinking purposes too. The scheme uses a double cropping system for rice production. Maize, and other vegetables are also grown in conjunction with rice in the dry season. A rainy season crop runs from January to June and a dry season crop from July to December. The schemes use gravity fed irrigation into paddies or basins termed plots. Farmers heavily rely on inorganic fertilizers. However, due to availability of livestock and advocacy for conservation agriculture, application of organic manure is also common. Earlier work done along this river revealed considerable socio-economic uses of the river banks. The river is used for agricultural activities as well as domestic purposes (Pullanikkatil et al., 2020). Along its course and catchment area are settlements, hospitals, military barracks, government offices and academic institutions (Jamu et al., 2003; Njaya et al., 2011). Therefore, water used for irrigation downstream contains lots of dissolved salts emanating from agricultural activities, dumping of domestic refuse as well as sewage from the urban area upstream.

Chavula and Mulwafu (2007) reported high pollution levels in Likangala river due to malfunctioning of the sewage treatment plants. Higher mineralization was also reported downstream towards the irrigation scheme. More studies have also reported pollution level of Likangala River from both natural and anthropogenic activities including agriculture (Chavula & Mulwafu, 2007; Chidya et al., 2011; Mussa et al., 2019).

1.2. General Description of the Study Area

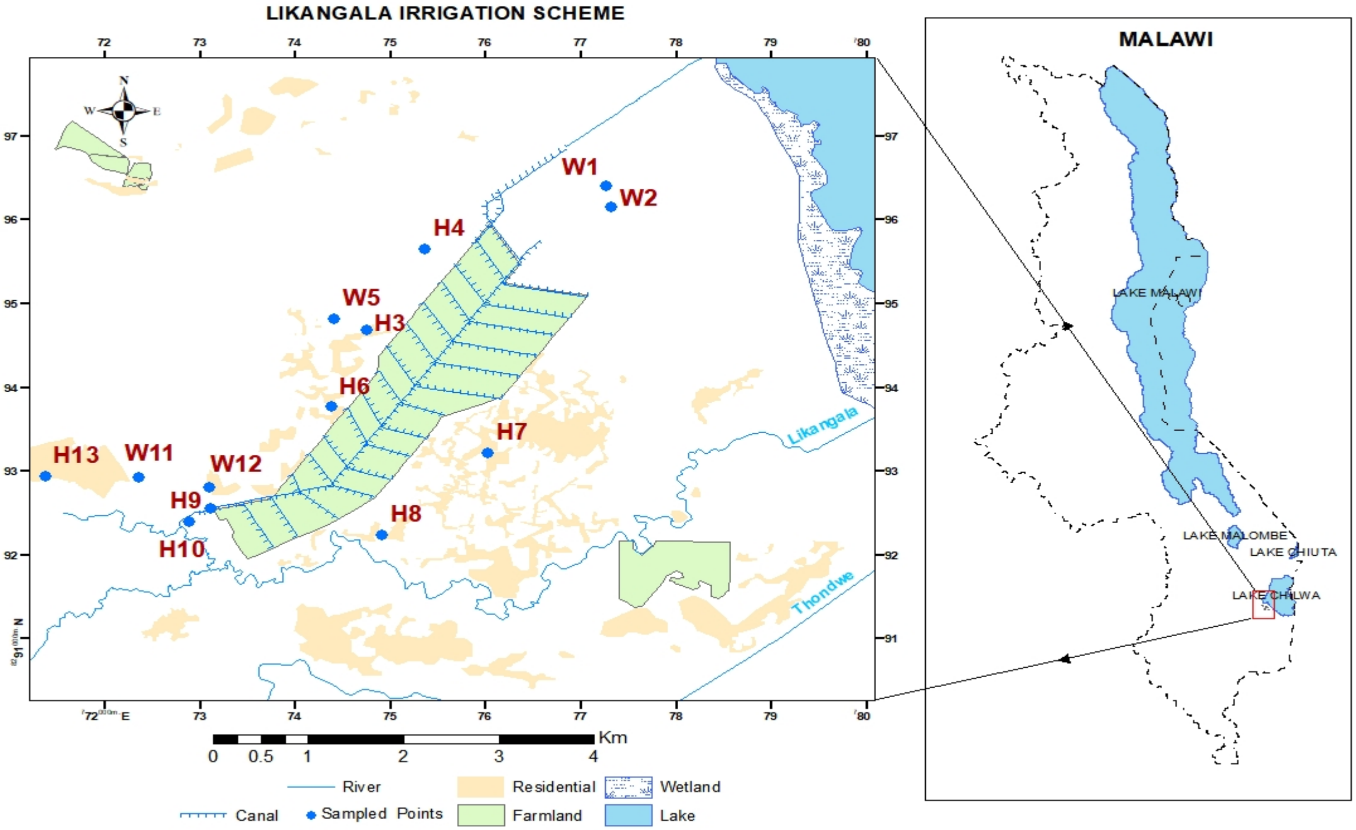

Figure 3: *Geographical location of the study area and sampling sites*

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1.2.2. Geology and Aquifer

The Lake Chilwa Basin is a tectonic depression of post-cretaceous age that has been progressively filled with sand, silt and various sediments from the denudation of the surrounding highlands (Sagona, 2016). The uplands have deep, well drained sandy soils derived from the weathering of gneisses, while the lowlands have very deep soils with variable drainage in fluvial, colluvial and lacustrine deposits (Morgan and Kalk, 1970). These deposits are washed down into the rivers and then carried on to the lowlands. The catchment is also characterized by basement complex (Carter and Bennett, 1973; Chilton and Smith-Carington, 1984; Mapoma and Xie, 2014). The major lithological units of the basement complex are charnockites and granulites. A large part of the Chilwa basin is underlain by quaternary alluvial and lacustrine deposits, which increase in depth eastwards to a line extending from Nayuchi, on the northern east of the sand bar, to the Phalombe River (Lancaster, 1979). This renders the basin suitable for agricultural activities.

Lake Chilwa basin, where the Likangala irrigation scheme is located, is predominantly underlain by an alluvial aquifer. Alluvial aquifers are fluvial and lacustrine sediment successions with variations in both vertical and lateral extent. These aquifers are relatively high yielding in comparison with the basement complex aquifers with recorded yields in excess of 10 liters per second. The main lithological component of the alluvial aquifers is clay with significant occurrences of poorly sorted sands in some localities. Most of the alluvium aquifers are unconfined, although most thick clay sequences are semi-confined (Chimphamba, et al., 2009). Therefore, unconfined aquifers are prone to ionic contamination by surface waters. In the Lake Chilwa Basin, which is perched on the eastern side of the rift valley, most of the alluvium aquifers are clayey with the highest yields obtained from sand and gravel aquifers that are found in buried river channels (GOM-UNDP, 1986). Lack of an outlet for Lake Chilwa promotes the infiltration of salts and make the lake waters increasingly saline away from the swampy shores.

