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HYDROCHEMICAL CHARACTERISTICS AND SUITABILITY OF KANZENZE RIVER FOR IRRIGATION OF AKAGERA UPPER CATCHMENT IN RWANDA

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ABSTRACT

The purpose of the study was to assess the hydrochemical characteristics of the Kanzenze River and its suitability for irrigation use in the Akagera upper catchment in Rwanda. In this respect, 12 samples of surface collected water in four sites namely Karumuna, Muzi, Karugenge, and Nyamabuye were at a distance of 100.00 meters one to another. The Food and Agriculture Organization (FAO) standards were referred to analyze water quality parameters such as potential hydrogen (pH), electrical conductivity (EC), total dissolved solids (TDS), sodium adsorption ratio, soluble sodium percent, total hardness, magnesium adsorption ratio and Kelly index were used for the evaluation of water quality and its suitability for irrigation. Data were analyzed using descriptive analysis and principal components analysis. All parameters analyzed were within the FAO standards stipulated for irrigation. The mean pH of the water sample was 7.30; the mean TDS was 205.10 mg l^{-1}; mean sodium adsorption was 2.30 while the mean EC was 302.26 µS/cm which indicated that Kanzenze River is in category I of classification standard suitable for irrigation. This indicated that the Kanzenze River was suitable for irrigation.

Key words: water quality, irrigation, Akagera upper catchment, Rwanda

INTRODUCTION

Seasonal fluctuations of crop yields as induced by weather variability and change in soil physical and chemical conditions require higher irrigation system performance and better water quality, which is still elusive during hot climatic conditions (Ayers and Westcot, 1985). According to Kumarasamy *et al.* (2014), the variation of water quality parameters is mainly directed by the good quality and permissible levels of accumulated salts to be dissolved in the water body. The appropriateness of agricultural water use in irrigation can be determined by an estimation of some physical and chemical compounds which normally go with calculated hydrogeo-chemical parameters like sodium adsorption ratio (SAR), total dissolved solids (TDS), potential Hydrogen (pH) and electrical conductivity (EC) (Rouabhia *et al.*, 2010). Studies conducted in sub-Saharan African (SSA) countries showed that about 66% of Africa is changing from semi-arid to arid conditions and more than 300 of 800 million people in the region live in a water-scarce environment (Njarui *et al.*, 2018), translated at less than 1,000.00 m^3 per capita per year (Reidsma *et al.*, 2010). According to Mukanyandwi *et al.* (2019), Rwanda has a wetland cover of approximately 280,000 ha accounting for about 11% of the total land of the country and of which 56,000.00 ha are currently irrigated, representing 9.5% of the total potential irrigable area (Habineza *et al.*, 2020).

Furthermore, agriculture is practiced in three cropping seasons namely A, B and C in which farmers rotate staple food crops in season A and B while in C, they can grow horticultural crops in marshland usingan irrigation system. The Kanzenze wetland in the Akagera upper catchment is used by the local people for the cultivation of rice, maize, and other horticultural crops. Recently, the Bugesera district experienced low crop production due to variations in weather conditions which sometimes are reflected by heavy rains. As observed by Lydie (2022), rainfall behavior shows that the rainy seasons in Rwanda are becoming shorter but with higher rain intensity. As a result, there are events such as floods and landslides in areas experiencing heavy rains with subsequentdry spells occurrence. This tendency leads to a decrease in agricultural productiondue to soil erosion, and performance failure of the crop development stages. Water from the Kanzenze River has experienced high levels of pollution due to anthropogenic activities on the River bank, soil erosion sediments deposit, and presence of car wash stations in the surrounding areas (Nsengiyumva *et al.*, 2021). Some scholars in Rwanda (Nigatu *et al.,* 2015) indicated that groundwater quality for irrigation from the Bugesera district has outweighed the permissible limits set by Rwanda Standard Board (RSB) in its RS 188:2013. This may cause deterioration of the soil complex adsorbent and plant growth. However, there is no

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specific study that has been conducted to assess the quality of surface water used as the main source of Irrigation in Rwanda. Hence, there is a need to support the local farmers by the way of taking up research to solve the field problem that can lead to increased crop production and improved economic welfare of the farmers around the Akagera upper catchment. This led to the study assessing water quality not only limited to levels of heavy metals but also other characteristics *viz* potential Hydrogen (pH), electrical conductivity (EC), total dissolved solids (TDS), sodium adsorption ratio (SAR), magnesium adsorption ratio (MAR), Kelly index (KI) and soluble sodium percent (SSP) in Kanzenze River for sustainable irrigation in Rwanda and come up with proposed solutions related to improved crop productivity.

MATERIALS AND METHODS

Location of Study

The study was carried out in Kanzenze swamp, Akagera upper catchment (Figure 1) located in Bugesera district, Ntarama sector. Kanzenze swamp is drained by the Akanyaru River in Rurambi marshland and is surrounded by four main landscape areas including Muzi, Karugenge, Nyamabuye, and Karumuna. As shown in Figure 1, the inflated land is located in the South-East while the highest elevation is in the North of the catchment. The total area of the swamp is estimated at 501 ha of which 300 ha is arable land. Maps 1 and 2 illustrate the features of Bugesera district and Kanzenze marshland. The annual rainfall ranges from 1,597 to 2,873 mm per year. The mean maximum temperature of the area is 29°C. The high temperatures and rainfall allow for crop development all year round, enabling farmers to have two cropping seasons.

Land Use Land Cover Change of Study Area

Most of the land is used for agriculture whereby the marshland near the river is covered by vegetation and the remaining is the river floodplain which has animal farms (cows, pigs, and chickens).

Topographical Features of Bugesera District

The topography of the area is characterized by a mixture of plateaus with an altitude varying between 1340 and 1700 m and undulating hills dominated by varying heights. The groundwater influence area is located in a wetland with flat topography whereby the altitudes vary between 1480 and 1350 m above mean sea level (amsl). The wetland is surrounded by a gentle hill with a high elevation of 1540 m amsl.

Soil Classification Map of Bugesera District

The soil type of Bugeserais mainly characterized by alluvial and colluvial from marshes and valleys which comprise minerals and organic materials derived fromthe valley of Nyabarongo. In Kanzenze cells, especially the Kanzenze Reservoirs location, the soil is typically sandy with a low quantity of humus and is highly permeable and quickly dries up after rains.

