Scholars Academic Journal of Biosciences
Abbreviated Key Title: Sch Acad J Biosci
ISSN 2347-9515 (Print) | ISSN 2321-6883 (Online)
Journal homepage: https://saspublishers.com

OPEN ACCESS

Biology

Spatial Characterization of Water Quality in the Kamagema River, a Tributary of the Ruzizi River, DR Congo

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DOI: https://doi.org/10.36347/sajb.2025.v13i01.002 | **Received:** 13.11.2024 | **Accepted:** 17.12.2024 | **Published:** 03.01.2025

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Abstract **Original Research Article**

This study evaluates the physicochemical state of the Kamagema River and the impact of human activities in its surrounding areas. Seasonal water samples were collected from three sites, selected based on local population activities. Physicochemical parameters were analyzed using standard methods, and the river's organic load was assessed through the Organic Pollution Index (OPI) by Leclercq and Marquet and the Interuniversity Laboratory for Education and Communication in Science (LISEC) index. The findings revealed spatial and seasonal variations in the physicochemical properties and pollution levels of the Kamagema River, with higher pollution levels observed during the rainy season ($F=46.34$; $p<0.05$). The pollution sources include domestic waste and effluents from the Hospital of Panzi located at Site 2. Principal Component Analysis (PCA) of the physicochemical parameters indicated significant differences among the three sites. The upstream site had the lowest sulfate concentrations, the middle site (Site 2) was characterized by moderate levels of alkalinity, phosphate, ammonium, and total phosphorus, while the downstream site showed higher levels of total hardness and magnesium hardness. The OPI values (3.1–3.4) indicated moderate organic pollution along the river, while the LISEC index (~10.5) showed moderate pollution at Sites 1 and 3 and heavy pollution at Site 2. The study recommends effective waste management along the Kamagema River to preserve its ecosystem.

Keywords: Pollution, physicochemical, index, OPI, LISEC, Kamagema river.

INTRODUCTION

Freshwater ecosystems, critical for sustaining life (Simpi *et al*., 2011), face escalating threats from various pollution sources, jeopardizing their ecological, economic, and health-related functions. Key contributors to water pollution include industrial discharges, agricultural runoff, and domestic wastewater. Over the past century, human activities have become the primary drivers of freshwater degradation, rendering these ecosystems among the most impacted by anthropogenic pressures (Dudgeon *et al*., 2006; Buhungu *et al*., 2018).

Urbanization and population growth exacerbate these disturbances, with inadequate management of domestic and agricultural waste significantly impacting river quality (Karikari *et al*., 2007). Such activities introduce pollutants that compromise water quality, making it unsuitable for various uses and threatening aquatic biodiversity (Dèdjiho *et al*., 2013). The physical and chemical properties of water play a pivotal role in its suitability for life and its productivity as an aquatic habitat (Courtney and Clements, 1998). Protecting water from biodegradable contaminants, biological pollutants, non-biodegradable waste, and toxic inorganic substances is essential for maintaining ecosystem health.

In developing countries, water quality degradation often stems from poor waste management and inadequate environmental sanitation. In South Kivu, environmental management is particularly weak, with rivers frequently used as dumping grounds for domestic and industrial waste. These rivers often receive untreated waste, animal droppings, and latrine discharges, exacerbating pollution levels (Kiossa, 2011; Bagalwa *et al*., 2013).

Physicochemical characterization of water bodies is crucial for identifying the mineral and chemical constituents contributing to ecosystem degradation (Mama *et al*., 2011). While some of these elements occur naturally, human activities such as wastewater discharge, industrial effluents, and agricultural practices often introduce harmful substances, including heavy metals and pesticides (Koudenoukpo *et al*., 2017).

The Kamagema River, flowing through the Panzi district in Bukavu, eastern DR Congo, and joining the Ruzizi River—a tributary of Lake Tanganyika—is significantly polluted by domestic runoff, hospital effluents, and other anthropogenic factors. Despite its importance, few studies have been conducted to evaluate the pollution levels in this river. This study aims to assess the physicochemical parameters of the Kamagema River, determine its water quality, and quantify pollution levels using the Organic Pollution Index (OPI) and the Interuniversity Laboratory for Education and Communication in Science (LISEC) index. These findings are intended to guide decision-makers and support environmental preservation while improving the well-being of the local population.

MATERIALS AND METHODS

Study area and sampling stations

The Kamagema River is about 6.5 km long. It crosses a very populated locality and characterized by a rugged relief on steep slopes. The soil is bare and favorable to erosion. To conduct the study, three sampling stations were chosen according to the diversity of activities carried out along its watercourse (Figure 1).