2.0. MATERIALS AND METHODS

2.1. Sampling

In order to assess the groundwater quality for the Likangala Irrigation Scheme, all boreholes and shallow wells located within the irrigation scheme were sampled. Additionally, all boreholes and shallow wells located very close to the irrigation scheme were also sampled. Samples were collected from seven (7) boreholes (Lamusi 2, Simaoni 2, Mkungwi 2, Chidothe 3, Thunya, Likangala HC and Chiliko) and Six (6) shallow wells (Chodothe 1, Chidothe 2, Simaoni 2, Lamusi , Lamusi 1 and Lamusi 3). During the rainy season, people’s movement around this area is usually limited due to flooding of water which renders many paths impassable and slippery. Therefore, people resort to use of unprotected hand-dug wells within their home compound. However, such waterpoints dry up soon after the rainy season and were not included in this study. Sampling was carried out during the dry season between the months of September and October 2021 in order to target only perennial water sources. The depths of the boreholes were recorded as indicated by the drilling contractor on borehole aprons. In a case where there was no depth indicated, waterpoint committee (WPC) members were asked to give the number of rods in the borehole. Since each rod has a length of 3m, the depth of the borehole was therefore estimated. The depths of all shallow wells were measured by dropping a tape measure with a weight tied at the end until the weight touched the bottom middle of the well. Consumers of water from each waterpoint were also asked to give their perception of water quality for that particular borehole or shallow well. Samples for cation analysis were filtered and acidified with nitric acid (HNO_3) to a pH less than 2. The sample was then stored in pre-cleaned polyethylene bottles of 500ml volume. Samples for analysis of anions (in 500 ml) were kept at 4 oC in a mobile fridge and this preservation was continued until commencement of sample analysis in the laboratory

2.2. Sample Lab Analysis analysis

The parameters for pH, total dissolved solids (TDS), electrical conductivity (EC) and turbidity were analyzed in the field. TDS, EC and pH were measured using Hanna model HI-991300N pH/EC/TDS meter (Hanna Instruments Limited) after calibrating it as described by the manufacturer. The values were recorded as corrected to 250C. Distilled water, pH 4 and pH 7 buffers were used in the calibration of the meter to ascertain accuracy. Turbidity measurements ware also done in the field using OAKTON turbidimeter T-100 model after calibrating the meter with recommended standards from the manufacturer. Chlorides, carbonates and total hardness were determined using titrimetric methods. Nitrates and Fluorides were determined using an Ion-Selective Electrode (ISE). All cations (Ca, Mg, K, Na) were analyzed using Atomic Absorption Spectrophotometer (AAS, Agilent technologies). Concentration of sulphates in the water samples were determined turbidimetrically using precipitation. In principle, excess solid Barium chloride ($BaCl_2$) was added to a known and same volume of water sample to completely precipitate out all the sulphate (SO_4^{2-}) ions into Barium sulphates ($BaSO_4$).

3.0. RESULTS AND DISCUSSIONS

3.1. Consumer perception and observation

Consumers decribed the water quality of four (4) shallow wells (Chidothe 1, Simaoni 2, Lamusi 2 & Lamusi 3) and three boreholes (Chidothe 3, Thunya & Chiliko) as good for dometic use (Table 1). However, consumers registered concern for salty taste for water from Chidothe 2 (W2), Lamusi 2 (H3), Simaoni 1(H4), Mkungwi 2 (H6), and Likangala HC (H10), some of which are not preferred for drinking purposes. Consumers also complained of turbid water at Lamusi 1. It was observed that at the time of sampling, the water levels in the shallow wells were low, wells not covered and frequently patronized by consumers avoiding salty borehole water from the other waterpoints.

Table 1: *Description of waterpoints used in the study*

WATERPOINT	ID	DEPTH (m)	CONSUMER PERCEPTION	OBSERVATION
Chidothe 1	W1	3.86	Good	Alternative to W2
Chidothe 2	W2	3.33	Too salty	Neglected by many
Lamusi 2	H3	39.0	Salty water	Mosque site
Simaoni 1	H4	45.0	Too salty	Only used for washing clothes
Simaoni 2	W5	5.73	Good	Used as alternative to H4
Mkungwi 2	H6	42.0	Less salty	Good hygiene
Chidothe 3	H7	27.0	Good	Close to graveyard
Thunya	H8	33.0	Good	Reliable
Lamusi 1	W9	4.25	Muddy water	Located at the irrigation intake
Likangala HC	H10	40.0	Salty water	Used by people at the market closeby
Lamusi	W11	3.80	Good taste	Located right on the rice farm
Lamusi 3	W12	4.40	Very good	Not reliable in dry season
Chiliko	H13	45.0	Very good	Close to irrigated area

3.2. Physico-Chemical parameters

3.2.1. pH, Turbidity, Total Dissolved Solids and Electrical Conductivity

The pH for groundwater samples ranged from 4.92 to 6.77 with a mean value of 5.95 implying that generally the groundwater in this region was slightly acidic during this particular dry season. Based on pH, 53.8% of the samples (Lamusi 2, Simaoni 1, Simaoni 2, Chidothe 3, Thunya, Likangala HC & Lamusi) did not meet groundwater quality standards for drinking purposes based on Malawi standards (MS 733:2005).