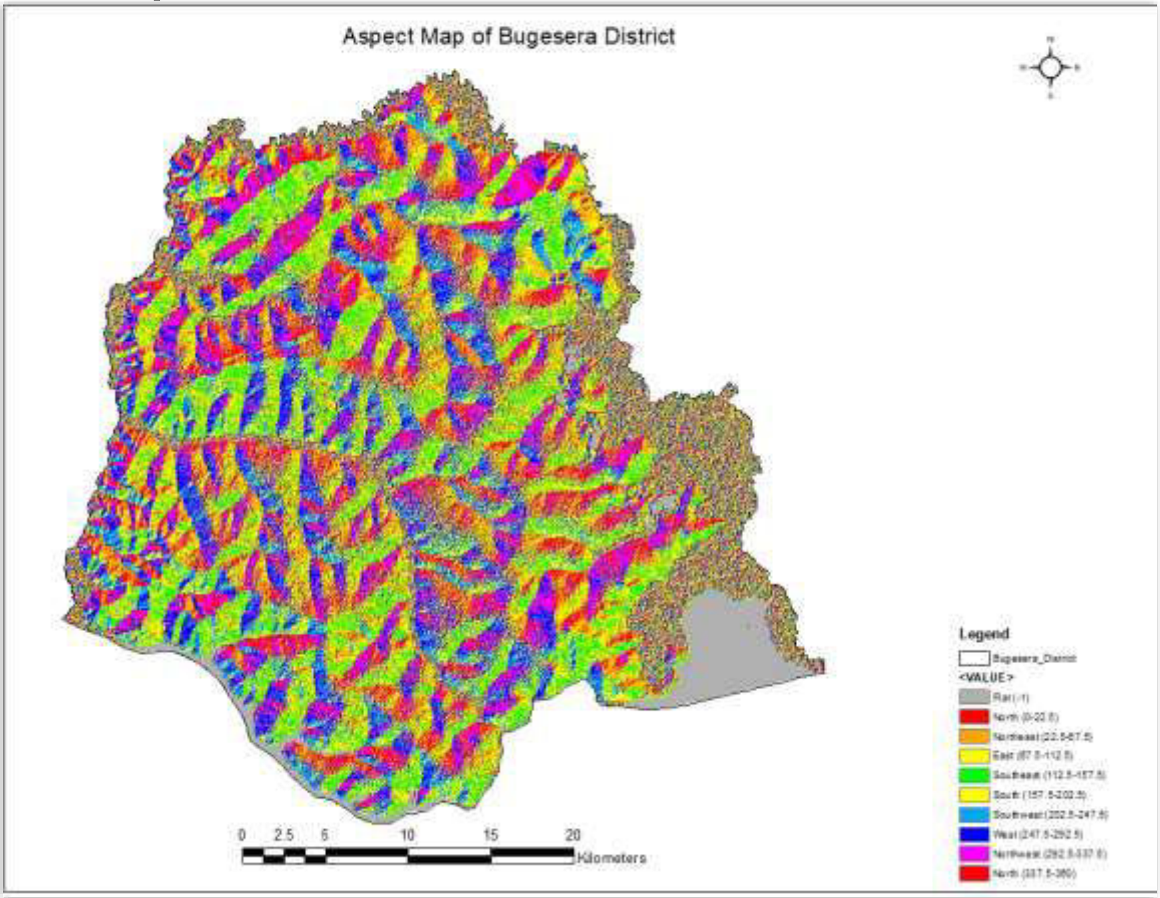

Figure 1: General aspect of Bugesera district

The shores of the river and marshes give, in some areas, clay which is used for making bricks, tiles, and traditional pottery. Figure 6 shows the total area and percentage of each soil types of Kanzenze marshland.

Based on Soil Taxonomy and soil dom of Bugesera marshland, the Kanzenze marshland is dominated by ferralsols: 49731.40 ha (38.59%), acrisols: 29208.71 ha (22.66%), histosols: 13125.33 ha (10.18%) and water bodies: 16357.68 ha (16.69%) of the total area of the district. In this marshland, there are other important soil types like gleysols: 7448.18 ha (5.78%), combisols: 7730.10 ha (6%), alisols: 4895.50 ha (3.8%) and phaeozems: 152.30 ha (0.12%). The last but not the least class is Lixisols: 212.20 ha (0.16%) and luvisols: 13.60 ha (0.01%), respectively. There are also many kinds of sand used for the construction of houses. The major crops grown in the swamp are sugar canes, tomatoes, carrots, onions, eggplants, and chillies for export.

Field Water Sampling

The water samples were collected from the surface of the Kanzenze River with sterilized plastic bottles. The screw-capped bottles were packed in a sterile cool box and then transported to the laboratory for analysis (Latchmore *et al*., 2020). The first sampling point was selected from the flooded area alongside the river. After fixing the first point, other points were taken at 200 m alongside the river away from the reference point. Simple immersion of well-cleaned plastic bottle of 250 ml below the surface of the water body was used for collecting surface water samples. The techniques used were to immerse the scoop in water and then pour the collected water into a plastic bottle. This was done smoothly to avoid the disturbance of water sediments, heavy metals content, turbidity, and other needful water quality parameters. A total of 12 water samples were collected from all four sites Muzi, Karugenge, Nyamabuye, and Karumuna on a basis of three samples per site as indicated in Figure 2. There was no replication per sampling point to avoid the disturbance of biological oxygen demand which may accelerate bacteria development. Thereafter transported in plastic bottles for laboratory analysis. The samples collected were kept in containers that were thoroughly washed to avoid any contamination.

Sample Preparation

It is worth mentioning that regardless of where or how analysis is performed, certain precautions should be observed in preparing a water sample for transfer to a laboratory. A plastic screw-capped bottle was used, and new bottle for each test of recommended procedures by Bishwakarma *et al.* (2022). After the water samples collection, the researcher traveled 4.00 km from the sites to the laboratory. The water samples were stored in the cooler box that contain ice to inhibit the activities of microbes that may consume nutrients available in the water samples before taking it to the laboratory where samples ought to be stored in a refrigerator at 4ºC for stability until their diverse chemical parameters were analyzed. This was done to conserve the nature and content parameters to be studied which include temperature, potential Hydrogen (pH), electrical conductivity (EC), total dissolved solids (TDS), sodium adsorption ratio (SAR), soluble sodium percent (SSP), total hardness (TH), magnesium adsorption ratio (MAR) and Kelly index (KI).

