Assessment of Water Quality and Suitability for Irrigation of Rugende Dam, Rwanda

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Abstract: *This study was carried out to assess the water quality of Rugende dam located in Eastern Province of Rwanda and its suitability for irrigation purposes based on various physicochemical parameters and water quality indices. Water samples were collected from eight different locations in the dam and analyzed for general, physical and chemical parameters. Hydrochemical modeling was done and Schoeller Berkaloff diagram showed that the predominant cation trend in water from Rugende dam is ordered as $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+}$ with the Calcium (Ca^{2+}) as the dominant cation. The predominant anion trend followed the order $Cl^{-} > SO_4^{-2} > HCO3^{-}+CO_3^{2-} > NO_3^{-}$ and the Chloride (Cl^{-}) was found to be the dominant. Water quality indices (TDS, SAR, TH, %Na, PI, SP, SSP, MAR, RSC and KR) were determined and the results showed mean values of 283.6±18.4mg/l; 2.2±0.3; 122.2±9.3mg/l; 23±2.3; 42.5±2.9%; 16.6±6%; 23±3%; 27.1±2.4%; 98.1±12mg/l and 0.2±0 respectively. According to FAO standards for irrigation water quality, all samples analyzed showed that all indices figured in normal ranges. EC was plotted to %Na using Wilcox's diagram and the classification showed that all the samples belong to the excellent category. US Salinity Laboratory's diagram was used to indicate the salinity hazard and sodium hazard by plotting EC to SAR and showed that water samples are found in class C1S1 (low-low) and class C2S1 (medium-low). Based on the findings, water from Rugende dam has low ionic concentration with no salt effects and it is suitable for irrigation. Further researches may focus on seasonal quality assessment and temporal trends analysis of those parameters.*

Keywords: Rugende dam, Rwanda; Water quality indices; Wilcox's diagram; Suitability for irrigation.

1. INTRODUCTION

The projections for the future on global population showed that it will increase by 30% and reach above 9 billion by 2050 (Foley et al., 2011; Tilman et al., 2011). Consequently, this increase in population is expected to increase food demand by 70 up to 100% level comparably to the current situation (World Bank, 2008; Tilman et al., 2011; Gregory and George, 2011).

Agriculture as one of important sectors must be improved to respond to global food demand. Even though this sector is still depending on rainfall at global level (Rost et al., 2008), a transition from rainfed to irrigated agriculture is highly needed and it was found that it can increase crop yield three times on average comparably to the current production (Howell, 2001).

Freshwater contributes to nearly 70% of irrigation. Nowadays, global freshwater resources are under pressure which will increase especially in the countries experiencing chronical short of water where the predictions showed it to increase from a 0.5 to 4 billion by 2050(Taikan and Kanae,2006; Evans,2009).

The quality of water used for irrigation can vary greatly due to the type and quantity of dissolved salts (James et al. 2012; Ahmed and Al- Taani 2013). The low quality of irrigation water has many characteristics including mainly high total dissolved salts(TDS), high electrical conductivity (EC), high alkalinity and other more (Al Hadrami,2013). The use of low-quality water in irrigation causes several environmental impacts on plants, soil, plants, animals, and humans (Ali, 2019; El-Hassanin, 2020), as well as the deterioration of soils and agricultural crops grown on those soils (Ayers and Westcot, 1985; Rowe and Abdel-Magid, 1995).

The suitability of irrigation water is mainly based on the total dissolved substances including dissolved salts; and these dissolved salts should be present at small concentrations in order to keep good quality of irrigation water for high soil-water productivity (Thorne and Peterson, 1954). However, the increase of dissolved salts in water for irrigation can affect some soil properties such as aeration and permeability. The higher quantities of dissolved salts affect the increase of osmotic pressure, thus affect plant water availability which leads to the reduction of soil productivity (Todd, 1980; Ali et al., 2009; Thorne and Peterson, 1954).

In order to assess the suitability of water for irrigation it was discovered that it very important to consider various parameters such as salinity, sodicity/sodium hazard and toxicity (Todd, 1980; Alexander and Mahalingam, 2011; Ali et al., 2009; Almeida et al., 2008; Karmegam, 2010; Tank and Chandel, 2010).

In Rwanda, most studies conducted in irrigation sector focus on agricultural water distribution and performance of irrigation infrastructure, but they don't look on quality of water used in irrigation to increase crop yield. Rugende dam built for irrigation purposes is located in eastern part of Rwanda which experiences lowest rainfall and high evaporation (ADF, 2006); and these characteristics may affect water quality in reservoirs of the region and accelerate salinization in irrigation schemes apart from use of fertilizers. Therefore, the results from this study will provide information on irrigation water quality of the dam; which will be helpful to decision makers in planning for irrigation water management in downstream irrigation schemes of Rugende area.