Table 2: *Results of Physico-chemical parameters*

Waterpoint	**ID**	**PH**	**Turb NTU**	**TDS (mg/L)**	**CO₃ (mg/L)**	**HCO₃ (mg/L)**	**F (mg/L)**	**NO₃ (mg/L)**	**Cl (mg/L)**	**SO₄ (mg/L)**	**Mg (mg/L)**	**Ca (mg/L)**	**TH (mgCaCO₃/L)**	**Na (mg/L)**	**K (mg/L)**	**Mn (mg/L)**	**Zn (mg/L)**
Chidothe 1	W1	6.65	**7.97**	209	70.39	**368.24**	0.65	3.68	98.06	2.17	17.37	23.26	129.72	151.61	0.74	0.55	0.01
Chidothe 2	W2	6.77	**10.21**	**1106**	**96.36**	**352.26**	0.28	11.5	**1294.35**	10.42	85.41	183.48	**810.58**	**752.74**	3.80	1.44	0.006
Lamusi 2	H3	**5.79**	**45**	462	**88.16**	**678.12**	0.59	6.16	**285.57**	7.40	45.59	61.31	**341.11**	**311.19**	1.40	0.05	0.022
Simaoni 1	H4	**4.92**	1.34	**1027**	0	**195.93**	0.92	4.33	**1504.93**	ND	129.42	163.18	**941.15**	**483.07**	2.21	1.09	0.030
Simaoni 2	W5	**5.75**	**6.49**	72.6	57.41	48.64	0.27	1.4	42.44	6.09	7.70	9.04	54.34	40.57	0.99	0.05	0.01
Mkungwi 2	H6	6.13	2.05	399	**111.39**	**316.13**	0.63	4.91	381.4	19.57	31.50	42.16	**235.19**	239.22	1.35	0.05	0.009
Chidothe 3	H7	**5.63**	2.48	78.9	51.94	122.28	0.3	0.7	32.08	14.83	8.12	12.26	64.08	40.19	0.30	0.20	0.030
Thunya	H8	**5.75**	0.47	69.4	43.05	**156.33**	0.38	0.62	18.97	29.29	10.16	12.48	73.05	31.74	0.05	0.23	0.018
Lamusi 1	W9	6.07	**57.7**	46.4	31.44	79.21	0.30	0.62	20.00	29.54	8.79	9.86	60.88	21.25	0.55	0.48	0.018
Likangala HC	H10	**5.75**	1.09	797	**115.49**	**235.53**	0.25	2.31	**1014.95**	50.13	98.93	156.54	**798.94**	**327.09**	2.33	0.05	0.024
Lamusi	W11	**5.72**	2.63	47.7	49.89	50.02	0.35	0.86	19.36	15.73	12.62	16.66	93.63	11.30	0.23	0.51	0.006
Lamusi 3	W12	6.29	**9.13**	48.8	53.31	0	0.37	6.78	33.5	28.8	4.91	6.00	35.20	27.31	1.02	ND	0.012
Chiliko	H13	6.12	0.19	200	**90.89**	**212.61**	0.40	0.83	71.54	10.67	22.09	26.59	157.47	118.43	0.90	0.06	0.022
	Min	4.92	0.19	46.4	31.44	48.64	0.25	0.62	18.97	2.17	4.91	6	35.2	11.3	0.05	0.05	0.006
	Max	6.77	57.7	1106	115.49	678.12	0.92	11.5	1504.93	50.13	129.42	183.48	941.15	752.74	3.80	1.44	0.03
	Mean	5.95	11.29	351.06	71.64	234.61	0.44	3.44	370.55	18.72	37.12	55.6	291.95	196.59	1.22	0.39	0.017
MS 733:2005		6.9.5	25	2000	NS	NS	6	45	750	800	200	250	800	500	NS	1.5	15
WHO 2017		6-8.5	5	1000	75	150	1.5	50	250	250	150	300	200	250	10	0.10	5

ND: Not detected. **NS**: Not Specified. Values in bold indicate deviation from MS 733:2005 or WHO 2017

The mean turbidity value for Likangala Irrigation Scheme was 11.29NTU with the lowest turbidity of 0.19NTU recorded at Chiliko water point (H13). The highest turbidity of 57.7 NTU was registered at Lamusi 1 (W9). There was noncompliance against Malawi standards for Lamusi 2 and Lamusi 1 waterpoints. However, based on international guideline for World Health Organization (WHO, 2017), 46.2% of the groundwater samples from Likangala Irrigation Scheme (Chidothe 1, Chidothe 2, Lamusi 2, Simaoni 2, Lamusi 1 & Lamusi 3) were above recommended limit of 5NTU. Generally, groundwater from boreholes has very low turbidity levels. The high turbidity levels registered at Lamusi 2 borehole suggests engineering problems resulting in leakage and short-circuiting of groundwater across the well casing and screen. This encourages water mixing during pumping (Appelo & Postma, 2005)

Based on international guideline of 1000mg/L (WHO, 2017), groundwater samples from Likangala irrigation scheme showed total dissolved solids (TDS) exceedances for Chidothe 2 (W2) and Simaoni 1 (H4), with values of 1027mg/L and 1106mg/L respectively. In the study area, TDS values ranged from 46.4mg/L to 1106mg/L with a mean of 351.1mg/L. High values of TDS in groundwater would cause undesirable taste and gastrointestinal irritation.Based on consumer interviews during sample collection, groundwater from Chidothe (W2), Simaoni 1 (H4) and Likangala HC (H10) are not preferred for drinking, cooking and bathing due to their elevated salinity levels. Consequently, communities opt for shallow wells of Chidothe 1 (W1), Simaoni 2(W5) and Lamusi (W11) respectively. This suggests that in this area, salinity is related to depth of the groundwater source. In the study area ,84.6% of the samples in the study area fell under fresh water type (TDS < 1000mg/L) while 15.6% belonged to brackish water type (TDS between 1000mg/L and 10,000mg/L) (Sherry, 1979).

Groundwater samples for Likangala irrigation scheme registered electrical conductivity from 92.90 µS/cm to 2220 µS/cm with a mean of 703.08 µS/cm. All samples in Likangala scheme were below the maximum limit based on Malawi standards. Using the classification by Subba Rao (2018), 76.9% of the groundwater samples in this study area fell under type I (low enrichment of salts) while 23.1% of the samples fell under type II (medium enrichment of salts). Most (76.9%) of the samples belonged to a very weakly mineralized class , 7.8% to a weakly mineralized class and 15.3% belonged to a slightly mineralized class (Rao, 2018). Ramesh and Elango (2012) attributes large variations in EC to geochemical processes such as ionic exchange, reverse exchange, evaporation, silicate weathering, rock-water interaction, sulphates reduction and oxidation processes, as well as anthropogenic activities. Chidothe 2 (W2), Simaoni 1 (H4) and Likangala HC (H10) registered elevated electrical conductivity above or close to WHO maximum guideline. This is presumably due to salt water intrusion from the saline Lake Chilwa and geochemical processes especially weathering.

3.1.2. Calcium, Magnesium and Total hardness

In Likangala Irrigation Scheme, the concentration of calcium (Ca) ranged from 6.00mg/L to 183.48mg/L with a mean of 55.60mg/L. Calcium exceedances were registered at Chidothe2 (183.48mg/L), Simaoni 1(163.18mg/L) and Likangala HC (156.54mg/L). These elevated levels of calcium are likely due to lithological processes from granulites which are calcium-containing minerals.
Magnesium (Mg) concentration for Likangala Irrigation Scheme portrayed a range from 4.91mg/L to 129.41mg/L with a mean of 37.12mg/L. All samples fell under the maximum limit for local standard (MS 733: 2005). However, the study revealed elevated levels of magnesium at Chidothe2 (W2), Simaoni 1 (H4), and Likangala HC (H10). Based on international guideline (WHO 2017), magnesium exceedance was registered only at Simaoni 1 (129.41mg/L).

Water can be grouped into four classes from soft to very hard depending on the concentration levels of the cations (Sawyer & McCarty1967). Therefore, based on hardness, water is classified as soft water (0- 60 mg/L), moderately hard water(60–120 mg/L), hard water (120–180 mg/L) and very hard water (> 180 mg/L) (Rawat et al., 2018).In Likangala scheme, the range for total hardness was 35.20-941.15mgCaCO3/L with a mean of 291.95 mgCaCO3/L. There was noncompliance with international standards (WHO 2017) in 38.5% of the samples. Two samples, *Chidothe 2* and *Simaoni 1* did not comply with local standards (> 800mg/L). In Likangala irrigation scheme, samples from 15.4% of the waterpoints were soft water, 30.8% of the water samples were moderately hard, 15.4% were hard water and 38.4% belonged to very hard water category (Table 1). Except for Chidothe1 (W1) and Chidothe 2 (W2), hard and very hard water samples came from boreholes indicating the contribution of geological units with magnesium and calcium and possible agricultural activities involving introduction of calcium-sulphur containing fertiizers.