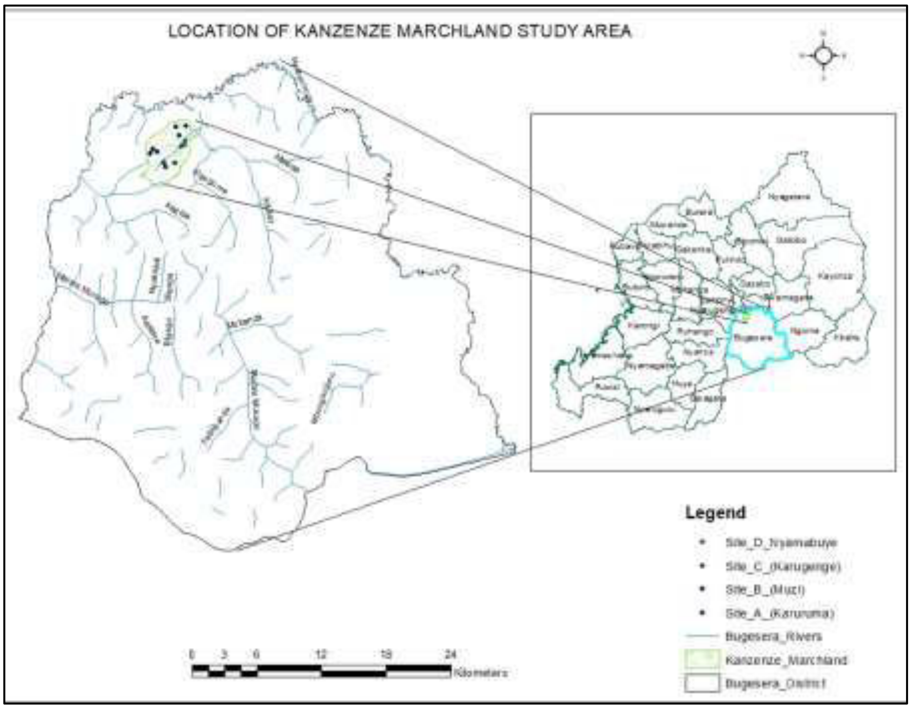

Figure 2: Location of Kanzenze swamp in Bugesera district

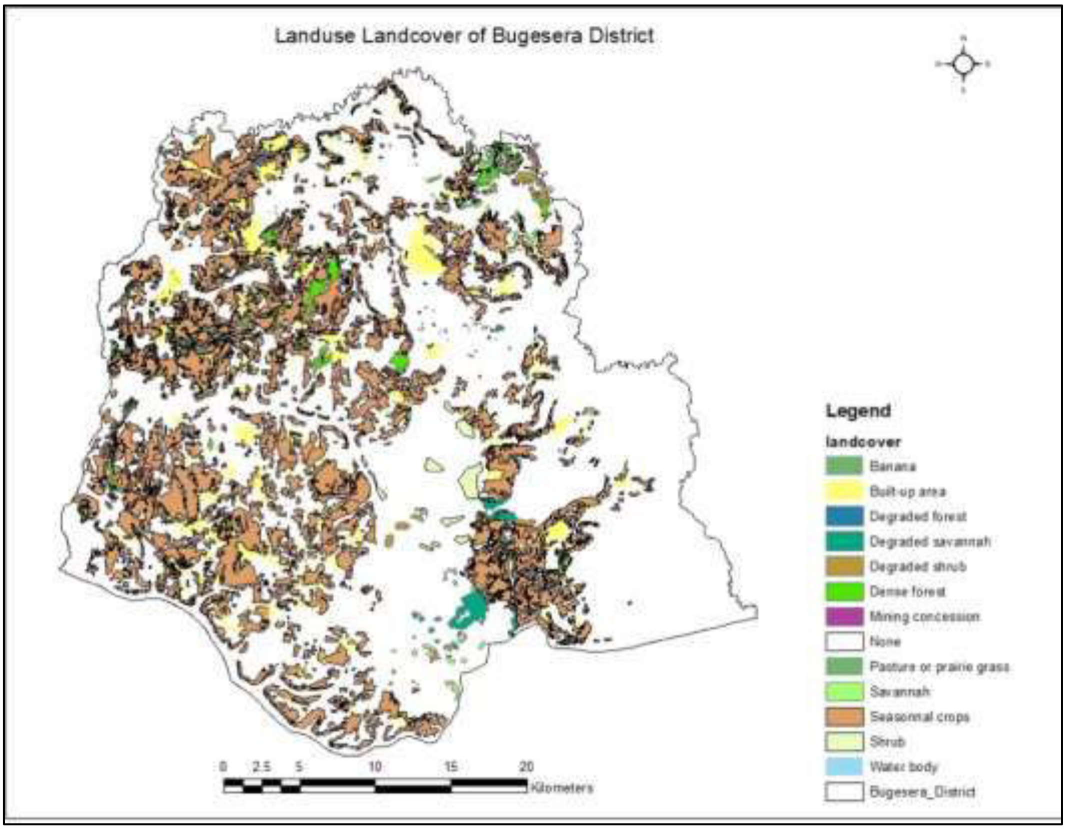

Figure 3: Land use land cover change

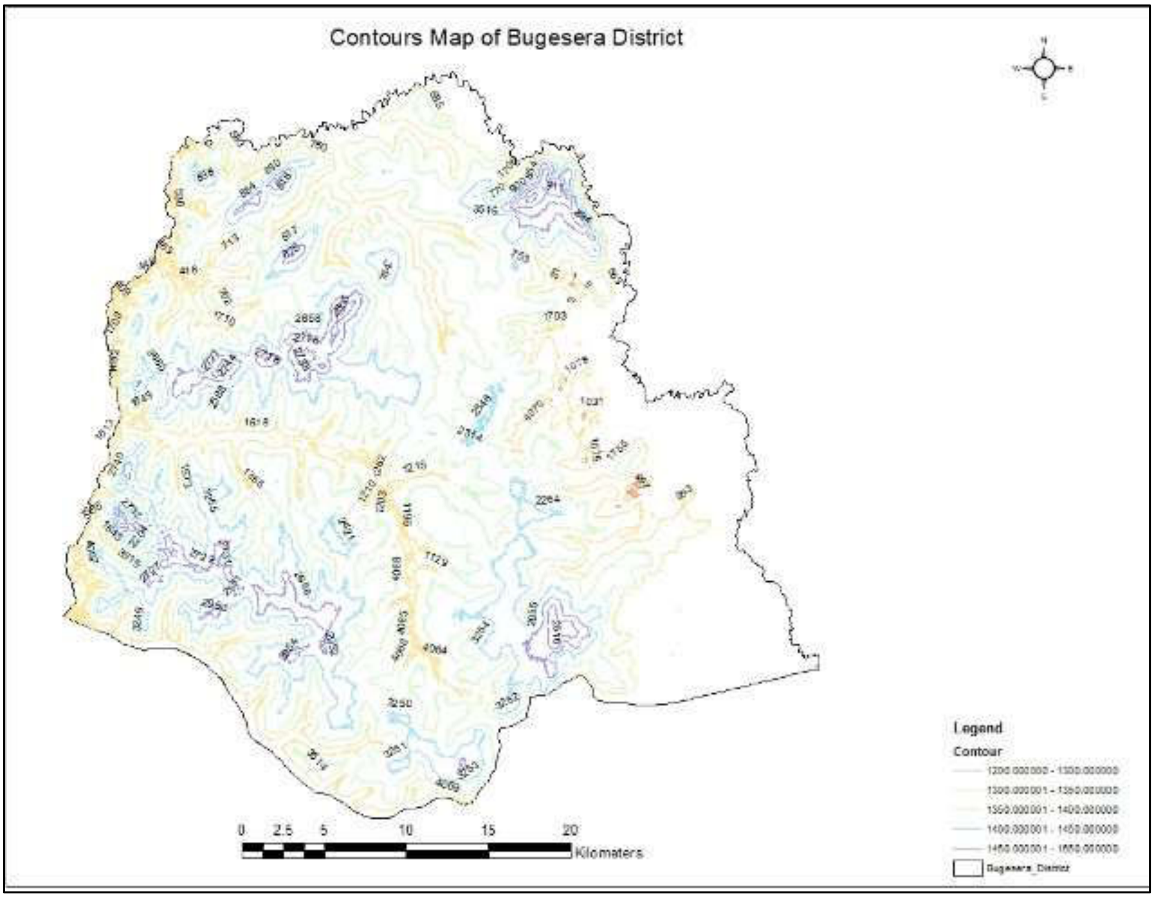

Figure 4: Contour map of Bugesera district

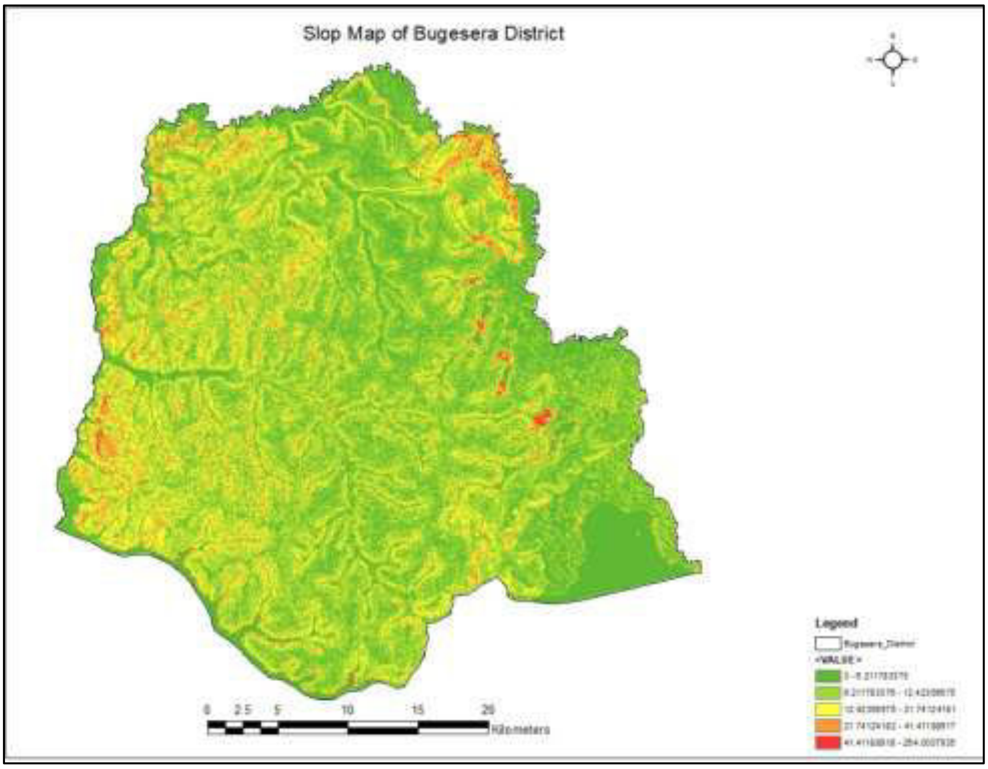

Figure 5: Slope map of Bugesera district. Source: Application of GIS and Remote Sensing (RS)

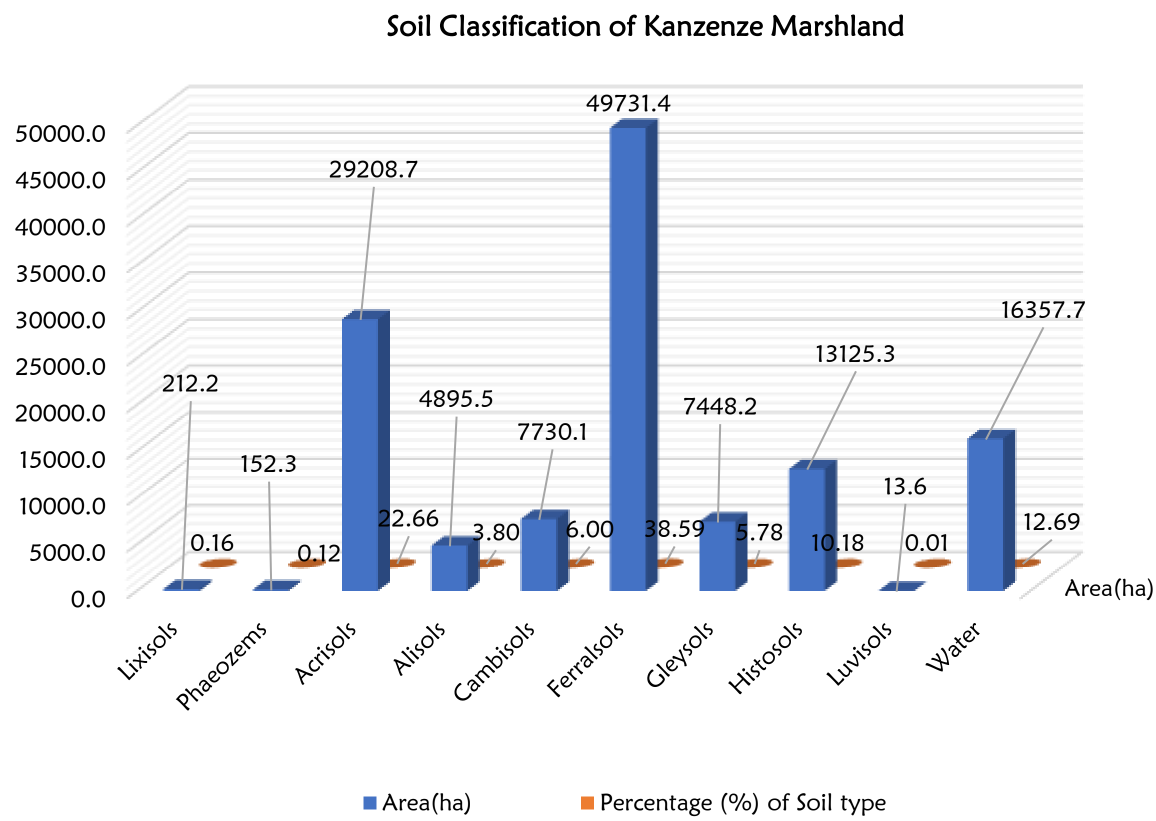

Figure 6: Soil Taxonomy and classification of Kanzenze marshland

Laboratory Analysis of Samples
Samples were analyzed at the Rwanda Standard Board (RSB) laboratory. During analysis, the concentration of Calcium, Magnesium, and Sodium was determined by Atomic Absorption Spectrophotometer (AAS) using standard procedures as laid down by Bisergaeva and Sirieva (2020). The other hydro-chemical parameters like pH, EC and temperature were directly determined through their specific analytical method of surface water analysis (Al-Maliky *et al*., 2015). The Press water method was used to analyze water acidity and salinity (Hounslow, 2018). The pH and EC were determined electrometrically following the procedure mentioned by Islam *et al*. (2021) using pH meters (Hanna instrument-211 model). The samples were homogenized in a mechanical shaker for 15 min. (Quevauviller *et al*., 1994), stabilized for 24 h, and filtered prior to measurement of pH and EC using an appropriate soil laboratory tool kit.