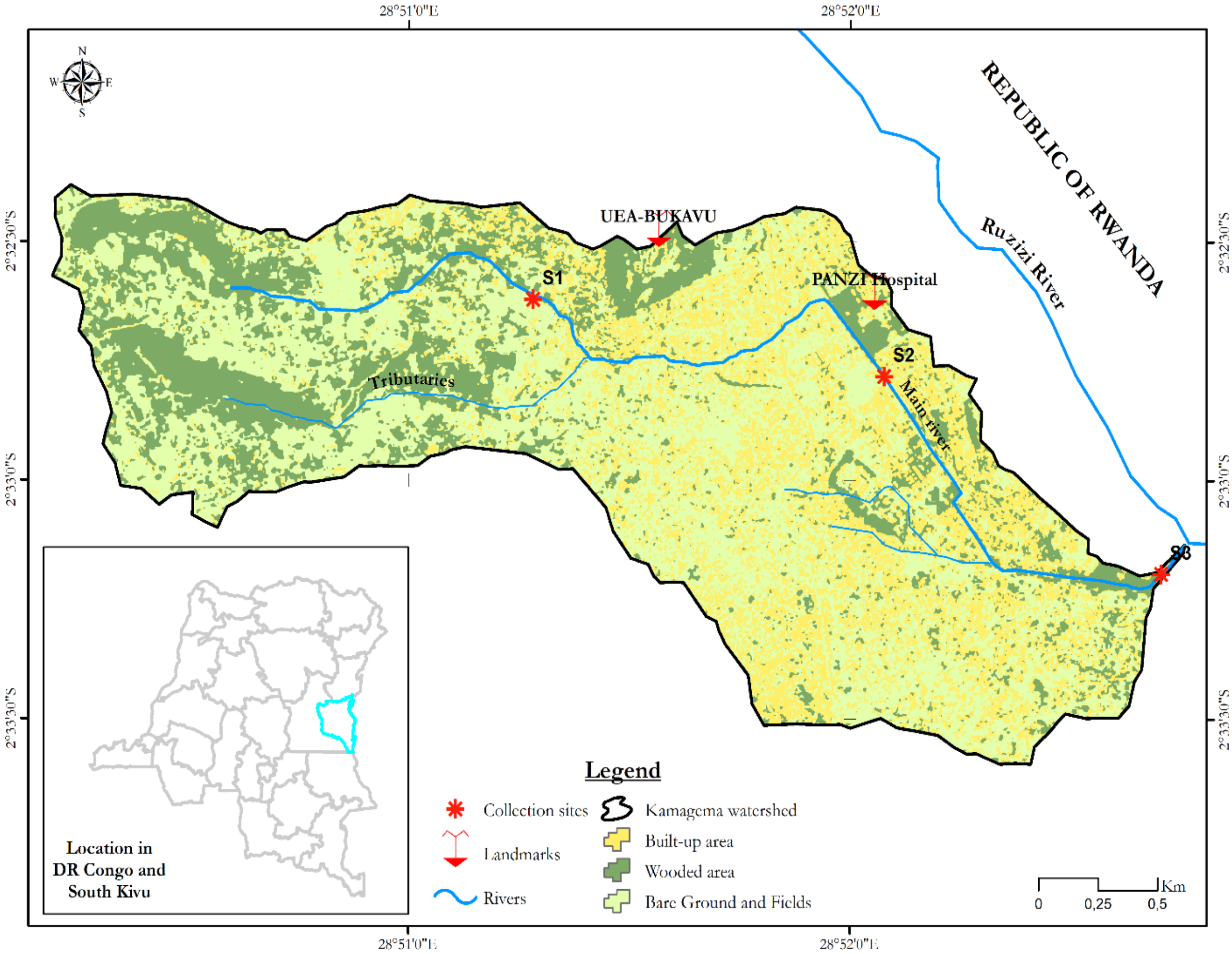

Figure 1: Map of the Kamagema River and location of sampling sites

The first station S1 (2.543667 S, 28.854683 E and an altitude of 1674 m) is located upstream of the Kamagema River. It was chosen in a low-density location to reflect the state of the river at the source, residents use this water for their laundry, swimming and even for cooking food. The second station S2 (2.546350 S, 28.867933 E and an altitude of 1548 m), for its part, is located on the concrete channel that receives water from the Panzi Hospital drainage channel and the discharge of wastewater and household waste from the surrounding population. The third station S3 (2.553240 S, 28.878400 E and an altitude of 1511 m) is located downstream of the river 5 m from the outlet of the Ruzizi River.