Table 1: *Classification of Total Hardness ((Rawat et al., 2018)*

Class	**mgCaCO3/L**	**Waterpoints belonging to that class**
Soft water	<60	W5, W12 *(15.4%)*
Moderately hard water	60 -120	H7, H8, W9, W11 *(30.8%)*
Hard water	120-180	W1, H13 *(15.4%)*
Very hard water	>180	W2, H3, H4, H6, H10 *(38.4%)*

3.1.3. Sodium and Potassium

In the study area, sodium levels ranged from 11.30mg/L to 752.74mg/L with a mean of 196.59mg/L. *Chidothe 2* (W2) did not comply with both local and international standards. Farthermore,38.5% of the water point in Likangala scheme did not comply with international standards (WHO, 2017). The high concentration of Sodium as registered for Chidothe 2 (W2) and Simaoni 1(H4) as shown in Table 3 can be as a result of salt water intrusion (Alshehri et al.,2021) and weathering of rock-forming minerals such as halite. The concentrations of potassium fell below the maximum permissible limit of 12mg/L (WHO 2017). The level of potassium ranged from 0.047mg/L to 3.80mg/L with a mean of 1.22mg/L

3.1.4. Chlorides and Fluorides

Chlorides are widely distributed in nature as salts of sodium (NaCl), potassium (KCl), and Calcium ($CaCl_2$) existing in water due to high solubility (Cotruvo, 2017)**.** Excessive chloride concentrations increase rates of corrosion of metals in the distribution system, depending on the alkalinity of the water. This can lead to increased concentrations of metals in the supply. The higher concentration of chloride in water makes it hazardous to human health as it relates to laxative effects (Ghalib, 2017; Maghrebi et al., 2021; Umadevi et al., 2021). Chloride concentrations in excess of 250mg/L can give rise to detectable taste in water (WHO 2017). In the area of study, concentration of chloride ranged from 71.54mg/L to 1504.93mg/L with an average of 370.55mg/L. The study showed that 38.46% of the waterpoints exceeded the international guideline of 250mg/L (WHO 2017), while 23.07% of the samples (Chidothe 2, Simaoni 1, Likangala HC) were above Malawi maximum permissible limit of 750mg/L (MS 2005).
All water points registered fluoride levels below maximum permissible limits for local (6mg/L) and international standards(1.5mg/L). Concentration of fluoride ranged from 0.252mg/L to 0.924ml/L and an average of 0.44mg/L.

3.1.5. Sulphates and nitrates

The presence of elevated sulfates in drinking-water can cause noticeable taste, and very high levels might cause a laxative effect in unaccustomed consumers (Sharma & Kumar, 2020).Excessive use of fertilizers can lead to leaching of sulphates into groundwater. Sulphate levels in the groundwater samples ranged from 2.17mg/L to 50.13mg/L and an average of 17.28mg/L. All the waterpoints in this scheme complied with both local (MS 733:2005) and international (WHO 2017) guideline of 800mg/L and 250mg/L respectively.
Groundwater also contains nitrate due to leaching of nitrate with the percolating water from the surface. Groundwater can also be contaminated by sewage and

other wastes rich in nitrates (Shigut et al., 2017). In Likangala irrigation scheme, the range for concentration of nitrates was between 0.621mg/L and 11.5mg/L with an average of 3.44mg/L. Across this scheme, nitrates were elevated at *Chidothe 2* (11.5mg/L), *Lamusi mosque* (6.16mg/L), *Simaoni 1* (4.33mg/L), *Mkungwi 2* (4.91mg/L), *Likangala HC* (2.31mg/L) and *Lamusi 3* (6.78mg/L). The water points were influenced by leaching of nitrates from agricultural fertilizers and sanitary facilities. However, the major causative source of nitrate is anthropogenic activities such as agriculture (Adimalla & Li, 2019; Yu et al., 2020)

3.2. Integrated Drinking Water Quality Index (IDWQI)

This model was used to determine an overall judgement on suitability of the water for drinking purposes. For instance, water might be unsuitable for drinking with respect to pH and concentration of chloride ions, but still be compliant with other equally important parameters such as nitrates and fluoride concentrations. IDWQI model is a comprehensive and unbiased water quality index for water resources based on physicochemical parameters associated with existing drinking water quality standards. It focuses not only on the permissible limit, but also on the desirable limit (DL) of the physicochemical parameters (Mukate et al., 2019). In order to provide international interpretation of the water quality in this study, International guidelines for drinking water, WHO 2017, were used in determining the integrated water quality index. Application of this model involves selection of parameters of interest, calculation of range, calculation of modified permissible limit (MPL), calculation of a sub-index (SI) for each parameter; and finally the computation of the WQI by summing up all the sub-indices.

3.2.1. Selection of parameters

In this study, 16 parameters (pH, turbidity, carbonates, bicarbonates, total dissolved solids, fluoride, nitrates, chloride, sulphates, magnesium, calcium,total hardness, sodium, potassium, manganese and zinc,) were used to compute the index. Electrical conductivity was not considered as this effect was represented by total dissolved solids.

3.2.2. Calculation of range

Apart from having the maximum permissible limit (PL) some parameters also have minimum desirable limit (DL). For instance, according to WHO (2017), the pH for drinking water should range from 6.5 to 8.5. The range was calculated by taking the difference between the permissible limit (PL) and desirable limit

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(DL). In the case where the parameter has no desirable or lower limit (e.g. SO_4^2), it was assumed that DL is equal to zero in the calculation.

$$\textbf{Range} = \textbf{Permissible limit(PL)} - \textbf{Desirable limit (DL)} \quad (1)$$

3.2.3. Computation of Modified Permissible Limit (MPL)

Groundwater pollution is difficult to correct. As such, in groundwater monitoring the permissible limit is adjusted downwards as part of providing an alert for pollution.

$$\textbf{MPL} = \textbf{Permissible limit(PL)} - \textbf{(20\% range)} \quad (2)$$

3.2.4. Computation of Subindex (SI)

The subindex was calculated by taking the ratio of deviation of the observed or measured parameter (Pi) from the MPL or DL. Compliance therefore implies that a measured or observed value lies between MPL and DL (i.e. DL $\leq$ Pi $\leq$ MPL) of each physico-chemical parameter, hence its subindex will be zero ($SI_1 = 0$). Similarly, noncompliance entails that the measured value is either lower than DL or higher than MPL (SI_2 or SI_3)

$$\mathbf{SI_2} = \frac{DL-Pi}{DL} \quad (3)$$

$$\mathbf{SI_3} = \frac{Pi-MPL}{MPL} \quad (4)$$

3.2.5. Computation of IDWQI

The IDWQI was calculated by taking the sum of all the sub-indices for all the 16 physico-chemical parameters in the study:

$$IDWQI_i = \sum_{j=1}^{n} SI_{ij} \quad (5)$$

Where SI_{ij} is the sub-index value of ith sample and jth parameter.