Total dissolved solids
According to Islam *et al*. (2021), the total dissolved salt of a soil sample can be determined using the EC values in Table 1. The total dissolved solids (TDS) was calculated based on the formula (Richards, 1968):

$$\mathrm{TDS} = (0.64\ \times EC \times 1.06\ (\mathrm{Micro-Ohm/cm})\ ..\ (1);$$

where EC and TDS are expressed in µ-mhos cm^{-1} and mg l^{-1}, respectively. Electrical conductivity is influenced by the water salts and their concentrations that allow ions and cations movement (Omboga, 2011).

Sodium adsorption ratio
The content of Na^{+} compared to Ca^{++} and Mg^{++} in water for irrigation is termed sodium adsorption ratio (SAR) and it is computed based on the formula indicated by equation 2 (Alexakis, 2011).

$$SAR = \frac{Na^{+} meq/L}{\sqrt{\frac{(Ca^{++} meq/L)+(Mg^{++} meq/L)}{2}}} \quad ...... (2);$$

where SAR is sodium adsorption ratio, Na^{+} is sodium concentration, Ca^{++} is calcium concentration, and Mg^{++} is magnesium concentration.

Magnesium adsorption ratio (magnesium hazard)
The amount of magnesium in the water body compared to calcium and magnesium is called magnesium adsorption ratio (MAR) (Alexakis, 2011):

$$MAR = \frac{Mg^{++}}{Ca^{++}+Mg^{++}} \times 100\% \ .... (3);$$

where all the ionic constituents are expressed in meq/L and translated: MAR is magnesium adsorption ratio, Ca^{++} is Calcium concentration and Mg^{++} is magnesium concentration (Alexakis, 2011).

Kelly index
The amount of Na^{+} in the water body compared to Ca^{++} and Mg^{++} is called “Kelly's Index (KI). Kelly's Index was calculated by employing the following equation (Alexakis, 2011):

$$KI = \frac{Na^{+}}{Ca^{++}+Mg^{++}} \times 100\% \ .... (4);$$

where all the ionic constituents are expressed in meq/L. The KI is Kelly's Index, Na^{+} is sodium concentration and Ca^{++} is calcium concentration and Mg^{++} is magnesium concentration.

Soluble sodium percentage
The soluble sodium percent (SSP) for surface water was calculated as follows (Bhandari and Joshi, 2013):

$$SSP = \frac{Na^{+}+K^{+}}{Ca^{++}+Mg^{++}+Na^{+}+K^{+}} \times 100\% \ .... (5);$$

where all the ions are expressed in meq/L. The SSP is soluble sodium percent, Na^{+} is sodium concentration, K^{+} is potassium concentration, Ca^{++} calcium concentration, and Mg^{++} is magnesium concentration.

Total hardness of water
Generally, total water hardness is equivalent to total calcium and magnesium hardness. The total hardness of water was calculated by the means of the following formula as developed by Shammi *et al.* (2016):

$$TH = (Ca^{2+} \times 2.497)\ +\ (Mg^{2+} \times 4.118)...\ (6);$$

where TH is the total hardness expressed in mg/L and; Mg^{2+} and Ca^{2+} are ions concentration of magnesium and calcium in meq/L respectively.

Water Quality Standards and Suitability for Irrigation
The adoption of national standards as prescribed by the Rwanda Standard Board in its RSB ISO 188 was used for water quality assessment for irrigation in Rwanda. The permissible limits, suitability, and their effect on plant growth are shown in Tables 1 and 2.

Data Analysis
Data analysis was performed by STATA 13.0. Descriptive statistics like means, median, variance, standard deviation, minimum, maximum, and coefficient of variation were used to interpret the results. The application of Principal Components Analysis (PCA) was used to indicate the interrelationship between components during the water quality assessment. The overall significance of water samples by components was evaluated at a 5% level of probability ($p \leq 0.05$). For correlation analysis, the values of r vary from -1.00 to 1.00. If the magnitude of the correlation coefficient r is > |±0.5|. According to the classification made by Shrestha and Kazama (2007), factors with Eigenvalues of 1.0 or greater, parameters are strongly correlated when $r > 0.70$, moderate when $0.75 \leq r \leq 0.50$ and weak when $0.50 \leq r \leq 0.30$ (Liu *et al.*, 2003).

Table 1: Standard of water quality parameters for irrigation in Rwanda

Parameters	RSB Limits		Effect on plant growth	International Standard Organization (ISO)
	< 0.75		No problem	
Electrical conductivity, EC	0.75-3.00	(dS/m)	Increasing problem	ISO: 7888
	> 3.00		Severe problem	
	< 450.00		No problem	
Total dissolved solids, TDS	450.00-2000.00	(mg/L)	Increasing problem	ISO: 5907
	> 2000.00		Severe problem	
	< 3.00		No problem	
Sodium adsorption ratio, SAR	3.00-9.00	%	Increasing problem	ISO: 9964
	> 9.00		Severe problem	
	< 6.50		No problem	
pH	6.50-8.40		Increasing problem	ISO: 10523
	> 8.40		Severe problem	

Source: Rwanda Standard Board, RSB (2018)

Table 2: Suitability of irrigation water

S/No.	Parameters	Conditions		Suitability	Reference
1	pH	6.50-8.40		Suitable for irrigation	Tak *et al*. (2012)
		< 0.70		Good for irrigation	Becerra-Castro *et al.* (2015)
2	Electrical conductivity, EC	0.70-3.00	(dS/m)	Slightly to moderate for irrigation	
		> 3.00		Restricted (not useful for irrigation)	
		< 450.00		Preferred for irrigation	Rawat *et al.* (2018)
3	Total dissolved solids, TDS	450.00-2000.00	(ppm)	Slightly to moderate for irrigation	
		> 2000.00		Unsuitable for irrigation	
		0.00-60.00		Soft water, fit for irrigation	
4	Total hardness, TH	60.00-120.00	(ppm)	Moderately hard water to fit for irrigation	Rawat *et al.* (2018)
		120.00-180.00		Hard water, not fit for irrigation	
		> 180.00		Very hard water, unsuitable for irrigation	
		< 10.00		Ideal or excellent water for irrigation	
5	Sodium adsorption ratio, SAR	10.00 to 18.00	%	Good for irrigation	Westcot and Ayers (1985)
		18.00 to 26.00		Doubtful for irrigation	
		> 26.00		Unsuitable for irrigation	
6	Magnesium adsorption ratio, MAR	< 50.00	%	Recommended for irrigation	Rawat *et al.* (2018)
7	Kelly index, KR or KI	< 1.00		Recommended for irrigation	
8	Soluble sodium percent, SSP	< 60.00	%	Recommended for irrigation	