Sampling

Water sampling was conducted over four months, encompassing both dry and rainy seasons, with two months sampled during the dry season (July and August 2022) and two months during the rainy season (October and November 2022). At each of the three sampling stations, 500 mL water samples were collected from a depth of 15 cm using polyethylene bottles. These bottles, pre-cleaned and rinsed with deionized water in the laboratory, were also rinsed at the sampling sites with river water before filling. The samples were immediately stored in ice for transport and refrigerated at 4 °C for subsequent analysis of physicochemical parameters that were not measured in situ. Additionally, two separate samples were collected at each station for the analysis of dissolved oxygen and biochemical oxygen demand (BOD_5). Dissolved oxygen samples were fixed in the field using the Winkler method (Golterman *et al*., 1978; APHA, 1981), ensuring accurate preservation for laboratory analysis.

Key physicochemical parameters, including pH, conductivity (µS/cm), and total dissolved solids (TDS, mg/L), were measured in situ using a HANNA multi-parameter device (HI 9811-5). Chemical analyses of water samples were conducted in the laboratory using standardized methods. Chlorides (Cl^-) were measured using silver nitrate with potassium chromate as an indicator, following the Mohr method (Golterman *et al*., 1978). Alkalinity (mg/L) was determined through titration with 0.1N hydrochloric acid and methyl orange as an indicator. Total hardness (mg/L) and calcium hardness (mg/L) were determined by EDTA complexometry, with magnesium hardness calculated as the difference between total and calcium hardness (Benabdellonahad, 2006). Sulfates (SO_4^{2-}) were quantified through barium sulfate precipitation with Eriochrome Black T as an indicator. Nutrients, including total nitrogen (NT), nitrate (NO_3^-), ammonium (NH_4^+), total phosphorus (PT), and orthophosphate (PO_4^{3-}), were analyzed using a spectrophotometer (Wetzel and Liken, 2000), with results expressed in µmol/L.

All laboratory analyses were carried out at the Natural Sciences Research Center of Lwiro, with results expressed in mg/L and compared against water quality standards. The Organic Pollution Index (OPI) was calculated according to Leclercq and Marquet's method to evaluate the organic load, while the LISEC index was used to assess the level of pollution. These indices provided comprehensive insights into the degree of water quality degradation.

Statistical Analysis

The Kruskal-Wallis ANOVA test was used to compare the means of the different physicochemical parameters between stations and between seasons using PAST 3 software. In order to establish a relationship between the physicochemical parameters of the different stations, and to better assess the effect of anthropogenic activities on the water quality of the Kamagema River, a Principal Component Analysis (PCA) was applied to all the parameters in order to group the polluted and unpolluted stations. This analysis was done with the same software.

The Organic Pollution Index (OPI) of Leclercq (2001) and the Interuniversity Laboratory for Education and Communication in Science (LISEC) were also used to assess the organic load in the river. The OPI classifies water quality into five (05) classes (Table 1).

Table 1: Classes of Organic Pollution Index (OPI) and *from the Interuniversity Laboratory for Education and Communication in Science (LISEC)*

OPI	Class	LISEC
>4.6	Zero pollution	4 – 6
4.6 – 4	Low pollution	6 – 10
4 – 3	Moderate pollution	10 – 14
3 – 2	Heavy pollution	14 – 18
< 2	Very high pollution	18 – 20

The Organic Pollution Index is obtained using the values of ammonium, BOD_5, nitrites and phosphates (Leclercq and Maquet, 1987; Mezbour *et al*., 2018) and the second the Interuniversity Laboratory for Education and Communication in Science (LISEC) is obtained by the percentage of saturation in Oxygen, BOD_5, ammonium and Phosphate (Hachemi and Amarchi, 2012). The principle of the calculation is to divide the values of the four polluting elements into five classes and to determine, from the values obtained in the study, the corresponding class number for each parameter using the average data in Table 1. The final index is the average of the pollution classes for all the parameters.

RESULTS

Seasonal variation of physicochemical parameters of Kamagema River waters

Table 2 presents the spatial and seasonal variations of the mean values of the physicochemical parameters of the waters of the Kamagema River (Table 2).