The main objective of the present study is to assess the water quality of Rugende dam and its suitability for agricultural irrigation. For achieving that aim , physico-chemical parameters were measured, including, Potential hydrogen (pH), electrical conductivity (EC), total dissolved salts (TDS), Cations such as calcium (Ca^{2+}), sodium (Na^{+}), magnesium (Mg^{2+}), potassium (K^{+}) and anions such as such as chloride (Cl^{-}), sulfate (SO_4^{-2}), nitrates (NO_3^{-}), bicarbonates (HCO_3^{-}) and carbonates (CO_3^{2-}). The suitability of Rugende dam's water for irrigation was assessed based on different water quality indices, including Electrical conductivity(EC), Total dissolved salts(TDS), total hardness(TH), sodium adsorption ratio(SAR), sodium percentage (%Na), residual sodium carbonate(RSC), permeability index (PI), salinity index or salts percentage (PS), soluble sodium percentage (SSP), magnesium adsorption rate (MAR), and Kelly's ratio(KR).

2. DESCRIPTION OF THE STUDY AREA

Rugende dam is located in Rwamagana District of the Eastern Province of Rwanda. It is located on latitude of $1^0$57'43.74''S, longitude of $30^0$16'47.93''E and at an altitude of 1384m a.s.l. The dam was constructed at Gatoki River which is the outlet of Rugende catchment area of 34.5 km^2. The dam supplies water for irrigation in Rugende, Gatoki, Nyirabidibiri and Nyabugogo marshlands extended to an area of 600ha where different crops types (rice, vegetables and fodder crops for livestock) are grown.

Apart from serving for irrigation purpose, water from Rugende dam is also used by neighboring population in their daily home activities purpose. The reservoir coverage area is 22ha and its capacity is 725,000m^3(MINAGRI, 2016).

The dam is located in a region of moderate tropical climate with four seasons which are long-rain (September-December), short-dry(January-February) short rain(April-May) and long-dry(June-August).The region experiences the annual rainfall of 992.6mm and the average annual temperature ranging between 19^0C and 30^0C.

