Makerere University Journal of Agricultural and Environmental Sciences
Vol. 12 (2). pp. 182 - 196, 2023

pISSN 1563-3721
eISSN: 2958-4795

The suitability of water in river Mpanga for irrigation and domestic purposes in Mt. Rwenzori foothills - A short communication

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Abstract

River Mpanga supports livelihoods of an estimated 1.2 million people in Uganda. The people depend on it for domestic, irrigation and industrial purposes. This study assessed the suitability of water in River Mpanga for irrigation and domestic purposes. Laboratory analyses were made for the chemical parameters (pH, N, P, K, Na, Mg and Ca). Water quality was determined using the Weighted Arithmetic Index Method for assessing Water Quality Index (WQI). The quality of irrigation water was assessed using water quality indices that included Sodium Adsorption Ratio (SAR), sodium percentage (Na %), Magnesium Hazard (MH) and Kelly's index (KI). The chemical parameters of water in River Mpanga i.e., pH, N, K, Na, Mg and Ca, were below the permissible limits suggested by WHO (World Health Organization) and EPA (Environmental Protection Agency), except for Phosphorous (0.24mg/l) which was above the permissible limits in all sections of the river. However, based on the WQI, which is a collective index, the water of river Mpanga (reading of 466.8 ± 287.81) is not suitable for domestic use as its above >100 recommended by WHO. The SAR, Na%, MH, and KI values

were all within the permissible limits with the exception of KI at uppperstream points. Thus, the water in River Mpanga is mostly suitable for irrigation. Efforts should be initiated to stop/prevent soil runoff and other contamination into the river especially in upstream areas.

Key words: Kelly's index, magnesium hazard, sodium adsorption ratio, water pollution, water quality index

Introduction

The world population is approximately 7.89 billion (World Bank, 2023). Of this population, 3.6 billion (over 45%) people lack access to safe water (CDCP, 2022). In sub-Saharan Africa, an estimated 102 million people still use unsafe surface water (Baye, 2021). Water resources in Uganda comprise of large lakes, wetlands and rivers, rainfall, surface water runoff, and groundwater (WRMD, 2004). Most parts of Uganda lack safe water due to contamination with sewage, pesticides, and amounts of mineral contents exceeding normal levels (Lukubye and Andama, 2017). Surface water bodies, especially rivers, are also an essential requirement for agricultural development. However, due to the continuously growing human population, settlement in fragile ecosystems, farming on fragile landscapes and poor soil and conservation practices, pollution of surface water is increasing.

River Mpanga is one of the water bodies surrounded by highly populated communities supporting the livelihoods of an estimated 1.2 million people in Uganda (Amanyire, 2018). From its origin in the Rwenzori Mountains, the river flows 250 km through the districts of Kabarole, Kamwenge, and Kyenjojo before pouring into Lake George. People living along the river depend on it for various goods and services, including but not limited to domestic use, irrigation, and industrial development. Being a water ecosystem supporting highly populated communities, the river is prone to pollution and other forms of environmental degradation common in many developing countries. Over the past fifteen years, there has been an increase in human activity, encroachment, sand and stone extraction, agricultural practices, and it is not clear if the quality of the water in this river can meet internationally acceptable standards for domestic and agricultural use.

River water chemical characteristics are important in determining the effects of natural processes and human activities; this enables evaluation of its quality for human consumption and agricultural use. Several ions that are found in irrigation water e.g. sodium (Na^+), magnesium (Mg^+), potassium (K^+), and calcium (Ca^+), when in excess amounts, can become detrimental to soil health when used for agricultural purposes in irrigation and hence reducing crop production (Xu et al., 2019).