Table 2: Spatial and seasonal variation of physicochemical parameters of the waters of the Kamagema River

	Site 1		Site 2		Site 3	
	Dry season	**Rainy season**	**Dry season**	**Rainy season**	**Dry season**	**Rainy season**
pH	6.75±0.4	5.7±0.6	6.9±0.5	6.2±0.1	7.8±0.1	6.8±0.1
EC	270±198	320±127.3	545±7.1	660±28.3	470±183.8	405±63.6
TDS	120±84.9	150±56.6	255±7.1	320±14.1	215±77.8	195±35.4
O2	6±5.1	6±5.1	3.6±4.5	8.8±0.6	3.5±2.1	4±1.4
DBO5	4.2±1.1	6.6±2.8	0.8±1.1	0.8±1.1	5.8±6.5	5.7±1
DCO	30.2±25.2	15.4±16.1	17±12.7	27.4±15.6	23.4±23.5	52.8±21.5

	Site 1		Site 2		Site 3	
	Dry season	**Rainy season**	**Dry season**	**Rainy season**	**Dry season**	**Rainy season**
DT	57±49.5	26.5±2.1	72±9.9	45±15.6	44±11.3	40±4.2
Dca	8.5±3.5	10.5±3.5	24±8.5	25.5±0.7	20.5±19.1	23±1.4
DMg	48.5±53	16±5.7	48±16.4	19.5±14.8	23.5±7.8	17±5.7
Ca2+	0.3±0.1	0.4±0.2	1.0±0.4	1±0.03	0.9±0.8	0.9±0
Mg2+	1.2±1.3	0.4±0.1	1.2±0.5	0.5±0.4	0.6±0.2	0.4±0.1
Cl-	29.2±5	6.4±6.1	54±14.1	22.8±25	33.8±9.5	11.1±12.5
SO42-	112.5±10.6	104.4±5.8	129±4.2	118.7±10.8	130.5±4.9	104±21.2
Alkali	21±5.7	25.5±20.5	51±18.4	91.5±40.3	35±7.1	37.5±17.7
PT	10.6±11.1	14.7±3.3	41±39.4	35.1±16.4	16.3±5.2	17.7±5.9
PO43-	2.7±1.3	8.4±2.6	9.8±0.1	26.6±6.5	4.6±1.7	9.5±4.7
AT	8.4±3.5	11.1±10.1	15.2±5.9	11.5±4.8	6.3±6.5	6.6±4.4
NH4-	2.9±3.5	9.3±8.5	10.8±5	9.6±1.3	5.4±5.3	7.2±0.2
NO3-	4. ±0.3	7.1±4.3	6.4±1.9	7.1±2.5	4.9±5.9	6.6±2

The mean values of the different physicochemical parameters measured at the 3 sites on the Kamagema River are presented in Table 2. For pH, the highest value was observed at site S3, while the lowest was observed at site S1. Site 1 located upstream was generally characterized by the highest dissolved oxygen contents. Site 2 which is located in the middle recorded the lowest average dissolved oxygen. The highest electrical conductivity value was observed at site S2 while the lowest corresponds to site S1. For total dissolved solids (TDS), the lowest average was recorded at site S1, the highest at station S2. It was noted that total dissolved solids and electrical conductivity evolved in the same direction.

As for phosphates, the minimum average value was noted at site S1 while the highest average was recorded at site S2. The minimum and maximum averages of total phosphorus were recorded at site S1 and site S2 respectively. It was noted that phosphates and total phosphorus evolved in the same direction. Similarly, the highest concentration of ammonium and nitrate was noted at site S2 and the lowest at site S3. But a difference was observed for total nitrogen where the maximum average was found at site S2 and the minimum value at site S1.

The lowest mean values of total alkalinity were recorded at site S1 and the highest at site S2. The lowest mean value of total hardness was noted at site S1 and the highest at site S2. COD has the maximum mean value at site 1 and the minimum value at site 2. And BOD_5, the mean values were low at site S2 and high at site S3. Calcium and chloride have high means at site S2 and minimum at site S1. These two parameters evolved in the same direction. But on the other hand, magnesium has similar maximum values at sites S1 and S2 and minimum values at site S3.

As for seasonal variation, the physicochemical parameters of the Kamagema River waters vary from one site to another and according to the seasons ($F = 46.34$; $p < 0.05$). Some parameters increased significantly during the rainy season compared to others. Table 3 shows the correlation coefficients between the different parameters measured (Table 3).

Table 3: Pearson correlation matrix of physicochemical parameters of Kamagema River waters

	pH	**EC**	**TDS**	**O2**	**DBO5**	**DCO**	**DT**	**Dca**	**DMg**	**That**	**Mg**	**Cl**	**SO4**	**Alkali**	**PT**	**PO4**	**AT**	**NH4**	**NO3**
pH		0.86^{c}	0.86^{c}	-0.96^{c}	0.79^{c}	0.19	-0.84^{c}	0.62^{b}	-0.23	0.60^{a}	-0.17	-0.97^{c}	0.78^{c}	0.99^{c}	-0.94^{c}	-0.91^{c}	-0.51^{a}	-0.86^{c}	-0.84^{c}
EC			0.00	-0.10	-0.35	-0.95^{c}	0.30	0.24	0.91^{c}	0.26	0.97^{c}	0.17	0.08	0.14	0.20	0.24	0.63^{b}	0.28	0.31
TDS				-0.10	-0.35	-0.95^{c}	0.30	0.24	0.91^{c}	0.26	0.97^{c}	0.17	0.08	0.13	0.20	0.23	0.63^{b}	0.28	0.30
O2					0.25	0.85^{c}	-0.20	0.34	0.81^{c}	0.36	0.87^{c}	0.07	0.18	0.04	0.10	0.14	0.53	0.18	0.21