1 dS/m = 1000 µS/cm

RESULTS

Hydrochemical Characterization of Water Quality of Kanzenze River

Table 3 shows values of measured parameters in the Kanzenze River. The pH ranged from 6.30 to 8.60 indicating slight alkalinity in the water. The electrical conductivity (EC) values varied from 49.50 µS/cm to 577.00 µS/cm with a mean of 302.30 µS/cm which indicates that the water is slightly saline. This could affect the quality of water for irrigation or domestic purposes due to high concentration level of salts which increases the impurities and degradation of water. About the *r* standards presented in Table 1, the water of the Kanzenze River is not suitable for irrigation. The results of TDS vary between 33.60 and 391.40 ppm with a mean of 205.10 ppm. The total hardness of the water varies from 76.90 to 223.90 ppm with a mean of 132.70 ppm. Water that contains elevated levels of calcium or magnesium salts, or both, is depicted as being 'hard'. The study findings also revealed a mean sodium adsorption ratio (SAR) ranging from 0.50 to 3.90 with a mean of 2.30. The mean magnesium adsorption ratio (MAR) or magnesium hazards (MH) varies from 38% to 80.2% with 52.2% of the mean. The research findings showed that the mean Kelly index or Kelly ratio on the other hand ranges from 4.6% to 30.8% with a mean of 17.10. The mean content of soluble sodium percent (SSP) of the Kanzenze River was found to be 36.7% from a range of 26.5% to 56.2%.

Principal Component Analysis for Water Quality Assessment

The data of different parameters for water quality assessment were subjected to principal component analysis (Table 4). After rotation, each variable was only related to one loading factor and each factor to be discussed here contained high and weak correlation this technical approach is appropriate for classification of surface water quality. Based on principles of principal component analysis (PCA), the findings showed three components that are statistically significant, notably pH, EC, and TDS. They are intercorrelated with other hydrochemical parameters found in the same cluster. They accounted for a cumulative value of 0.809 as shown in Table 3. This indicates that the three components accounted for 80.9% of the total variance of the original data set after transformation into a factor analysis. Eigenvalues greater than 1 were significant and correlated with other factors from the same clusters.

The pH of Water

Table 4 shows the total proportional variation value for principal component one (PC1) with 0.416 (41.6%) variation of pH. It shows that 41.6% of the variations are due to the first factor pH, which is having the highest effect on water quality. The variability of water pH can either influence the change in water acidity and or alkalinity. The Eigenvalue of the pH of water from Table 3 was found to be 3.193. It is higher than 1; so, it has strong effect

Table 3: Descriptive statistics of water quality parameters from Kanzenze River

Water samples		pH	EC (µS/cm)	TDS (ppm)	TH (ppm)	% SAR	% MAR	% KI	% SSP
1		8.60	501.30	340.10	138.50	1.50	63.00	11.80	49.70
2		7.10	288.30	195.60	223.90	1.50	47.30	9.10	34.50
3		8.50	215.60	146.30	107.20	0.50	80.20	4.60	26.50
4		8.60	171.50	116.30	102.80	3.50	51.20	26.50	37.70
5		6.70	347.70	235.90	145.60	1.70	69.10	13.50	29.80
6		7.10	298.60	202.60	178.60	0.90	45.10	6.10	31.70
7		6.40	491.00	333.10	171.30	3.20	44.60	21.70	31.50
8		7.50	154.10	104.50	105.40	2.40	38.00	17.30	27.50
9		6.30	49.90	33.90	129.30	3.90	48.60	30.80	45.80
10		6.60	49.50	33.60	76.90	3.00	49.50	26.70	56.20
11		7.20	577.00	391.40	93.90	1.70	40.40	12.20	32.40
12		7.60	482.60	327.40	118.50	3.60	49.10	25.30	37.30
Descriptive statistics	Mean	7.30	302.30	205.10	132.70	2.30	52.20	17.10	36.70
	Median	7.10	293.50	199.10	123.90	2.10	48.90	15.40	33.40
	Variance	0.70	32696.30	15045.80	1748.70	1.30	153.80	78.60	85.90
	standard deviation	0.90	180.80	122.70	41.80	1.10	12.40	8.90	9.30
	Minimum	6.30	49.50	33.60	76.90	0.50	38.00	4.60	26.50
	Maximum	8.60	577.00	391.40	223.90	3.90	80.20	30.80	56.20
	Range	2.30	527.50	357.80	147.00	3.40	42.20	26.20	29.70
	Coefficient of variation	0.116	0.598	0.598	0.315	0.499	0.238	0.517	0.253
	Number of observations	12	12	12	12	12	12	12	12

The abbreviations EC, TDS, TH, SAR, MAR, KI and SSP are as explained in Table 2.

Table 4: Factor analysis for the assessment of surface water quality

Variable	Comp 1 (pH)	Comp 2 (EC)	Comp 3 (TDS)	Comp 4 (TH)	Comp 5 (SAR)	Comp 6 (MAR)	Comp 7 (KI)	Comp 8 (SSP)
pH	0.35	-0.46	0.60	-0.14	0.07	0.45	0.69	0.06
EC	0.67	0.63	0.38	0.07	0.01	-0.06	-0.09	0.02
TDS	0.67	0.63	0.38	0.07	0.01	-0.06	-0.09	0.02
TH	0.42	0.30	-0.64	0.30	0.29	0.30	0.63	0.09
SAR	-0.83	0.41	0.19	-0.12	0.29	0.07	0.29	-0.66
MAR	0.36	-0.64	0.23	0.28	0.40	-0.28	-0.14	-0.05
KR	-0.91	0.28	0.23	-0.03	0.21	-0.03	0.12	0.74
SSP	-0.59	-0.01	0.28	0.67	-0.22	0.10	0.00	-0.09
Eigenvalue, difference, proportion and cumulative based on factor analysis								
Eigenvalue	3.19	1.75	1.27	0.66	0.43	0.39	0.00	0.00
Difference	1.45	0.48	0.61	0.23	0.04	0.39	0.00	.
Proportion	0.42	0.23	0.17	0.09	0.06	0.05	0.00	0.00
Cumulative	0.42	0.64	0.81	0.89	0.95	1.00	1.00	1.00

Comp stands for components (from 1 to 8). The abbreviations EC, TDS, TH, SAR, MAR, KI and SSP are as explained in Table 2.

on other factors. The correlation coefficient '*r*' of principal component pH with more than 0.50 was considered to be highly significant based on its magnitude as shown in Figure 2.

A positive correlation coefficient indicated a directly proportional relationship between the principal component pH of water with other water quality parameters in irrigation water found in cluster 1. This was found for the factors such as EC, TDS, TH, and MAR, suggesting that the increased values of these parameters could increase the pH of water of the irrigation water given the highest coefficient of correlation of TDS (0.672), which is considered as the most important parameter to measure the quality of a water sample because it is directly correlated and affected by increased turbidity, hardness, alkalinity and conductivity of tested water sample. This means that 1 unit addition of pH of water resulted in a 67.2% increase in TDS in water for irrigation. The negative sign of the correlation coefficient shows the inverse relationship between the principal components' pH with other factors which was revealed in SAR, KR, and SSP. The lowest coefficient of correlation of -0.909 was observed for Kelly's Ratio (KR). This reveals that for every addition of pH of water there is a 90.9% decrease in KR content in irrigation water.