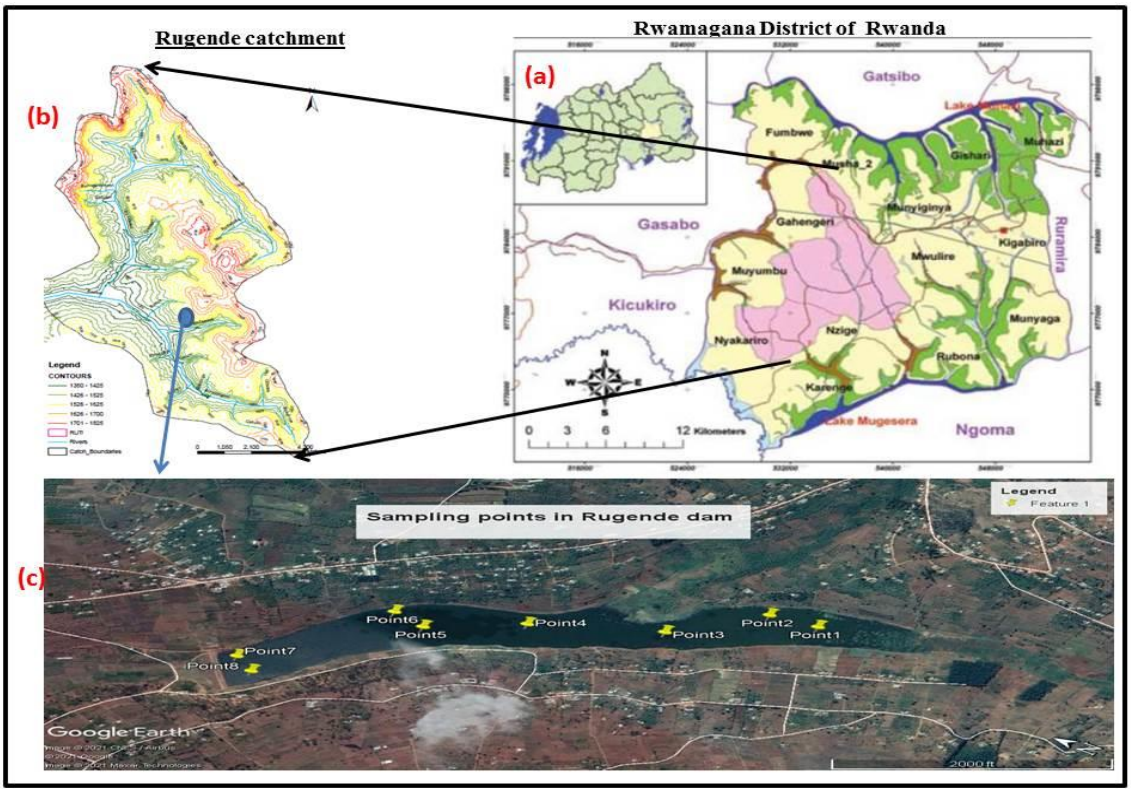

Fig1. Maps showing (a) Rwamagana District of Rwanda; (b) Rugende catchment; (c) Rugende dam location and sampling points.

3. METHODOLOGY

The sampling was done in December 2020 during long-rain season and water samples were collected from the dam by means of small boat at eight different locations using plastic bottles.

Irrigation water samples were taken to the laboratory and analyzed using appropriate analytical methods (Table1) for general parameters such as hydrogen ion concentration (pH), electrical conductivity (EC) and total dissolved solids (TDS). The important cations such as calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}) and potassium (K^{+}) were analyzed as well as anions such as chloride (Cl^{-}), sulfate (SO_4^{-2}), nitrates (NO_3^{-}), bicarbonates (HCO_3^{-}) and carbonates (CO_3^{2-}). All the steps from collection to analysis were followed as per APHA (1999) and Hem (1991).

The classification of water samples based on irrigation suitability was done by calculating irrigation water quality indices such as total hardness(TH), sodium adsorption ratio(SAR), sodium percentage (%Na), residual sodium carbonate(RSC), permeability index (PI), salinity index or salts percentage (PS), soluble sodium percentage (SSP), magnesium adsorption rate (MAR), and Kelly's ratio, using formula referring to Richards (1954); Eaton (1950); Wilcox (1955); Szabolcs and Darab (1964).

The statistical measures for all parameters considered in this study such as maximum, minimum, mean, coefficient of variation and standard deviation were determined (Tables1,2) and Hydrochemical analysis was done in evaluating the predominant ion trend order for water samples from the dam by using Schoeller Berkaloff diagram (fig.1). The salinity hazard and sodium hazards were analyzed by using USSL classification (EC versus SAR) and Wilcox diagram (EC versus %Na).

Table1. Laboratory instruments and analytical methods used for physical and chemical parameters analysis as per APHA (1999) [a] and Hem (1991) [b]

Parameter	Unit	Analytical method	Reagents	Reference
pH		pH/EC/TDS/meter	pH 4,7 and 9.2	a
Electrical conductivity(EC)	µS/Cm	pH/EC/TDS/meter	KCl	a
Total Dissolved Solids(TDS)	mg/L	Gravimetric	HCl	b
Calcium	mg/L	EDTA titrimetric	EDTA, sodium hydroxide and murexide	a
Potassium	mg/L	Flame photometric	NaCl and KCl	a
Sodium	mg/L	Flame photometric	NaCl and KCl	a
Magnesium	mg/L	Calculation	MgH = TH-CaH Mg = MgH X Eq.Wt of Mg × Normality of EDTA	a
Chloride	mg/L	Titrimetric	AgNO3 ,Potassium Chromate	a
Fluoride	mg/L	Ion selective electrode	TISAB III and NaF	a
Nitrate	mg/L	UV–visible spectrophotometer	KNO3,Phenol disulfonic acid,ammonia	a
Sulfates	mg/L	UV–visible spectrophotometer	HCl, ethyl alcohol, NaCl,barium chloride, sodium,Sulfate	a
Bicarbonates	mg/L	Titrimetric	Hydrosulfuric acid,phenolphthalein, methyl orange	a

4. RESULTS AND DISCUSSION

4.1. General parameters

The quantities of general parameters (pH, EC, TDS), concentrations of different types of anions (Cl^{-}, SO_4^{-2}, NO_3^{-}, HCO_3^{-}, and CO_3^{2-}) and cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) are presented in table2. The values of quality indices (TH, SAR, %Na, RSC, PI, PS, SSP, MAR and KR) are presented in table 3.

pH is an indicator of acidity or alkalinity. The mean pH of water from Rugende dam was 7.2±0.1. The normal pH range for irrigation water is 6.5 to 8.4 (Ayers and Westcot, 1985). In this study, the pH of water samples tested showed a range of 7.08-7.22 that indicates water suitability for irrigation. Electrical conductivity (EC) of water is a function of the total dissolved salts (Harilal et al., 2004). EC can be used as an index and representing the total quantity or concentration of soluble salts present in water (Gupta et al, 2008) .The desirable EC mean is 2000 µS/cm and the permissible EC mean is 3000 µS/cm. In this study, the mean EC value was 443.4 ± 28.5µS/cm, which is in the permissible range.