	DBO5	DCO	DT	Dca	DMg	That	Mg	Cl	SO4	Alkali	PT	PO4	AT	NH4
pH														
EC														
TDS														
O2														
DBO5														
DCO	0.60^{a}													
DT	-0.05	-0.65^{b}												
Dca	-0.59^{a}	0.81^{c}	0.54^{a}											
DMg	-0.56^{a}	-0.04	0.61^{b}	-0.85^{c}										
That	-0.61^{b}	0.79^{c}	0.56^{a}	0.02	-0.83^{c}									
Mg	-0.62^{b}	-0.02	0.67^{b}	-0.79^{c}	0.06	-0.77^{c}								
Cl	-0.18	-0.78^{c}	0.13	0.41	0.74^{c}	0.43	0.80^{c}							
SO4	-0.43	0.97^{c}	0.38	0.16	0.99^{c}	0.18	-0.95^{c}	0.25						
Alkali	-0.21	-0.81^{c}	0.16	0.38	0.77^{c}	0.40	0.84^{c}	0.03	0.22					
PT	-0.15	-0.75^{c}	0.10	0.45	0.71^{c}	0.46	0.77^{c}	0.03	0.28	0.07				
PO4	-0.11	-0.71^{c}	0.06	0.48	0.67^{b}	0.50^{a}	0.74^{c}	0.07	0.32	0.10	0.03			
AT	-0.28	-0.32	0.33	0.87^{c}	0.28	0.89^{c}	0.34	0.46	0.71^{c}	0.49	0.43	0.39		
NH4	-0.07	-0.67^{b}	0.02	0.52^{a}	0.63^{b}	0.54^{a}	0.69^{b}	0.11	0.36	0.14	0.08	0.04	0.35	
NO3	-0.05	-0.65^{b}	0.01	0.55^{a}	0.60^{a}	0.57^{a}	0.67^{b}	0.14	0.39	0.17	0.10	0.07	0.32	0.03

Legend: a= simple correlation (50-60%); b= moderate correlation (61-70%); c= strong correlation (71-99%)

It is noted that some parameters are positively or negatively correlated with others in this river. The parameter such as the pH of the waters are strongly positively correlated with TDS, conductivity, alkalimetry, BOD_5 and sulfate on the one hand and negatively correlated with oxygen, total hardness, chloride, total phosphorus, phosphate, nitrate and ammonium on the other hand. A strong correlation of conductivity and TDS with magnesium hardness and magnesium and a strong negative correlation with DCO. There is also a strong positive correlation between oxygen and DCO contents, magnesium hardness and magnesium. A strong positive correlation of DCO with calcium hardness, calcium and sulfate and a strong negative correlation with chloride, alkalinity, total phosphorus and phosphate. We also observe a highly positive correction of calcium hardness and calcium with total nitrogen and a highly negative correlation with magnesium hardness and magnesium on the one hand and magnesium on the other hand. A highly positive correlation of magnesium with chloride, alkalinity, total phosphorus, and phosphate on the one hand and a highly negative correlation with sulfate. Finally, a strong positive correlation is observed between sulfate and total nitrogen.

The PCA (Figure 2), shows that there are 3 clusters of parameter groupings. Each sampling site is grouped according to its parameters that characterize it. Site 1 is characterized by sulfate, Site 2 is characterized by alkalinity, phosphate and ammonium and Site 3 by magnesium hardness and total hardness.