Electrical Conductivity (EC)

Results indicated that the total proportional variation of the PC for electrical conductivity (EC) is indicated in Table 3. It is revealed that 22.8% of the variations were due to the EC of water, which plays a significant effect on water quality for irrigation after the pH. There is an inverse relationship between pH and the EC of water. Once water indicated higher salinity levels, water tends to be highly concentrated with different types of salts The Eigenvalue of EC (Table 3) of 1.75 being > 1 suggests a strong effect on other factors in the cluster as shown by Figure 9.

A positive correlation coefficient indicated a directly proportional relationship between the principal component EC with pH, TDS, TH, and MAR. This means that these factors will increase as EC increases in the irrigation water. A high EC *r* correlation coefficient of 0.67 was observed with TDS, which indicates that for every 1.00 µS/Cm addition of EC of water, there is a 67.2% increase in TDS in the water for irrigation. The negative correlation coefficient translates the inverse relationship between the principal component EC and other factors. The lowest coefficient of correlation of –0.909 was observed for KR, indicating that every addition of 1.00 µS/Cm of EC corresponds to a 90.9% decrease in KR content in the irrigation water.

Total Dissolved Solids (TDS)

Table 3 shows that the total proportional variation value of the PC for TDS is 0.165 (16.5%), which is attributed to the highest effect on the water for irrigation after pH and EC due to its high proportion of variation. The Eigenvalue of TDS (Table 3) of 1.26 being > 1.00 suggests a strong effect on other factors in the cluster. The correlation coefficient '*r*' of > 0.50 was considered to be highly significant based on its magnitude as shown in Figure 10.

From Figure 10 it is revealed that the positive value of the correlation coefficient is directly proportional to the principal components TDS with other water quality parameters in irrigation water. The direct proportional relationship with TDS is well demonstrated for the factors like pH, EC, SAR, MAR, KR, and SSP. This implies that these factors will increase as TDS increases in the irrigation water. The pH has the highest coefficient of correlation of 0.599 which indicate that every 1.00 mg l^{-1} addition of TDS, resulted in a 59.9% increase of pH in the water for irrigation. The negative sign of the correlation coefficient shows the reverse relationship between the principal components of TDS with other factors. The lowest coefficient of correlation of -0.63 was observed for TH, which translates that every addition of 1mg l^{-1} of TDS contributed to a 63.6% decrease in the TH content of irrigation water.

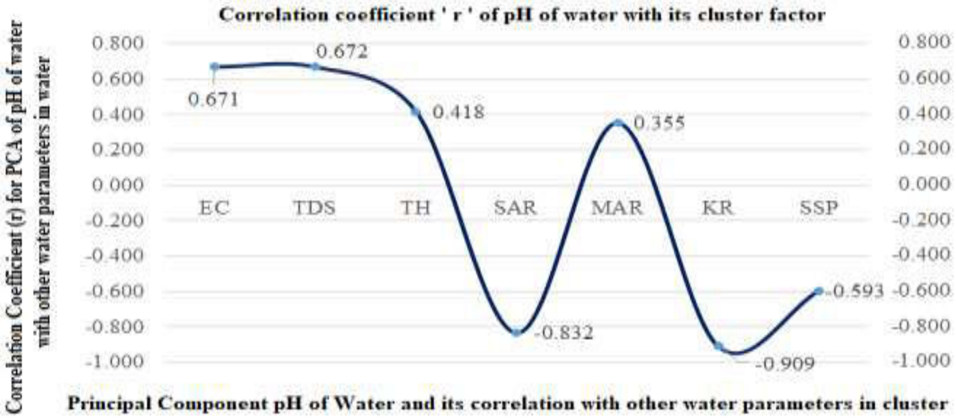

Figure 8: Variation of correlation coefficient of pH in water with its clusters

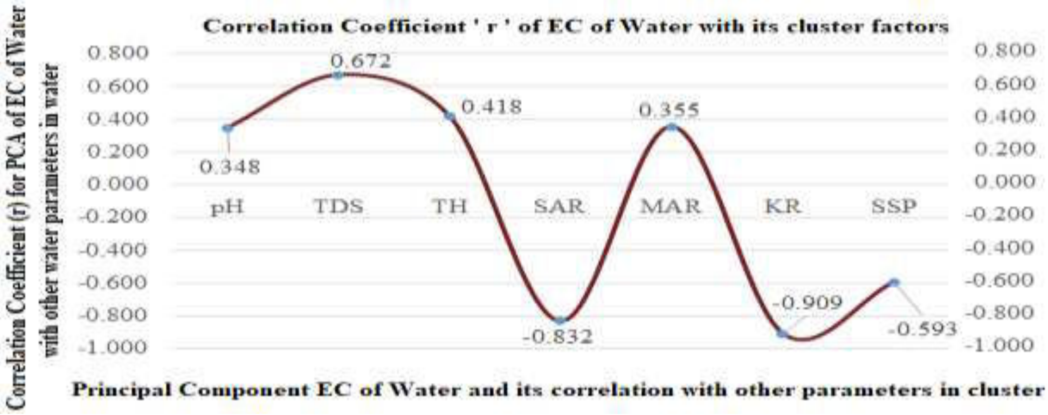

Figure 9: Variation of correlation coefficient of EC in water with its clusters

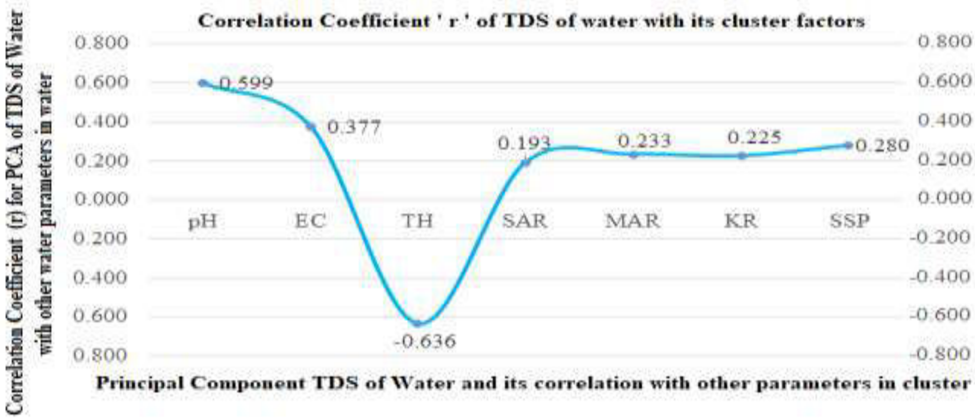

Figure 10: Variation of correlation coefficient of TDS in water with its clusters