Total dissolved solids (TDS) consist of salts, metals, minerals, anions and cations dissolved in water (Langenegger, 1990). The TDS concentrations out of range can limit the growth, and lead to the death of some aquatic living forms. The Permissible limit

of TDS mean is 2000mg/l according to Ayers and Westcot (1985). In the present study, the mean TDS value in water samples tested is 283.6±18.4mg/l which is in the normal limits.

Table2. Physical and chemical parameters of water samples from the dam

Sampling Points	Physico- Chemical parameters										
	pH	EC µS/cm	TDS mg/l	Cl^- mg/l	SO_4^{-2} mg/l	NO_3^- mg/l	HCO_3^- mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^+ mg/l	K^+ mg/l
P1	7.11	411	263	11.8	15	0.8	134.2	28.8	10.5	11.6	2.4
P2	7.08	486	311	16.9	11	0.3	152.5	35.2	11.9	9.6	2.5
P3	7.11	413	264	18.2	12	0.4	128.1	29.9	11.4	8.7	2.1
P4	7.18	410	262	4.6	8	0.9	140.3	25.1	10.7	9.4	2.4
P5	7.14	455	291	5.9	13	0.6	164.7	34.2	11.1	12.1	2.8
P6	7.21	450	288	21.1	10	0.5	122	30.8	10.4	8.6	1.9
P7	7.18	462	296	10.2	12	0.8	140.3	30.2	10.6	9.8	2.1
P8	7.22	460	294	16.3	14	0.3	134.2	27.9	12.8	10.4	2.3
Max	7.22	486	311	21.1	15	0.9	164.7	35.2	12.8	12.1	2.8
Min	7.08	410	262	4.6	8	0.3	122	25.1	10.4	8.6	1.9
Mean	7.2	443.4	283.6	13.1	11.9	0.6	139.5	30.3	11.2	10.0	2.3
SD	0.1	28.5	18.4	6.0	2.2	0.2	13.6	3.3	0.8	1.3	0.3
CV	0.01	0.06	0.06	0.45	0.19	0.41	0.10	0.11	0.07	0.13	0.12

SD: Standard deviation CV: Coefficient of Variation P: Point of sampling in the dam

4.2. Ionic concentration and dominance

The cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+) measured in water samples showed mean values of 30.5±3.3mg/l; 11.2±0.8mg/l; 10.0±1.3mg/l and 2.3±0.3mg/l. The anions (Cl^-, SO_4^{-2}, NO_3^- and $HCO3^-$) measured in water samples showed mean values of 13.1±6mg/l, 11.9±2.2mg/l, 139.5±13.6mg/l and 0.6±0.2mg/l respectively.

Hydrochemical analysis by Schoeller Berkaloff diagram showed that the predominant cation trend in water from Rugende dam followed the order $Ca^{2+} > Na^+ > Mg^{2+} > K^+$, and the Calcium (Ca^{2+}) is the dominant (Fig.2). Schoeller Berkaloff diagram showed also that the predominant anion trend followed the order $Cl^- > SO_4^{-2} > HCO3^- + CO_3^{2-} > NO_3^-$ and the Chloride (Cl^-) is the dominant (Fig.2)