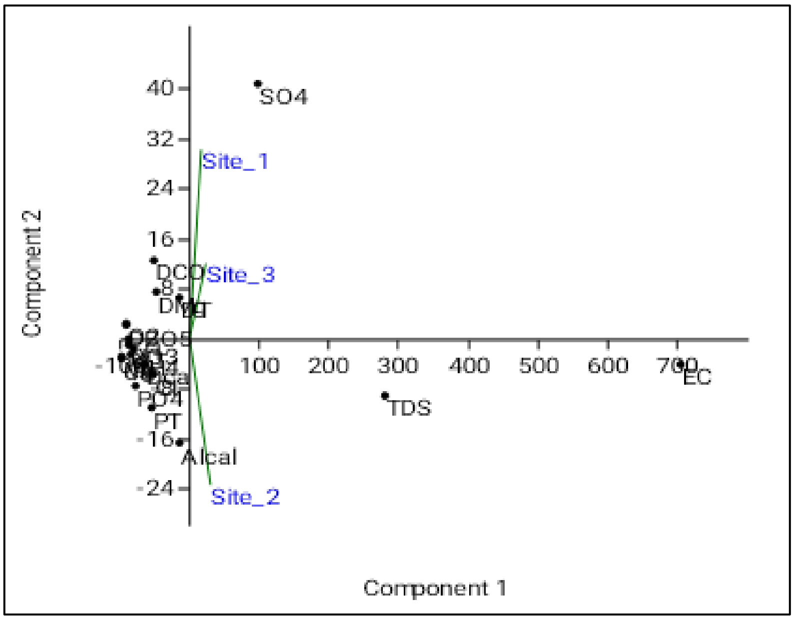

Figure 2: PCA of physicochemical parameters of the Kamagema River

Spatio-temporal variability of water pollution of the Kamagema River by OPI and LISEC index

The calculated values of the OPI showed that the waters of the Kamagema River belong to two classes of pollution. These are strong organic pollution and very strong organic pollution (Table 3).

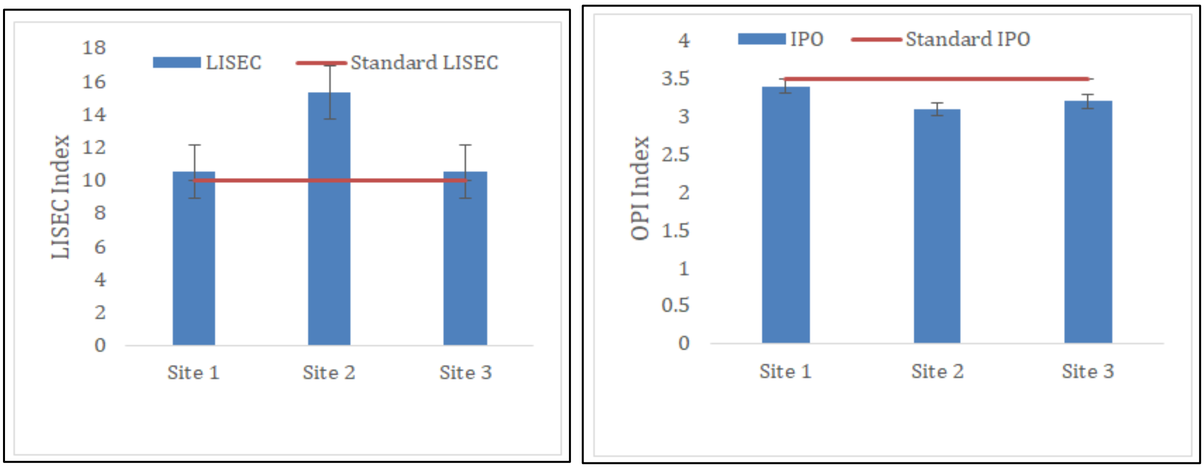

Figure 3: Spatial variation of OPI and LISEC index of Kamagema River waters

The analysis of Table 3 showed that the OPI varied according to the sites. Thus, the OPI also categorized the stations into two groups as shown by the PCA. Group 1 is formed by the sites (S1, S3) whose index varied between 3.1-3.4 which shows that the pollution is moderate. As for the LISEC index, it shows a variation of 10.5 and 15.3. The pollution is classified into the groups of moderate and heavy pollution.

Seasonal variations of the index show fluctuations across seasons (Figure 4).