DISCUSSION

The increasing request for high-quality water for irrigation in Rwanda in the last years has led to the use of poor-quality water for irrigation mainly in farmland. The use of low-quality water could cause a decline in crop productivity (Nwite *et al*., 2017; Abdel-Fattah *et al*., 2020; Nnadi *et al*., 2021). The current study indicated that the water of the Kanzenze River was classified as moderate for salinity and acidic hazard. It could, therefore, be suitable for most crops including horti-cultural crops due to its low limitations (Gupta *et al*., 2003). The TDS was found to be within the FAO standards of 1985 as reported by Rawat and Singh (2018) stipulating that the water is safe for irrigation purposes when TDS values range between 450 to 2000 ppm. According to Rawat and Singh (2018), the irrigation water from the Kanzenze River is safe for irrigation. Thus, these findings are consistent with by Joshi *et al*. (2009) indicating minimum values of TDS ranging from 42.58 to 70.12 mg l^{-1} and maximum values from 545.68 to 950.15 mg l^{-1} as suitable for irrigation. If the magnitude of the correlation coefficient r is > |±0.5|, it means there is a high correlation between TDS and other variables considered. The results from PCA are similar to those obtained using fuzzy and Nemerow methods as a new approach to achieving the sustainable manage-ment of water resources (El-Alfy *et al*., 2019; Shirmohammadi *et al*., 2020) and could be used for identifying physiochemical para-meter correlations and factors responsible for water quality variations (Kazi *et al*., 2009; Said *et al*., 2020).

Regarding soil properties, intensive irrigation will influence the decrease in soil EC through leaching and seepage operations (Obalum and Azuka, 2021). Findings from this study were comparable with research conducted by Kachi *et al*. (2016) and Azffri *et al*. (2022) who confirmed that the decrease of EC of irrigated soils is due to salt leaching by percolated waters after intensive irrigation. A similar effect was noticed by Sadeghian *et al*. (2018) and Kachi *et al*. (2016) who testified that leaching by irrigation water reduced the soil salinity. Hence, based on the results of salinity (EC) of 302.00 μS/cm of the water, the Kanzenze water River is classified as class 1 standard, not suitable for irrigation with severe problems (Table 1) (Wilcox and Magistad, 1943). The irrigation water from the Kanzenze River falls in the category of excellent to good, suitable for most plants under most conditions. Although the salinity (EC) level of irrigation water is the main factor limiting plant growth, under specific soil texture circumstances, using water with a sodium imbalance might further diminish agricultural output. Irrigation water with a high salt level compared to calcium and magnesium contents could cause reductions in water infiltration and hydraulic conductivity. Those with excessive sodium content could lead to sodicity or sodium buildup in the soil. The quality of irrigation water available to farmers and other irrigators has a considerable impact on what plants can be successfully grown, the productivity of these plants, water infiltration, and other soil physical conditions.

By Rhoades *et al*.'s (1992) standards, when SSP < 60%, the water is of good quality and suitable for irrigation. Based on the international and national standards developed by FAO and RSB and referring to the classification made by Rawat *et al*. (2018), the values of SSP > 60% indicate that the water is of poor quality and not suitable for irrigation. The mean SSP of the Kanzenze River was 36.71%, which fits well within the range of better quality and hence confirms that the Kanzenze River water is suitable for irrigation purposes. The total hardness (TH) is usually classified as soft at 0 to 60 mg l^{-1}, moderately hard at 60.00 to 120.00 mg l^{-1}, hard at 120.00 to 180.00 mg l^{-1}, and very hard at > 180.00 mg l^{-1} (Rawat *et al*., 2018).

Sodium content is another important factor in assessing the water quality for irrigation. Water with SAR between 0.00 to 3.00 is considered acceptable and with more prominent than 10.00 is considered inadmissible for a water system for irrigation purposes. The mean value of SAR of the Kanzenze River water of 2.28 is far less than 10.00, indicating that Kanzenze River water is ideal for irrigation. These findings are consistent with the research conducted by Joshi *et al*. (2009) whose results showed SAR values ranging between 0.40 and 1.49 in the Ganga River in India.

The magnesium hazards in irrigation water are a crucial factor to be assessed because once it exceeds permissible limits of 50%, it affects the soil colloids containing more Mg^{2+} and leads to deterioration and degradation of land and food. The effect of continual application of such water for irrigation purposes is dubitable and may lead to problems of soil infiltration. Referring to international and national standards developed by FAO and RSB and the classification made by Chegbeleh *et al*. (2020), whenever MAR < 50.00, water is considered to be suitable while it is classified as unsuitable for irrigation whenever MAR > 50.00. The KI is another important factor that is crucial in irrigation water to be assessed because once it exceeds permissible limits of 1.00, it affects the content of sodium in the water body. Consequently, whenever KI > 1.00, there is an effect of excessive levels of sodium in the water body. Hence, water with KR < 1.00 is considered suitable for irrigation purposes.

Additionally, referring to research conducted by Chegbeleh *et al*. (2020), SSP < 20.00: excellent, 20.00 ≤ SSP ≤ 40.00: good, 40.00 ≤ SSP ≤ 60.00: permissible, 60.00 ≤ SSP ≤ 80.00: doubtful and SSP > 80.00: water is said to be unsuitable for irrigation. Last but not the least, the research findings concluded that water from the Kanzenze River is not suitable for irrigation purposes and this is consistent with the classification made by Chegbeleh *et al*. (2020) when analyzing hydrochemical characteristics of selected irrigational water.

CONCLUSION & RECOMMENDATIONS

This study consisted of hydrochemical characterization and suitability of surface water quality for sustainable irrigation in the Kanzenze River of Akagera Upper Catchment. Factors especially pH, EC, TDS, SAR, MAR, KI, and SSP were the main key parameters of the evaluation. Findings from this study show that water from the Kanzenze River is safe when considering pH, electrical conductivity (EC), and total dissolved solids (TDS). Alkalinity and sodium percent were both within the FAO permissible standards limits for irrigation purposes and do not need any actions for water treatment. The TH of Kanzenze River was found to be 132.70 ppm higher than the moderately hard water. However, the difference between the observed and standard limits is very little, hence use of Kanzenze River water for irrigation would require minor water treatment to minimize the negative effect on soil and plant growth. Furthermore, water treatments should be undertaken to normalize MAR of the Kanzenze River which was found to be slightly higher that the acceptable value. It is recommended that water treatment measures be undertaken by using some additive to normalize the Kelly index of the Kanzenze River.

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AUTHORS' CONTRIBUTIONS

Ideation and conceptualization: J.N.N.; Literature review: J.N.N., N.K.T., H.V., and N.A.E.; Data collection and analysis: J.N.N. and P.M; Methodology: J.N.N., N.K.T., E.M., and R.V.; Writing original draft: J.N.N., N.K.T., and E.M.; Review, editing and proof reading: H.V., J.N.N., N.K.T., and V.R.

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