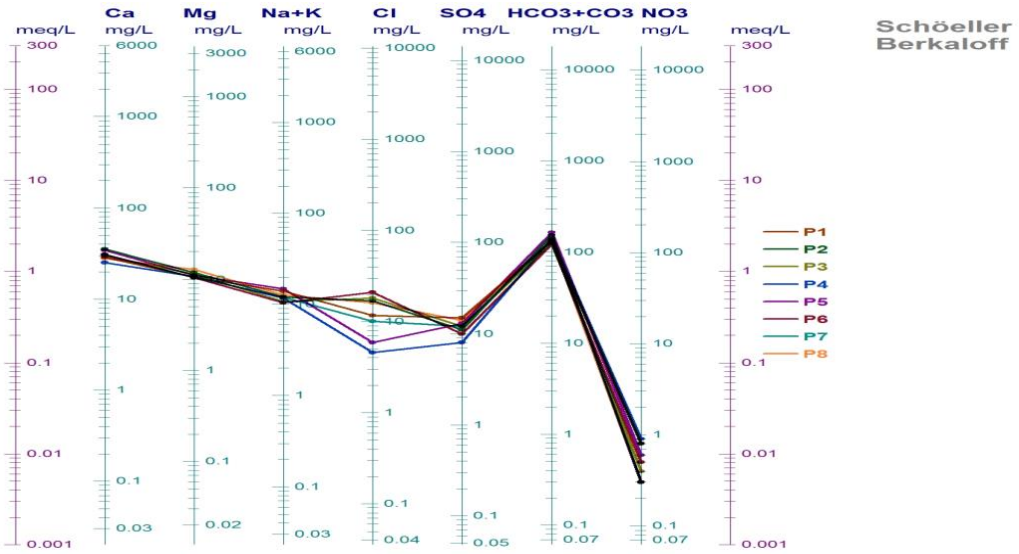

Fig. 2: Schoeller diagram illustrating ionic dominance in irrigation water of Rugende dam

4.3. Irrigation water quality indices

Irrigation water quality parameters (TDS, SAR, TH, %Na, PI, SP,SSP, MAR, RSC and KR) determined using formula(Table2) showed mean values of 283.6±18.4mg/l; 2.2±0.3; 122.2±9.3mg/l; 23±2.3; 42.5±2.9; 16.6±6; 23±3; 27.1±2.4; 98.1±12mg/l and 0.2±0 respectively.

Table3. Irrigation water quality indices

Quality parameters	TDS (mg/l)	SAR	TH (mg/l	%Na	PI (%)	SP	SSP (%)	MAR (%)	RSC (mg/l)	KR
Max	311.0	2.6	137.6	26.3	47.0	24.3	27.8	31.4	119.4	0.3
Min	262.0	1.9	107.3	20.3	38.7	7.4	19.4	24.5	80.8	0.2
Mean	283.6	2.2	122.2	23.0	42.5	16.6	23.0	27.1	98.1	0.2
Median	289.5	2.2	121.3	23.2	42.9	17.9	23.5	26.3	97.2	0.2
SD	18.4	0.3	9.3	2.3	2.9	6.0	3.0	2.4	12.0	0.0
CV	0.06	0.12	0.08	0.10	0.07	0.36	0.13	0.09	0.12	0.14

SD: Standard deviation CV: Coefficient of Variation

4.4. Irrigation water quality criteria

The assessment of water suitability for irrigation of Rugende dam was conducted by considering different quality indices such as Total Dissolved Salts (TDS), Electrical conductivity(Ec), Total hardness(TH), Sodium absorption rate (SAR), Magnesium adsorption rate(MAR), Sodium percentage(%Na), Soluble sodium percentage(SSP),Residual sodium carbonate, Permeability index(PI), Salinity index(SP) and Kelly's ratio(KR). Water quality indices were calculated by using appropriate formula with references from Richards (1954); Eaton (1950); Wilcox (1955); Szabolcs and Darab (1964). The results are presented in Tables4-14.

Total dissolved solids (TDS)

The Results showed that TDS ranged between 262 and 311mg/l with an average of 283.6 mg/l (Table3). It was also found that water from 100% of the samples of the dam tested are in good category. Based on suitability appraisal and according to the standards (FAO, 1985), water for irrigation of Rugende dam is good in Total dissolved solids (Table4).

Electrical conductivity (EC)

The Results showed that EC ranged between 410 and 486 µs/cm with an average of 443.4 µs/cm (Table3). All water samples (100%) tested are in good category. Based on suitability appraisal (Table5) and according to FAO (1985) water from Rugende dam has good Electrical conductivity (EC).

Total Hardness TH)

The total hardness was determined using the formula (1).

$$TH= \left[\left(2 \times \frac{Ca^{2+}}{40}\right) + \left(2 \times \frac{Mg^{2+}}{24}\right)\right] \times 50 \quad (1)$$

The results presented in table 2 show that Total hardness (TH) ranged between 107.3 and 137.6 mg/l with an average of 122.2mg/l . All water samples (100%) tested are in moderate category. Based on suitability appraisal and according to FAO (1985) water from Rugende dam is moderately hard (Table 6).

Sodium absorption ratio (SAR)

The Sodium absorption ratio was determined using the formula (2).

$$SAR= \frac{Na^{+}}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}} \quad (2)$$

The results presented in table 2 show that Sodium adsorption ratio (SAR) ranges between 1.9 and 2.6 with average of 2.2. All water samples (100%) tested showed excellent indicator. Based on suitability appraisal and according to FAO (1985) water from Rugende dam has excellent SAR (Table7). The Sodium adsorption rate is an expression of alkali hazard (Gholami and Srinkanaswamy, 2009) and the excess leads to the reduction of water infiltration and soil permeability (Kelley, 1946). However, water from Rugende dam which has an excellent SAR doesn't affect both infiltration and permeability of the soil.