Irrigation water quality can be assessed using various water quality indices that include Sodium Adsorption Ratio (SAR), sodium percentage (Na %), Magnesium Hazard (MH), and Kelly's index (KI). SAR is the ability of water to adsorb sodium ions; it is used as an indicator of water quality in agricultural irrigation (<10 (mmoles $l^{-1})^{0.5}$. The smaller the SAR value, the better the water quality. Water quality adversely affects plants and soils. Irrigation water with a high sodium concentration affects the soil structure, permeability, and infiltration rate. Accumulation of salts in the root zone is an indicator of sodium hazard and increased soil salinity (Wantasen et al., 2021). Na% is also an indicator of sodium hazard. A high Na% in soil has negative impacts on soil structure, aeration, and infiltration (Singaraja *et al*., 2014). MH indicates the degree of damage to soil structure caused by magnesium in irrigation water. A high level of magnesium ions in irrigation water leads to alkalinity and reduced infiltration capacity (Ravikumar *et al*., 2011).

Water chemical parameters can also be used to assess the quality of water through the Water Quality Index (WQI). WQI is one of the most effective methods of measuring water quality. The WQI gives water values that can be used to monitor and ensure that water consumed is safe for humans. The parameters assessed are included in a mathematical equation to rate water quality and determine the suitability of the water for drinking (Ochuko *et al.*, 2014).

This study, therefore, used standard irrigation and water quality assessment parameters to determine the suitability of water in River Mpanga for agricultural and domestic purposes.

Methodology

Study area description

River Mpanga catchment is located in the south-west of Uganda along the border with the Democratic Republic of Congo and is part of Lakes George and Albert basins located within the Nile basin (Fig. 1). It sheds a total surface area of about 4700 km², with its waters flowing over a distance of approximately 250 km through the districts of Kabarole, Kyenjojo, and Kamwenge before discharging into Lake George. River Mpanga's headwaters originate from the slopes of the northern part of the Rwenzori Mountain range (around 1700 m above sea level). The river then flows eastwards, crossing Fort Portal City and several tea estates before entering Kibaale Forest National Park and turning southeast (Amanyire, 2018).

The catchment comprises a variety of climatologically and ecologically different regions, ranging from a year-round wet climate in the source area of the steep Rwenzori mountains (2000-3000 mm annual rainfall), over a wet climate with two short dry