Lastly, the calculated IDWQI for each sample was used to classify the quality of the water as summarized in table 4.

Table 2: *Interpretation of IDWQI according to Mukate 2019*

WQI range	Class of water	Explanation
<1	excellent	excellent for drinking
1 - 2	good	good for drinking
>2 - 3	marginal	acceptable for drinking
>3 - 4	poor	not suitable for drinking
>5	unsuitable	Unacceptable

Table 3: *Interpretation of Groundwater Samples Based on IDWQI model*

Point code	Water point name	IWQI	Interpretation	Major Contributing Parameter(s)
W1	*Chidothe 1*	9.15	unsuitable	Mn, HCO_3, Turbidity
W2	*Chidothe 2*	34.75	unsuitable	Mn, Cl, TH, Na, HCO_3, Turbidity
H3	*Lamusi 2*	17.98	unsuitable	Turbidity, HCO_3, TH, Na
H4	*Simaoni 1*	27.85	unsuitable	Mn, Cl, TH, Na
W5	*Simaoni 2*	0.738	excellent	-
H6	*Mkungwi 2*	4.42	unsuitable	HCO_3, Cl, CO_3
H7	*Chidothe 3*	1.67	good	Mn
H8	*Thunya*	2.29	marginal	Mn
W9	*Lamusi 1*	18.5	unsuitable	Turbidity, Mn
H10	*Likangala HC*	11.35	unsuitable	Cl, TH, Na, HCO_3, CO_3
W11	*Lamusi*	5.48	unsuitable	Mn
W12	*Lamusi 3*	0.32	excellent	-
H13	*Chiliko*	1.35	good	HCO_3, CO_3

Application of the IDWQI model revealed that 61.5% of the samples were unsuitable for drinking mainly due to elevated turbidity, manganese, carbonates and hardness.

3.3. Irrigation Water Quality Assessment

The United States Regional Salinity Laboratory (USRSL) and Food and Agriculture Organization (FAO) developed the use of four parameters to judge the suitability of water for irrigation purposes (Arshad & Shakoor, 2017). The parameters of interest are Electrical Conductivity (EC), Total Dissolved Solids (TDS), Sodium Absorption Ratio (SAR) and Residual Sodium Carbonate (RSC).

3.3.1. Sodium Absorption ratio (SAR)

Sodium adsorption ratio (SAR) is a measure of the relative proportion of sodium ions in a water sample to those of calcium and magnesium. It is one of the most vital irrigation suitability indicators that measure sodium or alkali hazards. When Sodium increases replacing Ca^{2+} and Mg^{2+}, that soil turns into hard soil and reduces soil permeability (Kaur et al., 2017; Roy et al., 2018). SAR is calculated using by using concentrations in milliEquivalents of sodium,calcium and magnesium ions

$$\textit{Sodium Adsorption ratio (SAR)} = \frac{Na^{+}}{\sqrt{\frac{(Ca^{2+}+Mg^{2+})}{2}}} \qquad (6)$$

The groundwater quality can be classified into four categories based on the sodium absorption ratio as excellent for irrigation (SAR< 10), good (10 ≤ SAR < 18), doubtful (18 ≤ SAR < 26) and unsuitable (SAR ≥ 26). In the area under study, all the groundwater samples fell under excellent category for irrigation based on SAR alone.

3.3.2. Residual Sodium Carbonate (RSC)

Residual Sodium Carbonate (RSC) is an index for the measurement of the sodicity hazard of irrigation water represented as the amount of sodium carbonate ($NaCO_3$)and sodium bicarbonate ($NaHCO_3$) present in the irrigation water (Rawat et al., 2018). RSC is calculated by using concentrations in illiEquivalents of carbonates,bicarbonates, calcium and magnesium ions as shown in equation 7.

$$\textit{Residual Sodium Carbonate (RSC)} = (HCO_3^{-} + CO_3^{2+}) + (Ca^{2+} + Mg^{2+} \qquad (7)$$

The high concentration of sodicity enhance the pH level of the groundwater, which causes the dissolution of organic matter (Singaraja, 2017). RSC has been classified into three classes as low (RSC < 1.25), medium (1.25 - 2.5) and high (> 2.5) (Sutradhar & Mondal, 2021). Low RSC is good while medium RSC is doubtful for irrigation purposes implying that this condition is unsatisfactory for most crops. A high range of RSC in irrigation water means an increase in the adsorption of sodium on the soil. Water having RSC > 5 has not been recommended for irrigation because of damaging effects on plant growth. Generally any source of water in which RSC is higher than 2.5 is not considered suitable for agriculture purpose. It is therefore important in such contexts to calculate the required amount of gypsum or sulfuric acid per area in irrigation water to neutralize such residual carbonates effect (Rawat et al., 2018). When values of RSC are positive, it means the sum of bicarbonates and carbonates exceeds that of calcium and magnesium. In the area under study, Simaoni 1 (H4),Chidothe 3 (H7) and Likangala HC (H10) registered positive RSC. The rest of the groundwater samples yielded negative values indicating that the bicarbonates are not in excess over calcium and magnesium ions. Therefore, the selection of four parameters (EC, TDS, SAR and RSC) can be used to interpret the suitability of groundwater in Likangala irrigation scheme as summarized in table 4.

***Table 4:** Irrigation Water Quality Classification based on USRSL and FAO*

Water Quality Classification	Salinity Hazard		SAR(mE/L)	RSC(mE/L)
	EC(μS/cm)	TDS (mg/L)		
Excellent	<250	<160	≤10	<1.25
Good	250 -750	160 -500	10-18	1.25-2.50
Medium	750-2250	500 - 1500	18-26	>2.50
Bad	2250-4000	1500-2500	>26	-
Very bad	>4000	>2500	>26	-

Based on this classification, 46% of the groundwater samples were excellent for irrigation, 15% fell under good category while another 39% belonged to the medium category as shown in table 5. However, this classification still incorporates only four parameters and hence this provides significant limitation from relying solely on this assessment. For instance, the effect on irrigation water quality from toxic anions and cations has not been individually considered in the USRSL and FAO assessment. It is therefore against this limitation that the use of an integrated irrigation water quality index model is necessary.