Magnesium adsorption rate (MAR)

The Magnesium adsorption rate (MAR) was determined using the formula (3).

$$MAR= \frac{Mg^{2+}}{Ca^{2+}+Mg^{2+}} \times 100 \quad (3)$$

The results presented in table2 show that Magnesium adsorption rate (MAR) ranges between 24.5-31.4 mg/l with average of 27.1mg/l. As it is shown in table 8, all water samples (100%) collected belong to acceptable conditions. As per literature MAR can be an indicator of magnesium hazard; and when its quantity reaches permissible range it can affect crop yield (Naragaju et al., 2006). As far as the present study is concerned, water of Rugende dam contains MAR in acceptable range limits that cannot affect the yield.

Sodium percentage (%Na)

The sodium percentage (%Na) was determined using the formula (4).

$$\%Na= \frac{(Na^{+}+K^{+})\times 100}{(Ca^{2+}+Na^{+}+Mg^{2+}+K^{+})} \quad (4)$$

The results presented in table2 show that Sodium percentage (%Na) ranges between 20.3 and 26.3 with average of 23.

All water samples (100%) collected fall in good class of water for irrigation (Table9). Sodium is crucial in water for irrigation purpose but it become toxic to plant when it reaches higher concentrations (Singh et al., 2005). As far as % Na is concerned in this study area, water of Rugende dam contains good sodium percentage (%Na) which is not toxic to plants.

Soluble sodium percentage (SSP)

The soluble sodium percentage (SSP) was determined using formula (5).

$$SSP = \frac{Na^+}{Ca^{2+}+Mg^{2+}+K^+} \times 100 \qquad (5)$$

The results show that Soluble sodium percentage (SSP) ranges between 19.4 and 27.8 with an average of 23 (Table2). Soluble sodium is helpful to classify water for irrigation in term of permeability of the soil (Naragaju et al., 2006). This also comes to express that when the concentration of Na^+ is high in irrigation water the soil permeability reduces; and during wet conditions the soil becomes hard when it is dried out (Collin and Jenkins, 1996; Salesh et al., 1999). Based on Soluble sodium percentage (SSP), water samples collected in Rugende dam indicated the categories from good (67.5%) to excellent (32.5%); which expresses no harmful effect of irrigation water to soil permeability (Table10).

Residual soluble carbonate (RSC)

Residual soluble carbonate (RSC) was determined using the formula (6).

$$RSC = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+}) \qquad (6)$$

As it is indicated in table2, Residual soluble carbonate (RSC) ranges between 80.8 and 119.4 mg/l with an average of 98.1mg/l. The Residual soluble carbonate (RSC) has an influence on irrigation water suitability and once it increases it directly increases sodium hazard (Bokhari and Khan, 1992). Based on the results shown in table11, all samples collected and tested for RSC show that irrigation water from Rugende dam is in good class of RSC and do not activate sodium hazard during irrigation.

Permeability index

The Permeability index (PI) was determined in this study using the formula (7).

$$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+}+Mg^{2+}+Na^+} \times 100 \qquad (7)$$

The results presented in table 2 show that Permeability index (PI) ranges between 38.7 and 47 with an average of 42.5. Permeability index (PI) as one of irrigation suitability indexes was classified by Doneen (1966) and can be classified in three categories (Table12). For this present study, the PI for all water samples (110%) has an excellent indicator of irrigation water quality.

Salinity index (PS)

The salinity index was determined in this study by applying the formula (8).

$$PS = Cl^- + \sqrt{SO_4^{2-}} \qquad (8)$$

Salinity index (PS) was determined and the results showed that it ranges between 7.4 and 24.3mg/l with an average of 16.6mg/l. For this study, 25% of water samples are classified in the type of good water to injurious and 75% of water samples are classified in the type of injurious water to unsatisfactory.

Kelly's ratio

Kelly's ratio as one of water quality parameter was determined by applying the formula (9).

$$KR = \frac{Na^+}{Ca^{2+}+Mg^{2+}} \qquad (9)$$

Kelly's ratio (KR) was determined and the results showed that it ranges between 0.2 and 0.3 with an average of 0.2. For this study, 100% of water samples are classified in the type of suitable water.