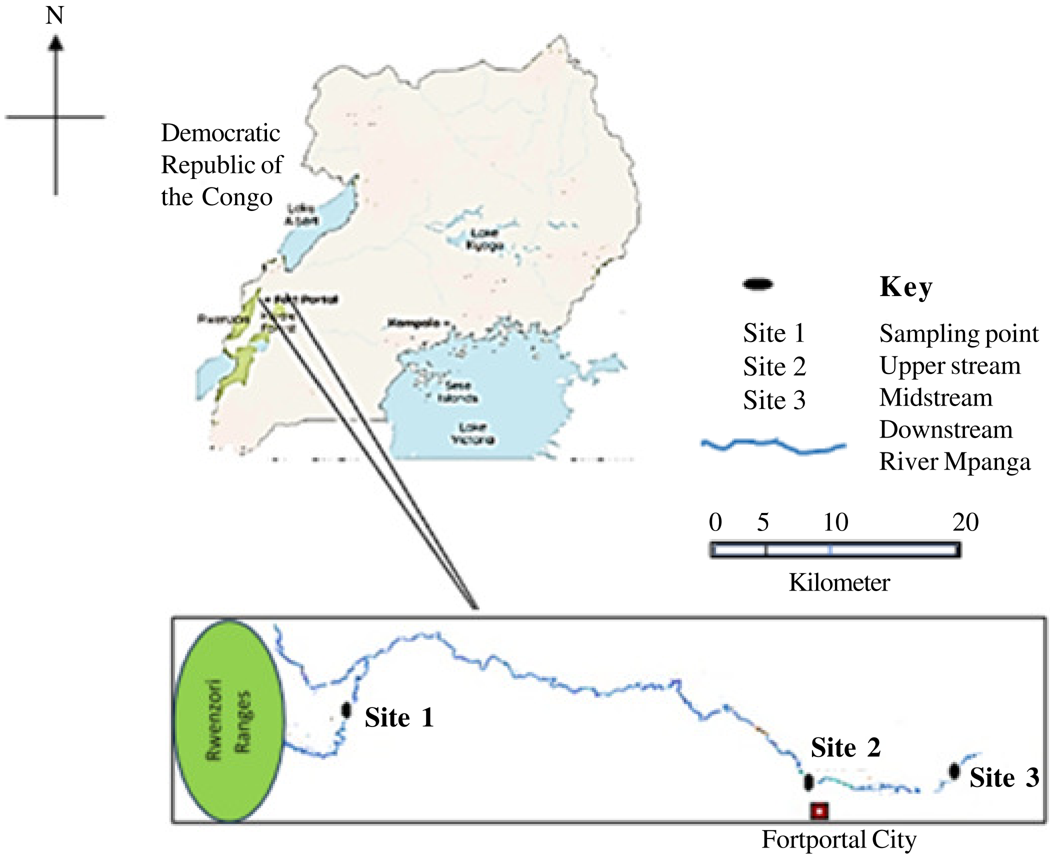

Figure 1. Mpanga Catchment in western Uganda and the extraction sites.

seasons per year (1400 mm annual rainfall) in the mid-range regions of the river system, to the drier downstream region (1000 mm annual rainfall) with pronounced dry and wet seasons. Depending on altitude and season, mean temperatures from source to mouth areas of River Mpanga may vary from below 10 to over 22 °C (Amanyire, 2018).

Mpanga catchment is covered in black loam soil over red sandy clay loam soil and in some parts the red sandy loams are covered by soft laterites. The soils are a result of volcanic and alluvial deposits. The vegetation is mainly savannah grasslands and humid tropical forests such as the Kibale national park. The catchment is neighboured by volcanic crater lakes, and has wetlands (Nyakaisiki *et al.*, 2019).

The main economic activity in the upper stream is subsistence agriculture. The major agricultural crops include; perennial crops (banana and tea) and annual crops (beans, ground nuts, maize, sweet potatoes, millet, cassava, potato and yams). The annual crops are usually intercropped. In the midstream trade is the major activity whereas in the downstream is mainly used for human settlement. (Majaliwa *et al.*, 2015).

Sampling sites, data collection, and analysis

Three sampling sites were purposively selected along River Mpanga in Kabarole District at three points to represent the upper stream, midstream, and downstream. Water samples were collected manually during the wet season from each location, from the surface (0-30 cm) and the bottom floor (60-100 cm) at a one-time point. The samples were collected in 500ml plastic bottles (High-Density Polythene, HDPE) which were previously washed with soap, rinsed and air dried to remove any contaminants. The samples were collected from Bukukuru Village, Nyakitokoli Parish, in Karangura sub-county (upper stream); Mpanga Ward village in Urban Division sub-county (midstream); and Bukwale village in Southern division sub-county (downstream).

The water samples were kept at 24^0C and on the same day taken to the Department of Agricultural Production at Makerere University for laboratory analysis. In the laboratory, the samples were stored at 4-5^{o}C. The samples were then analysed for pH, nitrogen, potassium, phosphorus, sodium, calcium, and magnesium following methods by Okalebo et al. (2002); pH was measured using a pH meter; available Phosphorous by spectrophotometry; Nitrogen by the Kjeldahl method; Potassium and Sodium by flame photometry; Magnesium and Calcium by complex metric titration with a standard EDTA solution using Eriochrome black T as an indicator under buffer conditions of H 10.0.

Water quality assessment was carried out using the Water Quality Index (WQI) using the Weighted Arithmetic Index Method (Brown et al., 1972) for the parameters of pH, N, P, K, Na, Ca, and Mg. The following equations were used:

$$WQI = \frac{\Sigma QnWn}{\Sigma Wn} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 1}$$

$$Qn = \frac{Vn}{Vs} \times 100$$

$$K = \frac{1}{\Sigma Vs}$$

Wn = K / Vs,

Where: Q = quality rating of nth water quality parameter, W = unit weight of nth water quality parameter, K = constant of proportionality, Vn = actual amount of nth parameter present, Vi = ideal value of the parameter (Vi = 0 except for pH where Vi = 7) and Vs = standard permissible value for the nth water quality parameter.