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Table 5: *Results of SAR and RSC for the waterpoints*

Point code	Water point name	EC (µS/cm)	TDS (mg/L)	SAR	RSC	Wate Quality Classification
W1	*Chidothe 1*	416	209	5.79	-0.18	good
W2	*Chidothe 2*	2220	1106	11.51	-12.91	medium
H3	*Lamusi 2*	924	462	6.85	-18.76	medium
H4	*Simaoni 1*	2050	1027	2.39	0.84	medium
W5	*Simaoni 2*	145	72.6	7.33	-3.76	excellent
H6	*Mkungwi 2*	801	399	6.79	-0.93	medium
H7	*Chidothe 3*	158	78.9	2.00	1.07	excellent
H8	*Thunya*	139	69.4	1.53	-0.16	excellent
W9	*Lamusi 1*	93	46.4	0.51	-0.2	excellent
H10	*Likangala HC*	1592	797	1.95	0.14	medium
W11	*Lamusi*	100	47.7	5.04	-12.06	excellent
W12	*Lamusi 3*	97.7	48.8	1.19	-0.15	excellent
H13	*Chiliko*	405	200	4.11	-0.08	good

3.4. Integrated Irrigation Water Quality Index (IIWQI) Model

Integrated Irrigation Water quality Index model(IIWQI) was used in the study to determine the actual suitability of the water for irrigation purposes(Islam & Mostafa, 2022). The use of IIWQI model reduces the temptation of using few parameters to make a general judgement on suitability of the water for irrigation. IIWQI model uses a mixed type of selection of parameters for consideration based on impact on the water quality for agricultural purposes. Unlike other water quality index models, IIWQI model uses selected parameters after grouping them into 6 hazard classes with different ratings. The 6 hazard classes (valued from 6 to 1) depend on salinity hazard (TDS), Sodicity hazard (Na%, SAR), Water infiltration rate (Na%, SAR, PI), Toxicity to crop (Na, Cl, K), Changing soil structure (Na, Ca, Mg) and Miscellaneous class (pH, Ca, Mg, TH, RSC, MHR, NO_3, SO_4, CO_3, HCO_3). The measured value of a particular parameter also determines the rating score (r) ranging from 3 (excellent) to zero (rejection). Each rating score has a corresponding rating coefficient (Rc). The rating co-efficient is a unitless and dimensionless factor. For r = 1, 2, and 3; Rc values are 0.167, 0.333, and 0.5, respectively. Determination of the IIWQI starts by calculating the rating factor (Qi) for every parameter in a hazard class

$$Q_i = \frac{2V_i}{V_{max}} \, x \, R_c \, x \, \frac{|100 - V_{min}|}{(V_i + V_{max})} \, x \, r_i \, x \, 100 \quad (8)$$

Where:

Q_i = the rating factor of the ith parameter in each hazard class

r = rating score of ith parameters

R_c = Rating coefficient

V_i = measured or observed value of the parameter

V_{min} = maximum value of parameter at $r = 3$

V_{max} = maximum value of the parameter at $r = 1$

The rating factors for each parameter in a particular hazard class are then aggregated to come up with a sub-index :

$$S_i = \frac{s}{n} \, x \, W_i \sum_{i=1}^{n} Q_i \qquad (9)$$

Where

S_i = sub-index value of a hazard class

s =Scoring value of each class

n = number of parameters included in a class

W_i = weight value of a hazard class as compare to total hazard scores

Finally, all the sub-indices are summed up to obtain a total index (IIWQI) for the water sample:

$$IIWQI = \sum_{i=1}^{n} S_i \qquad (10)$$

The value of IIWQI obtained from the foregoing calculation was interpreted as illustrated in table 6. In the study area, 76.9% of the groundwater samples were moderate – excellent category for irrigation purposes in Likangala scheme. However, Thunya (H8), Lamusi 1(W9) and Lamusi 3 (W12) were found to belong to poor category for irrigation purposes

Table 6: *Interpretation of IIWQI (Islam &Mostafa,2022)*

IIWQI value	**Category**	**Remarks**	**Waterpoints**
< 40	**Rejection**	Must be avoided this type of water for irrigation in any situation. In high sodic water, the permeability of soil must have very high (PI > 80), and to avoid saltation surplus excess water should be used. The high SAR and low salt in water require gypsum or lime application in soil. Limited high salt tolerance crop tolerates this type of water	None
40 to < 60	**Poor**	May be used in porous and sandy soils with high permeability. Heavy irrigation should be needed with high EC and SAR. Moderate to high salts tolerance crops may grow with special salinity control practices.	Thunya (H8) Lamusi 1(W9) Lamusi 3 (W12)
60 to < 70	**Moderate**	May be used in soils with moderate to high infiltration rate with low leaching of salts. Crops with moderate tolerance to salts may be grown.	None
70 to < 80	**Good**	Irrigated soils with low clay level, moderate infiltration rate, recommended salt leaching, and light texture. Avoid very salt-sensitive crops.	Chidothe 3(H7) Likangala HC (H10)
≥80	**Excellent**	Except for extremely low permeability in soils, water is used for all types of soils with a low probability of causing salinity and sodicity problems. No toxicity/hazard risk for most crops.	Chidothe 1(W1), Chidothe 2 (W2), Lamusi 2 (H3), Simaoni 1(H4), Simaoni 2(W5), Mkungwi 2(H6), Lamusi (W11) , Chiliko(H13)

3.5. Groundwater Chemistry

3.5.1. Abundance of Major Ions and Hydrogeochemical Faces

The levels of the abundance of the major cations for Likangala irrigation scheme are in the order Na > Ca > Mg > K. For anions, the abundance levels were in the order Cl > HCO_3 > CO_3 > SO_4 >NO_3 > F. A piper plot is used to describe the hydrogeological facies of water. The point on the diamond describes four basic categories of water chemistry as calcium sulphate water,calcium bicarbonate water,sodium chloride water or sodium bicarbonate water (Figure2)