Table4: Classification of irrigation water of the dam according to TDS (FAO, 1985)

Indicator	Suitability appraisal	Standard range(mg/l)	Measured range(mg/l)	Sample reference number	%
TDS	Excellent	<450	262-311	-	0
	Good	450-750		P1,P2,P3,P4,P5,P6,P7,P8	100
	Permissible	750-2000		-	0
	Unsuitable	>2000		-	0

Table5: Classification of irrigation water of the dam according to EC (FAO, 1985)

Indicator	Suitability appraisal	Standard range(µs/cm)	Measured range(µs/cm)	Sample reference number	%
EC	Excellent	<250	410-486	-	0
	Good	250-750		P1,P2,P3,P4,P5,P6,P7,P8	100
	Permissible	750-2250		-	0
	Unsuitable	>2250		-	0

Table6: Classification of irrigation water of the dam according to TH (FAO, 1985)

Indicator	Suitability appraisal	Standard range(mg/l)	Measured range(mg/l)	Sample reference number	%
TH	Soft	<75	107.3-137.6	-	0
	Moderately hard	75-150		P1,P2,P3,P4,P5,P6,P7,P8	100
	Hard	150-300		-	0
	Very hard	>300		-	0

Table7: Classification of irrigation water of the dam according to SAR (FAO, 1985)

Indicator	Suitability appraisal	Standard range(mg/l)	Measured range(mg/l)	Sample reference number	%
SAR	Excellent	<10	1.9-2.6	P1,P2,P3,P4,P5,P6,P7,P8	100
	Good	10--18		-	0
	Fair	18-26		-	0
	Poor	>26		-	0

Table8: Classification of irrigation water of the dam according to MAR (FAO, 1985)

Indicator	Suitability appraisal	Standard range(mg/l)	Measured range(mg/l)	Sample reference number	%
MAR	Acceptable	<50	24.5-31.4	P1,P2,P3,P4,P5,P6,P7,P8	100
	non-acceptable	>50		-	0

Table9: Classification of irrigation water of the dam according to %Na (FAO, 1985)

Indicator	Suitability appraisal	Standard range (%)	Measured range (%)	Sample reference number	%
%Na	Excellent	<20	20.3-26.3	-	0
	Good	20-40		P1,P2,P3,P4,P5,P6,P7,P8	100
	Permissible	40-60		-	0
	Doubtful	60-80		-	0
	Unsuitable	>80		-	0

Table10: Classification of irrigation water of the dam according to SSP (FAO, 1985)

Indicator	Suitability appraisal	Standard range (%)	Measured range (%)	Sample reference number	%
SSP	Excellent	<20	19.4-27.8	P2,P3,P6	37.5
	Good	20-40		P1,P4,P5,P7,P8	62.5
	Permissible	40-60		-	0
	Doubtful	60-80		-	0
	Unsuitable	>80		-	0

Table11: Classification of irrigation water of the dam according to RSC (FAO, 1985)

Indicator	Suitability appraisal	Standard range(meq/l)	Measured range(meq/l)	Sample reference number	%
RSC	Good	<1.25	0.76-1.12	P1,P2,P3,P4,P5,P6,P7,P8	100
	medium	1.25-2.5		-	0
	Bad	>2.5		-	0

Table12: Classification of irrigation water of the dam according to PI(FAO,1985)

Indicator	Suitability appraisal	Standard range	Measured range	Sample reference number	%
PI	Excellent	>75	38.7-47	P1,P2,P3,P4,P5,P6,P7,P8	100
	Good	25-75		-	0
	Unsuitable	<25		-	0

Table13: Classification of irrigation water of the dam according to SP (FAO, 1985)

Indicator	Suitability appraisal	Standard range	Measured range	Sample reference number	%
SP	Excellent to good	<5	7.4-24.3	-	0
	Good to injurious	5--10		P4,P5	25
	Injurious to unsatisfactory	>10		P1,P2,P3,P6,P7,P8	75

Table14: Classification of irrigation water of the dam according to KR (FAO, 1985)

Indicator	Suitability appraisal	Standard range	Measured range	Sample reference number	%
KR	Suitable	<5	0.2-0.3	P1,P2,P3,P4,P5,P6,P7,P8	100
	Unsuitable	5--10		-	0

Wilcox classification (EC versus %Na)

Wilcox's (1955) diagram is used to classify water for irrigation purposes; Where EC is plotted to %Na. For this study, with basis on Wilcox classification, all the samples (100%) belong to the excellent category. Wilcox diagram is plotted in Fig3.