The calculated WQI values are classified within a pre-determined range where under 50 represents excellent water quality of grade 1, WQI range 51 – 100 expresses good water quality of grade 2, WQI range 101 - 200 denotes poor water quality of grade 3, WQI range 201 - 300 indicates very poor water quality of grade 4 and a WQI range above 300 refers to very bad water quality of grade 5 (Howladar *et al.*, 2021).

The suitability of the water for agricultural production irrigation purposes was assessed using the following indices i.e. Sodium Adsorption Ratio (SAR), sodium percentage (Na %), Magnesium Hazard (MH), and Kelly's index (KI).
The Sodium Adsorption Ratio was calculated using the equation below:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Mg^{2+} + Ca^{2+}}{2}}} \quad \text{Equation 2}$$

Where: Na^+ are the sodium ions, Mg^{2+} are the magnesium ions and Ca^{2+} are the calcium ions that were analysed from the water samples.

Based on SAR values, water is classified into four classes: SAR < 10 is considered excellent (sodium hazard class S-I), SAR = 10 – 18 is considered as good (class S-II), SAR = 19 – 26 is considered doubtful, fair, or poor (class S-III) AND SAR > 26 is considered unsuitable (class S-IV) (Wantasen *et al.*, 2021).

Sodium percentage (Na %)
The percentage of sodium is widely used to determine the suitability of water for agricultural production purposes. This term is also referred to as the Soluble Sodium Percent (SSP) (Wilcox, 1955). The sodium percentage was calculated using the equation below:

$$Na\% = \frac{Na^{2+}}{(Ca^{2+} + Mg^{2+} + Na^{+} + K^{+})} \times 100 \quad \text{Equation 3}$$

Where: Na^+ are the sodium ions, Mg^{2+} are the magnesium ions, K^+ are the potassium ions andCa^{2+} are the calcium ions that were analysed from the water samples.

All concentrations are expressed in meq/l. Based on sodium percent, water is classified as safe or unsafe. Na% > 60 is considered unsafe and Na% < 60 is considered safe for agricultural production activities (Ravikumar *et al*., 2011).

Magnesium Hazard (MH)

The adverse effect of magnesium in agricultural production irrigated water is measured as the magnesium ratio. The formula used to calculate the index of the magnesium hazard is shown below:

$$MH = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100 \quad \text{..... Equation 4}$$

Where: Mg^{2+} are the magnesium ions and Ca^{2+} are the calcium ions that were analysed from the water samples (Ravikumar et al., 2011).

Kelly's Index (KI)

Kelly's index indicates an excess quantity of sodium in water. It is calculated using the formula below:

$$KI = \frac{Na^{+}}{Ca^{2+} + Mg^{2+}} \quad \text{..... Equation 5}$$

Where: Mg^{2+} are the magnesium ions and Ca^{2+} are the calcium ions that were analysed from the water samples.

Water with Kelly's index value less than one i.e. KI < 1, is acceptable for agricultural irrigation, whereas values greater than one i.e. KI > 1, indicate excess sodium in water, and values less than two i.e. KI < 2 indicate sodium deficiency in water (Sundaray *et al*., 2009).

To determine the whether there were differences between sites, Analysis of Variance (ANOVA) was used. Descriptive statistical analysis was also performed using MS Excel and R-Statistical programming 4.2.2.