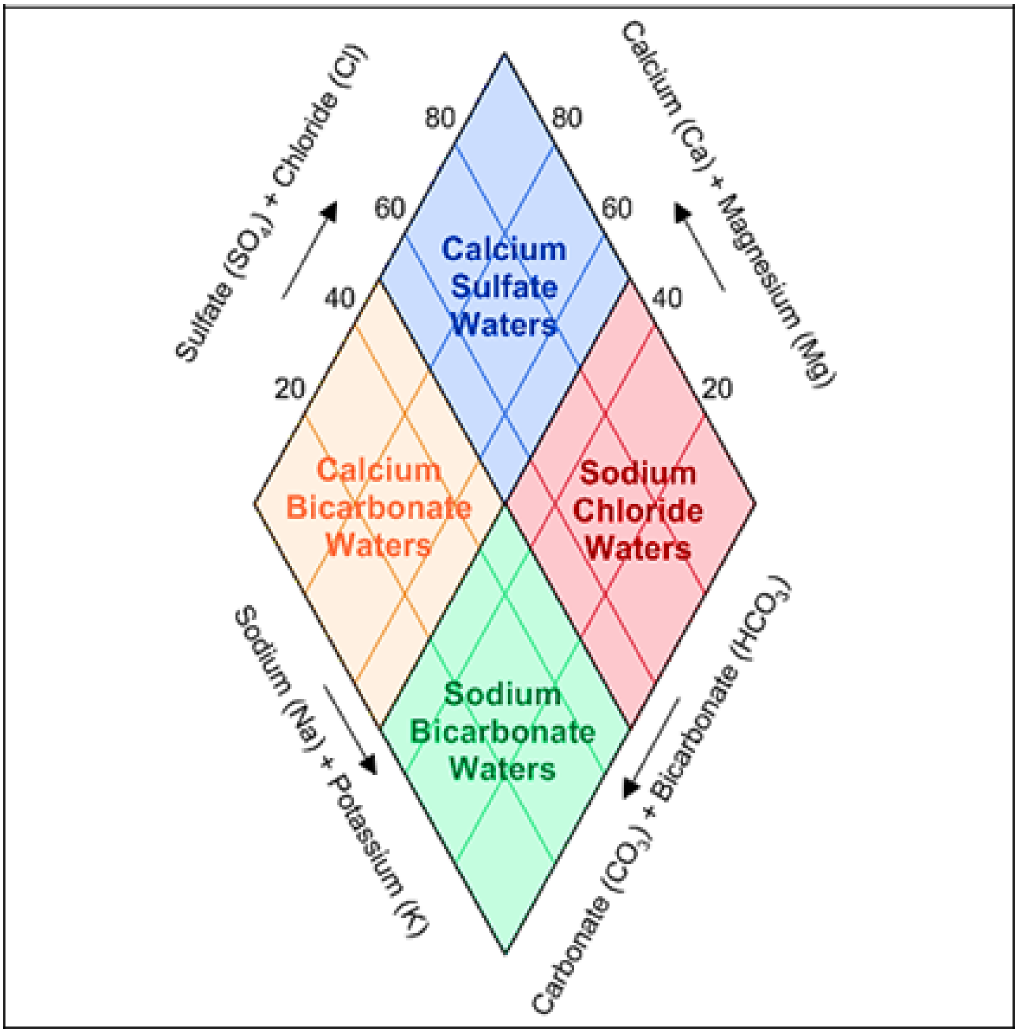

Figure 4: *Interpretating a piper plot*

For Likangala irrigation scheme, 46 % (6) of the water points portrayed a sodium-bicarbonate water type, 23% (3) as sodium chloride water, 23% (3) as calcium-bicarbonate type, and 8% (1) as calcium-sulphates water type (figure 3). Using Gibb's plot, 23% of the waterpoints in the study area indicated that rock dominance or weathering is the most prevalent cause for water chemistry (Figure 4).

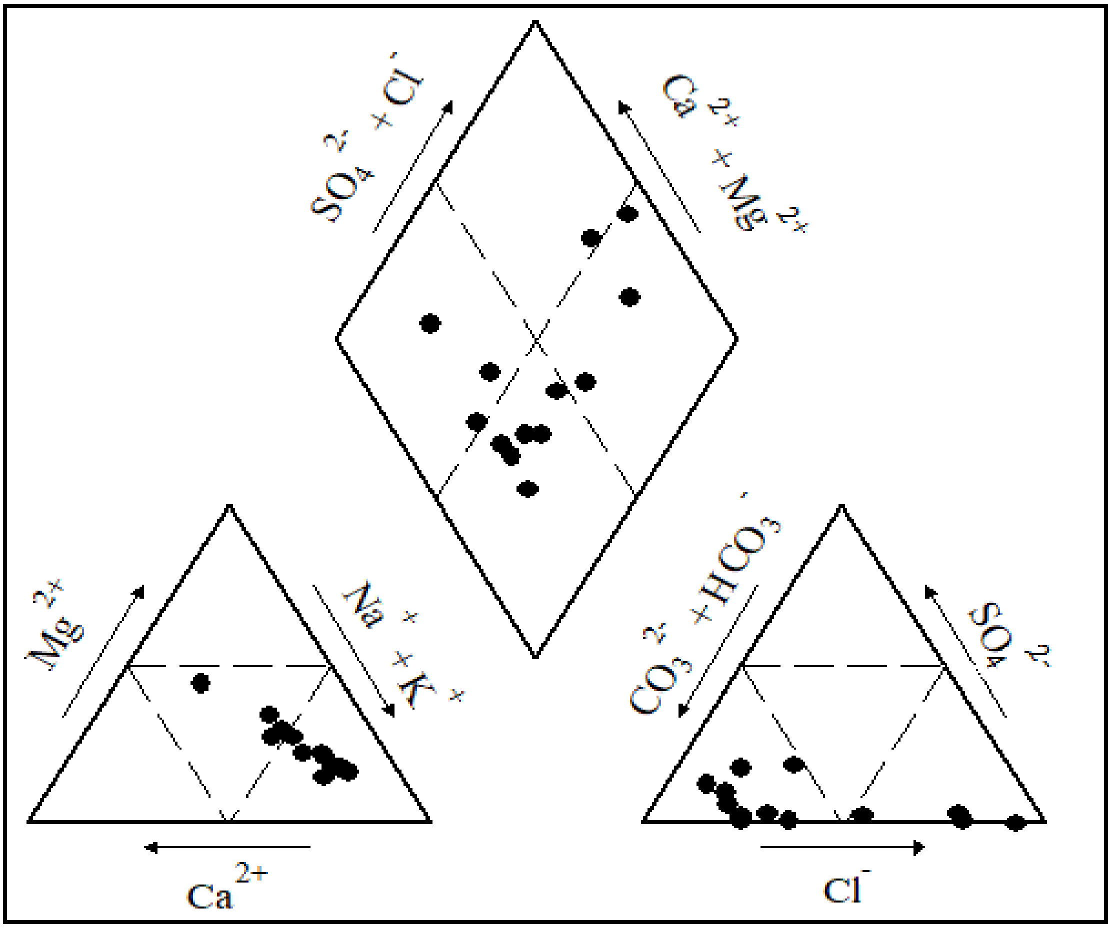

Figure 5: *Piper plot for Likangala Irrigation Scheme*

3.5.2. Chloralkaline and Saturation Indices

Cation exchange is a process that commonly modifies the major ion chemistry of groundwater (Xiao et al. 2012). It is of great significance in the evolution of hydro-chemical compositions (Li et al., 2013). Further exploration for possible ion exchange in the study area was done through calculation of the chloralkaline indices (CIA) 1 & 2 (Scholler,1965). When a sample yields negative indices for both CIA-1 and CAI-2, it shows existence of cation exchange between sodium and potassium from water with calcium and magnesium in rock or soil.Positive chloralkaline indices indicate a reverse cation exchange of magnesium and calcium from water with sodium and potassium.