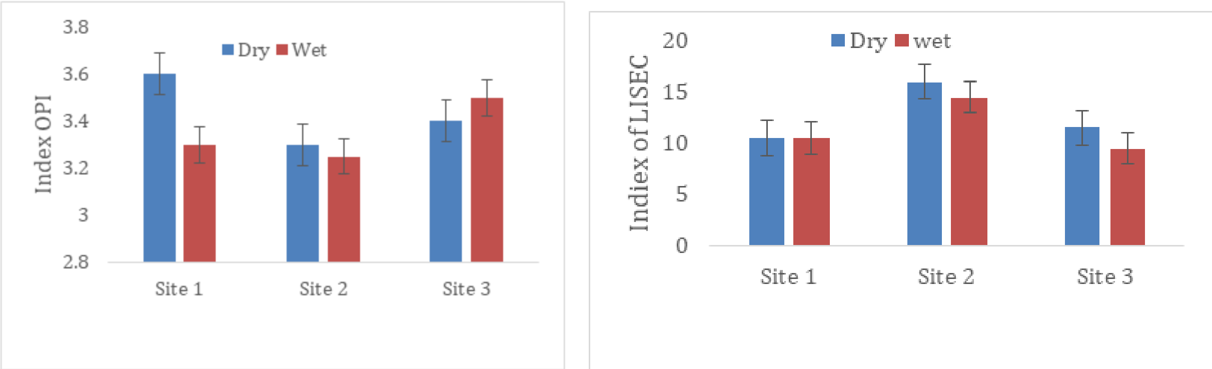

Figure 4: Seasonal variations of OPI and LISEC index in the waters of the Kamagema River

DISCUSSION

The physicochemical parameters of the Kamagema River were used to assess water quality and their spatio-temporal variation using the OPI and LISEC index. These measurements are useful tools for testing water quality (Omer, 2019). The pH and its variations in different sites are due to certain factors that influence the pH level of water, including the water source such as bedrock, sewage drainage, acid rain, water use, and the level of carbon dioxide in the water and atmosphere. The pH has values in the range of 6.2 and 7.3. These same results were found by Onana (2014) in the Mboppi and Simbi rivers in Cameroon. These values close to neutrality are characteristic of the majority of surface waters. These same values were found by Ahouanssou (2011) on the Pendjari River.

Indeed, the presence of high alkalinity in the water body means that it can neutralize acid pollution from precipitation or basic inputs from wastewater. Thus, the source of alkalinity comes from rocks and soils, some salts, also some plant activities, and some industrial wastewater discharges (detergents), especially water bodies containing large amounts of calcium carbonate compounds (CaCO3, limestone) are likely to be more alkaline (Addy *et al*., 2004). This is why Site 2 receiving effluent from Panzi Hospital and waste from latrines of nearby houses is high in alkalinity compared to other sites.

Total dissolved solids, abbreviated as TDS, is the term used to define all dissolved matter of inorganic minerals and some organic chemicals present in water. Standard constituents of TDS in water are not less than 250 mg/L. The main components are usually the cations sodium, calcium, magnesium, and potassium and the anions carbonate, hydrogen carbonate, chloride, sulfate, and nitrate (WHO, 2011). Total dissolved solids (TDS) have a positive correlation with the electrical conductivity of water. The higher the TDS of water, the higher the electrical conductivity. TDS is higher at Site 2 than at other sites because of the reasons discussed above. Electrical conductivity refers to the ability of a medium to carry an electrical current, in this case water. Electric current is carried in water by the presence of dissolved minerals such as calcium, chloride, and magnesium. According to Rahmanian *et al*., (2015), the standard electrical conductivity that can be allowed is 300μS/cm and the maximum permitted conductivity is 1000μS/cm. It varies from 295 – 602.5μS/cm averaged in the Kamagema River. The highest conductivity was measured at Site 2. Note that this value is slightly higher than those observed by Bonou and Adisso (2002) and the limit value of 500 µS/cm reported by Belaud (1987). These chemicals released into the environment as a result of natural processes or anthropogenic activities that influence conductivity and TDS can penetrate aquatic ecosystems and become integrated into suspended matter, which represents an enormous danger for aquatic organisms (Noumon *et al*., 2015).

Dissolved oxygen has values varying between 1 and 6 mg/L in the Kamagema River. Indeed, the presence of anthropogenic waste in the river water affects the amount of oxygen produced by the environment. Such water will not allow light to penetrate and will not promote photosynthesis. These values show that Site 2 is less oxygenated, but Site 1 is really within the limit of water quality in good condition from an oxygen point of view. Chouti *et al*., (2010), indicate that the oxygen content gives indications on the health of watercourses. The oxygen values found in this river show that these waters are of poor quality. The oxygen values found are accompanied by an increase in total dissolved solids reflecting more favorable conditions for the degradation of the organic load. Furthermore, the concentration of ammonium ions in these waters varies from 6–10 umol/L compared to the values found in the waters of the Kahuwa River in the same city (Bagalwa *et al*., 2013; Zirirane *et al*., 2014). The distribution of ammonium in an aquatic environment varies according to the level of productivity of the ecosystem and its degree of pollution by the presence of organic matter. Its presence in the river waters would result from the aerobic degradation of organic nitrogen (proteins, amino acids, urea, etc.) which comes largely from the discharge of untreated water. For the Kamagema River, the inhabitants use this river to drain their latrines and it is also a place of discharge of effluents from the Panzi Hospital and the various pirate markets erected along this river. This contributes to the increase in the concentration of these pollutants in Site 2.