Results

Chemical properties

The results indicated that the pH values of the water in river Mpanga ranged from 6.88 to 7.1 (Table 1). The average value of pH was 6.99 ± 0.09. The available phosphorus values of the water in river Mpanga ranged from 0.09 to 4.78 with an

Table 1. Chemical properties of water in River Mpanga

Samples	pH	N(mg/l)	Av. P(mg/l)	K (mg/l)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)
Upper stream surface	7.1	0.42	0.4774	5.5	12.9	5	2.54
Upper stream bottom	7.08	0.21	0.3542	6	13	4.5	2.65
Midstream surface	6.91	0.19	0.0924	4.9	11.2	26.5	8.77
Midstream bottom	6.96	0.23	0.1694	4.8	11.2	26	8.94
Downstream surface	6.88	0.22	0.1694	5.1	11.2	25.5	7.99
Downstream bottom	6.99	0.34	0.1617	10.3	11.3	26.5	8.87
Maximum	7.1	0.42	0.4774	10.3	13	26.5	8.94
Minimum	6.88	0.19	0.0924	4.8	11.2	4.5	2.54
Mean	6.99	0.27	0.24	6.1	11.8	19	6.63
St. dev	0.09	0.09	0.1465	1.9	0.81	10.1	3.14
Lsd	0.20^{ns}	0.41^{ns}	0.24*	8.91^{ns}	0.24***	2.08***	1.54***
c.v (%)	0.715	37.29	25.00	34.96	0.489	2.63	5.56
WHO standard	8	-	-	12	-	255	50
EPA	-	10	0.05	-	45	-	-

Where, *** P<0.001, *P<0.05, and ns is not significant average of 0.24 ± 0.15 mg/l. The highest level of phosphate ions was in the upper stream surface water and the lowest was in the midstream surface water (Table 1). The total nitrogen values of the water in river Mpanga ranged from 0.19 to 0.42 with an average of 0.27 ± 0.09 mg/l. The highest amount of nitrogen was in the upper stream surface water and the lowest was in the midstream surface water (Table 1). The potassium ion (K^+) values of the water in river Mpanga ranged from 4.8 to 10.3, with an average of 6.1 ± 1.90 mg/l. The highest amount of potassium ions was in the downhill bottom water and the lowest was in the midstream bottom water (Table 1). The magnesium ion (Mg^{2+}) values of the water in river Mpanga ranged from 2.54 to 8.94 with an average of 6.63 ± 3.14 mg/l. The highest amount of magnesium ions was observed in the midstream bottom water and the lowest in the upper stream surface water (Table 1). The calcium ion (Ca^+) values of the water in river Mpanga ranged from 4.5 to 26.5 with an average of 19 ± 10.10 mg/l. The highest amount of calcium ions was in the midstream surface and downhill bottom water and the lowest was in the upper stream bottom water (Table 1). The sodium ion (Na^+) values of the water in river Mpanga ranged from 11.2 to 13 with an average of 11.8 ± 0.81mg/l. The highest amount of sodium ions was in the upper stream water and the lowest was in the midstream water (Table 1).

Water quality properties

Table 2. Classification of water in River Mpanga based on the Water Quality Index (WQI)

Samples	WQI	Remarks	Class
Upper stream surface	938.478	Very bad water quality, proper treatment required before domestic use	5
Upper stream bottom	696.364	Very bad water quality, proper treatment required before domestic use	5
Midstream surface	181.86	Poor water quality	3
Midstream bottom	333.146	Very bad water quality, proper treatment required before domestic use	5
Downhill surface	333.203	Very bad water quality, proper treatment required before domestic use	5
Downhill bottom	318.189	Very bad water quality, proper treatment required before domestic use	5
Average	466.873	Very bad water quality, proper treatment required before domestic use	5
St. dev	287.81		

The WQI ranged from 181.86 - 938.48 and had an average of 466.8 ± 287.81 (Table 2). Any water with a value over 100 is unsuitable for domestic use. The highest value of water quality index was in the upper stream surface water and the lowest was in the midstream surface water. Generally, the water in River Mpanga is of very bad quality and proper treatment is required before human consumption (Table 2). The water quality index was determined using parameters of pH, N, P, K, Na, Ca, and Mg. The higher the value of the WQI, the poorer the water quality, and the lower the value of the WQI, the better the water quality.