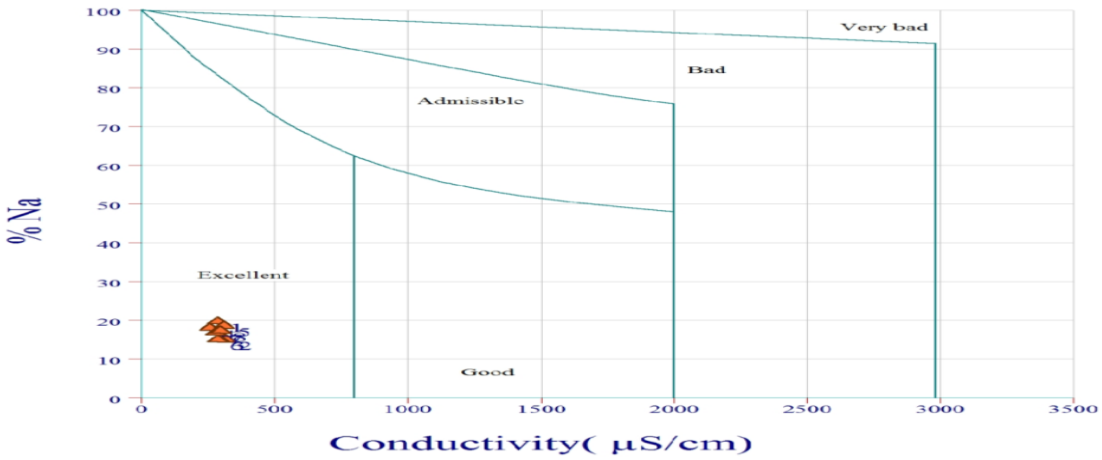

Fig3. Wilcox Log diagram of EC versus %Na in the study area

USSL classification (EC versus SAR)

Classification of Richards (1954) indicates the salinity hazard and sodium hazard by plotting EC to Sodium absorption ratio (SAR). In the present study, samples are found in class C1S1 (low-low) and class C2S2 (medium-low). This shows that water for irrigation from Rugende dam have low ionic concentration and have no salt effects (Fig.4).

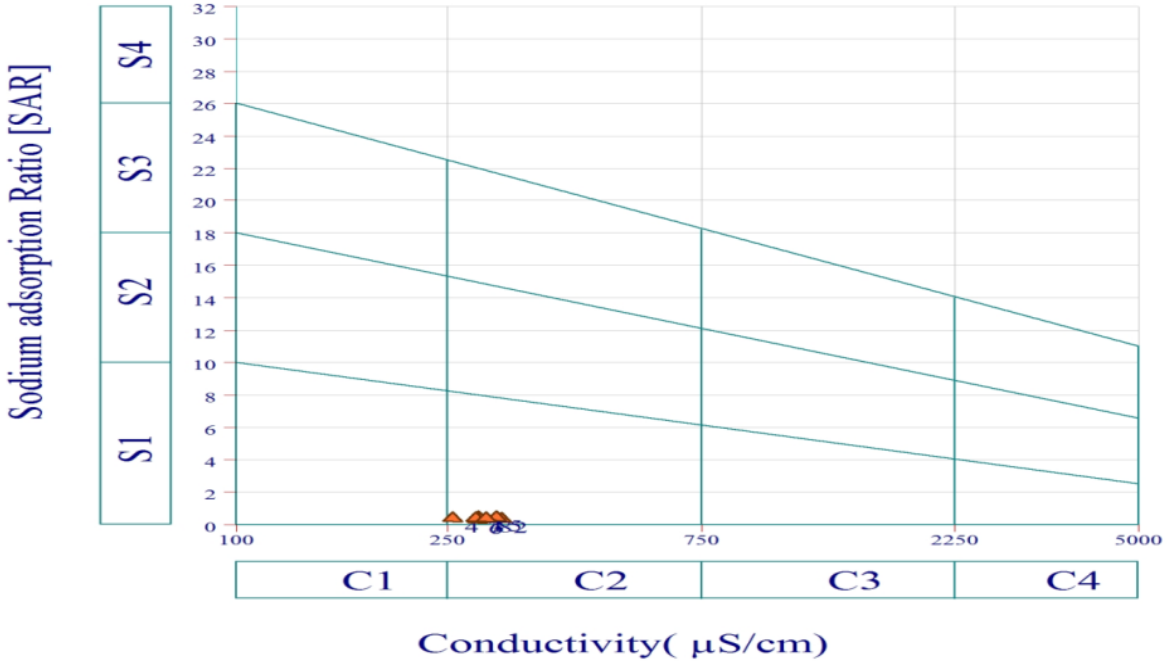

Fig.4. US Salinity Laboratory's diagram of EC versus SAR in the study area

CONCLUSIONS

The values of physicochemical parameters measured in the present study showed results falling within the permissible ranges of good quality of irrigation water. Wilcox's diagram used to classify water for irrigation purposes showed excellent category of irrigation water in all samples. The USSL diagram showed that samples are found in class C1S1 (low-low) and class C2S1 (medium-low) with information of no salinity and sodium hazards. Therefore, water of Rugende dam has good quality and it is suitable for any irrigation purpose.

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