Hébert and Légaré (2000) demonstrate that in a well-oxygenated environment, ammonium is quickly used and its concentration is low. The levels found therefore do not present a risk for the Kamagema River because it is not oxygenated.

The nitrate concentrations in the river are between 5.8 and 6.8μmol/L, these high nitrate concentrations are primarily explained by the presence of household and commercial waste of all kinds produced by local residents and the Panzi hospital. These high concentrations can affect the development of aquatic species (Vissin *et al*., 2010). Total nitrogen has values between 6.4 and 13.4μmol/L. The average total phosphorus and phosphate contents are 12.6–38.1 respectivelyμmol/Land 5.5 – 18.2μmol/L. Phosphates result from the degradation of organic phosphate bacteria from wastewater discharge (metabolism, washing powders, food and chemical industries) and the use of fertilizers. The high levels of phosphates and total phosphorus found in this river prove that anthropogenic inputs are the sources and these waters become bad for the biodiversity found there.

The seasonal variation of the Kamagema River shows that it is influenced by the different seasons (rainy and dry) of the year. Indeed, during the long rainy season, the nutrient salt contents, especially nitrogen and phosphorus, become significant. Phosphates, nitrates and ammonium increase during the rainy season because they are drained by runoff water loaded with leaching products from the watersheds and the unblocking of latrines during heavy rains by populations living around the river. This creates organic pollution in the river. These nitrogen and phosphorus elements are major pollutants in the organic pollution of water as several authors point out (Noumon *et al*., 2015; Tchakonté *et al*., 2015; Zinsou *et al*., 2016). They must be closely monitored because they represent major factors in the eutrophication of rivers and bodies of water.

The results of the various index, namely the index of the Interuniversity Laboratory for Education and Communication in Science (LISEC) and the organic pollution index (OPI), applied to the waters of the Kamagema River studied during two seasons of 2022 (June-July and September - October), were compared with each other in order to test the degree of agreement and / or discordance between the different methods. The two index LISEC and OPI show complete agreement between all stations and during the two seasons. The work of Talhaoui *et al*., (2020); El Hmaidi *et al*., (2020) on two other global index of IQE quality and OPI pollution also shows good agreement between these index as also coming from the observed for the LISEC and OPI index on the Kamagema River.

The quality and degree of organic pollution of the river waters remains the same for both index in the 3 sites and during the two seasons. However, the detailed examination of the results shows a small seasonal variation with a difference in pollution. Thus, the average values during the dry season are slightly higher than the values during the rainy season. This seasonal variation has been widely reported in the literature for the IQE and OPI quality index (Taybi *et al*., 2016; Talhaoui *et al*., 2020; El Hmaidi *et al*., 2020; Vital *et al*., 2018; Serge and Ernest, 2020; Miriac *et al*., 2020). But for the LISEC and OPI index, this study also shows this variation despite their concordance.

CONCLUSION

The spatio-temporal study of the water quality of the Kamagema River made it possible to carry out a physicochemical characterization and calculate the pollution index, in particular the OPI and the LISEC index. This characterization shows that the main physical parameters (dissolved oxygen, BOD_5, DCO, Ammonium, phosphate) present values demonstrating contamination by anthropogenic activities likely to increase the degradation of water quality. Monitoring of nutrient concentrations in the river reveals high levels of nitrogen and phosphorus compounds, responsible for water pollution, which is reflected in the calculation of index that show poor water quality.

The water quality of the Kamagema River has deteriorated significantly, limiting the real water potential and leading to significant health and ecological impacts. The effluents from latrines and the Panzi hospital, too often discharged without appropriate treatment into this river, are the main source of the deterioration in the quality of these waters. Monitoring of the LISEC and organic pollution (OPI) index of the water during this study shows that the waters are polluted. Seasonal variation in the physicochemical quality and the LISEC and OPI index is observed in this river.

These results show the urgency of setting up a system that controls and treats wastewater before it is discharged into the Kamagema River as well as management of household waste, latrines and pirate markets around the river. An integrated approach to the management of the river and its watershed should be established for its protection and the living organisms that inhabit it and in its receiving environment which is the Ruzizi River, a tributary of Lake Tanganyika.

ACKNOWLEDGEMENTS

The authors thank the Evangelical University in Africa (UEA), the Natural Sciences Research Center of Lwiro for its financial and logistical support. But also, the Malacology laboratory, Department of Biology for its contribution to the analysis of the samples and to Professor Foma Roland for the remarks and corrections in this manuscript.

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