Irrigation quality parameters

The SAR values of water in River Mpanga range from 2.67 – 6.88 with an average of 4.05 ± 2.10 (Table 3). The water in the midstream had the lowest SAR whereas the water in the upper stream had the highest SAR. SAR decreased from the upper streams downhill. The Na% values of water in River Mpanga range from 19.8 to 49.7 and an average of 30.9 ± 14.58 (Table 3). It was also observed that the water in the downhill bottom has the lowest Na% whereas the water in the upper stream has the highest Na%. River Mpanga water samples have values of Na% that are below 60% (Table 4), it was also observed that the water in the upper stream has the highest Na% compared to the rest of the river water along the course. The MH values of water in River Mpanga range from 23.9 to 37.1 with an average of 28.2 ± 5.57 (Table 3). It was also noted that the water in the downhill surface had the lowest MH whereas the water in the upper stream had the highest MH. The KI values of water in River Mpanga range from 0.32 to 1.82 with an average of 0.80 ± 0.75. It was also observed that the water in the midstream surface has the lowest KI, whereas the water in the upper stream has the highest KI (Table 3). All water samples, except those from the upper stream, had KI values below 1.

Table 3. Irrigation quality indices of River Mpanga water

Site	SAR	Na (%)	MH (%)	KI
Upper stream surface	6.64	49.7	33.7	1.72
Upper stream bottom	6.88	49.7	37.1	1.82
Midstream surface	2.67	21.8	24.9	0.32
Midstream bottom	2.68	22.0	25.6	0.32
Downhill surface	2.74	22.5	23.9	0.33
Downhill bottom	2.69	19.8	25.1	0.32
Average	4.05	30.9	28.2	0.80
St. dev	2.100	14.58	5.57	0.75
Permissible Limit	<10	<60	<50	<1

Discussion

The water of river Mpanga generally had a greater pH and nutrient concentration (available P, total N, K and Na) upstream than midstream and downstream except for Ca and Mg. This may be due to agricultural activities uphill such as production of bananas, coffee, cassava, onions, and livestock that cause organic matter decomposition, soil erosion, and sedimentation, which increase nutrient loads in the water. This is in line with the findings of Pearce and Yates (2020). The absence of buffer zones also increases the nutrient loads in the river water as discovered by Huang et al. (2020). Also, the general reduction of the water nutrient loads downstream may be due to the natural dilution effect with mixing of water sources that lowers the nutrient content.

The water in River Mpanga has a pH range of 6.88 - 7.1. The recommended pH range required for agricultural irrigation water is 6.5–8.4 (Ayers and Westcot, 1994) and for domestic and other purposes is 6.5–8.5. The pH values at all the river sites, Upstream to Downstream, all lie within the desirable limits for agricultural irrigation and domestic purposes. The water pH values for River Mpanga are also within the accepted limits (6.5-9.2) by WHO (2017).

Total nitrogen ranged from 0.19 to 0.42. The standard permissible limit of total nitrogen in water is 10 mg/l (EPA, 2022). Thus, the total nitrogen was below the permissible limit and can be considered safe. Concentrations of total nitrogen upstream were higher than in the other places. This could be due to N loading from the intensive agricultural land uses in the Rwenzori foothills. The nitrogen may have come from surface runoff that brought in fast-decomposing organic matter from cultivated areas as well as the animal manure from livestock units in the area which are deposited into the water. The reduction in nitrogen concentration downstream may be due to the minimum agricultural activities taking place in these areas.

The standard permissible limit of available phosphorous in water is 0.05 mg/l (EPA, 2022). I was observed that available phosphorous in the water of River Mpanga was above the permissible limit and therefore caution for treatment and prevention of water contamination should be observed. The main supply of phosphate ions in natural waters is the weathering of phosphorus-bearing rocks, run off and leaching of soils in the catchment area (Moss, 2009).