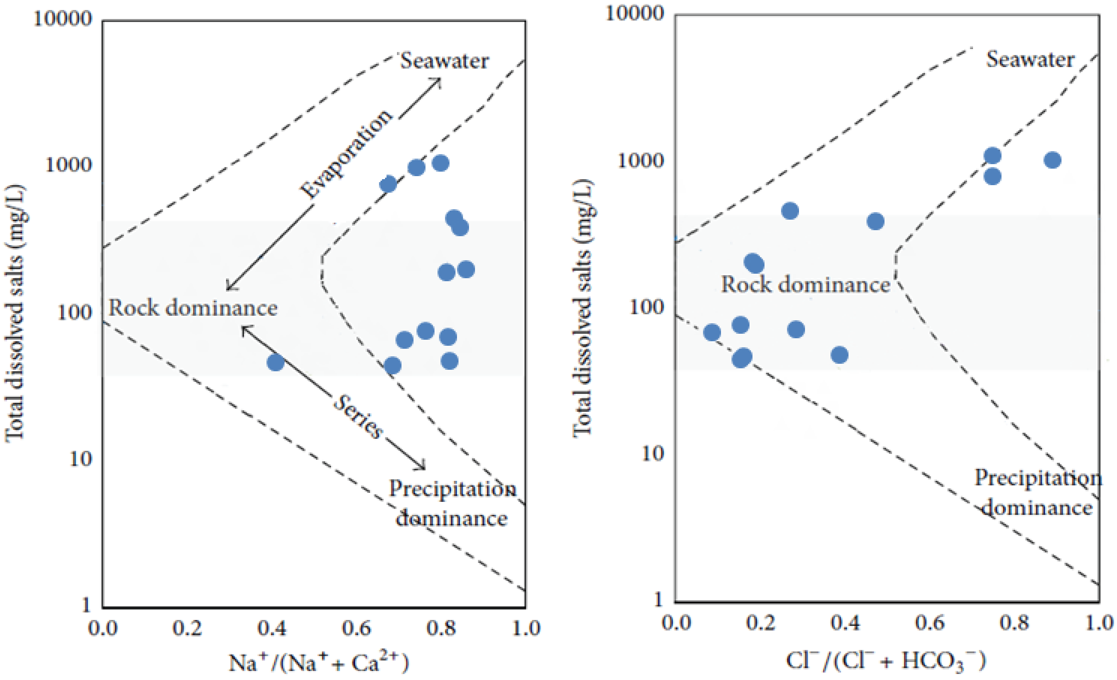

Figure 6: *Gibb's plots for Likangala Irrigation Scheme*

In Likangala irrigation scheme, 38.5% of the water points yielded positive values for both CAI-1 and CAI-2 (Table 7) implying the occurrence of reverse cation exchange. Thus, reverse cation exchange contributed to water chemistry for three shallow wells (Chidothe 2 (W2), Simaoni 2 (W5) and Lamusi 3 (W12)) and two boreholes (Mkungwi 2 (H6) and Chidothe 3 (H7)).

***Table** 7: Na/Cl, CAI-1 and CIA-2 values*

Waterpoint	Water point name	Na/Cl	CAI-1	CAI-2
W1	*Chidothe 1*	2.38	-1.39	-1.57
W2	*Chidothe 2*	0.90	0.10	1.06
H3	*Lamusi 2*	1.47	-0.49	-0.29
H4	*Simaoni 1*	1.68	-0.68	-1.72
W5	*Simaoni 2*	0.49	0.50	661.49
H6	*Mkungwi 2*	0.97	0.03	0.08
H7	*Chidothe 3*	0.90	0.09	0.02
H8	*Thunya*	2.58	-1.58	-0.41
W9	*Lamusi 1*	1.93	-0.94	-0.41
H10	*Likangala HC*	1.64	-0.66	-0.22
W11	*Lamusi*	1.26	-0.28	-0.11
W12	*Lamusi 3*	0.50	0.50	2.91
H13	*Chiliko*	2.55	-1.56	-0.96

The hydrogeochemical equilibrium model, PHREEQC interactive 3.5.0 -14000, was used to calculate the saturation indices of the groundwater samples collected under this study (Appelo & Postma 2010). Close attention was given to minerals containing the major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and anions (CO_3^{2-} , SO_4^{2-}, Cl^{-},F). Saturation indices with respect to aragonite, calcite, dolomite, fluorite, gypsum, anhydrite, halite and sylvite were negative for all but one samples implying undersaturation (Table 8).

4.0 CONCLUSION

The groundwater for Likangala Irrigation Scheme indicated to be of fresh and weakly mineralized type, except for Chidothe 1 (W1) and Simaoni 1(H4) that were of brackish type and slightly mineralized. The groundwater is generally not suitable for drinking purposes mainly due to influence of high turbidity, manganese and total hardness. Most people in this irrigation scheme consume turbid, hard or salty water during the dry season. The groundwater for this irrigation scheme is generally suitable for irrigating purposes for a wide range of crops.

Table 8: *Saturation indices*

SAMPLE	ARAGONITE	CALCITE	DOLOMITE	FLUORITE	GYPSUM	ANHYDRITE	HALITE	SYLVITE
	$CaCO_3$	$CaCO_3$	$CaMg(CO)_2$	CaF_2	$CaSO_4.2H_2O$	$CaSO_4$	NaCl	KCl
W1	-1.29	-1.15	-2.85	-2.03	-2.21	-2.51	-8.65	-9.71
W2	-0.75	-0.61	-1.81	-2.46	-0.87	-1.17	-7.35	-8.61
H3	-2.04	-1.90	-4.25	-1.81	-1.48	-1.78	-8.03	-9.24
H4	-4.02	-3.88	-0.2.11	-1.23	-0.62	**0.92**	-7.82	-9.26
W5	-3.55	-3.41	-6.58	-3.02	-2.75	-3.06	-9.44	-9.96
H6	-1.90	-1.75	-3.39	-1.94	-1.53	-1.83	-8.29	-9.35
H7	-3.54	-3.39	-6.18	-2.92	-2.88	-3.19	-9.61	-10.78
H8	-3.17	-3.02	-5.24	-2.66	-3.06	-3.36	-9.66	-11.64
W9	-2.93	-2.79	-4.71	-2.91	-3.09	-3.39	-9.76	-10.57
H10	-2.25	-2.11	-4.19	-2.42	-0.83	-1.13	-8.09	-9.49
W11	-3.40	-3.26	-6.08	-2.57	-2.89	-3.19	-9.38	-10.80
W12	-3.16	-3.02	-4.92	-2.98	-3.11	-3.42	-8.94	-9.26
H13	-2.08	-1.94	-3.85	-2.32	-2.21	-2.51	-9.22	-10.26

The groundwater chemistry is mainly influenced by weathering and reverse ion exchange. Dominance of cations in Likangala Irrigation Schemes is in the order Na > Ca > Mg > K. For anions, the order of dominance for Likangala Irrigation Scheme was found to be Cl > HCO_3 > CO_3 > SO_4 >NO_3 >. The water is, however, undersaturated with respect to the minerals in the order sylvite > halite > anhydrite > fluorite > dolomite.

The study recommends properguidance on drilling of boreholes to maximize utilizationby the public.The findings of this research also advocates for use of groundwater for maximum utilization for agriculture puposes during the dry season. Using solar power to abstract this suitable groundwater for irrigation purposes can improve food security in the area. There is need for further research to establish other appropriate crops that might do well if the groundwater is to be used for irrigation purposes in this area.

Declaration of competing interest

The authors declare that there is no conflict of interest.

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