The average potassium ions were below the WHO permissible limit of 12 mg/l and therefore can be considered safe with respect to potassium ion concentration (WHO, 2017). The relatively high K ion concentrations downstream may be due to the presence of several car and motorcycle washing bays where wash water directly drains into the river flow. Car washing agents such as liquid soap and bar soap have been shown to contain K^+. This should raise concerns since recent studies have documented problems with water inûltration caused by high levels of K^+ in applied waters from irrigation (Marchuk and Rengasamy, 2012). Increased K levels have also been shown to reduce the soils' hydraulic conductivity (Smith *et al.*, 2015). For domestic usage, the sodium ions levels in Mpanga river water had an upper level of 13 mg/L, which is far below the 45 mg/l standard permissible limit for sodium ions in water (EPA, 2022). Therefore, it is considered safe for domestic usage.

The magnesium ions levels in this study (<9mg/L) were below the permissible limit and can be considered safe for domestic and agricultural usage. The standard permissible limit of magnesium ions in water is 50 mg/l (WHO, 2017). This was also true for calcium ions in water (upper limit is 255 mg/l; WHO, 2017).

Though the individual chemical parameters were mainly within permissible levels, collectively, when the WQI was computed, the results showed that quality of water in River Mpanga is generally bad (class 5) for domestic use and needs treatment to bring it to standard. The high WQI values may be due to uncontrolled erosion deposits from poor soil and water conservation measures from the surrounding farmlands. In order to revert this, farmers can practice mulching, minimum or zero tillage, agroforestry, and cover cropping. Proper management of agricultural activities, establishing riparian buffer zones along the river banks plus regular monitoring and assessment can be done to check the WQI. Upstream has the highest WQI levels, probably due to the higher number of economic activities here including market trades and yearlong cropping due to favorable precipitation year-round. This raises concerns of potential toxicity hazards from consuming the water.

Irrigation water quality should be continuously monitored for sustainable development in agricultural areas. This study used the KI, SAR, Na%, and MH to evaluate the river water's suitability for irrigation. The results showed that the water from River Mpanga is in class I for the sodium adsorption ratio since its values are less than 10, and also within limits as far as Na^+, MH are concerned. Therefore, the water from River Mpanga can be effective for use in irrigation since the soil structure, permeability, and infiltration rate of the soils will not be damaged because of the low sodium adsorption ratio. Hence, it is considered good for agricultural irrigation (Wantasen et al., 2021). With the exception of the upstream samples, mid and downstream samples had KI values below 1; an indication that the water in these sectors is suitable for irrigation (Sundaray et al., 2009). Based on the KI parameter, water in the upstream sectors is not considered suitable for irrigation.

Conclusion

The individual chemical parameters of pH, N, K, Na, Ca, and Mg of the water in River Mpanga are below the maximum permissible limits of WHO and EPA, with the exception of P, which was above the permissible limits. The high WQI observed in this study indicates that the water in River Mpanga is not suitable for domestic usage. With the exception of KI (>1) for uppperstream, all the irrigation water quality parameters (SAR, Na^+, MH, and KI) returned values within the acceptable limits for water quality for agricultural use. Efforts should be initiated to stop/prevent soil runoff into the river especially in upstream areas.

Recommendations

A water quality monitoring program should be established to track changes over time, identify areas of concern and guide decision making. Public awareness and education of masses should be instituted in the Mpanga catchment about the impacts of pollution on water quality and the importance of sustainable agricultural practices. Farmers can engage in sustainable agricultural practices like cover cropping, mulching and agroforestry to reduce soil erosion, sedimentation and improve soil health, ultimately reducing the amount of nutrients and contaminants entering water bodies.

Acknowledgement

This research was funded by the Government of Uganda through Makerere University Research and Innovation Fund, round 3 (RIF 3). Many thanks to Kabarole District Local Government, the local leaders, research and field assistants.

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