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Spatial pattern assessment of Lake Kivu basin rivers water quality using National Sanitation Foundation Water Quality and Rivers Pollution Indices

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ABSTRACT

Spatial variation of water quality in rivers is a function of the surrounding environment and land, the reason why water indices are important to reduce the bulk of information into a simplified and understandable manner for specific purposes. This study aimed at assessing the spatial distribution of water quality of 23 Rwandan rivers that drain into the Lake Kivu by using the National Sanitation Foundation Water Quality Index (NSFWQI) and the River Pollution Index (RPI). The study collected field data and analyzed the parameters of the NSFWQI and RPI including suspended solids, turbidity, biological oxygen demand, nitrate, temperature, total phosphorus, pH, fecal coliform and dissolved oxygen. For gathering details related to entities adjacent to rivers, land use and land cover, topography and rainfall have been analyzed. The results showed that good water quality (negligibly polluted) was located in areas dominated by forestland while bad and very bad (39%, 26%) classes of rivers (severely polluted) were influenced by the dominance of farmland. Moreover, 22% of rivers in medium class were equivalent to 26% moderately polluted due to the disturbance of other land use types and other factors such as slope and tropical rainfall.

Keywords: Lake Kivu; Land use; NSFWQI; Rivers; River pollution index; Rwanda; Water quality

1. Introduction

Water is an essential resource for the sustenance of life, directly affecting the quality of people's life, health and productivity. Rivers, as one of the available freshwater sources, constitute the main necessary ingredient for human health, agriculture and industry [1,2]. Apart from being natural and precious assets, rivers are counted as the planet's most affected water bodies [3]. They are defenseless to pollution due to easy accessibility for point and non-point discharges in their drainage basins [3–5]. With the increase in population and diversified forms of land use and land cover, the quality of water has been deteriorated due to either natural or anthropogenic factors. Therefore, reliable information on

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water quality in light of Water Quality Indices is paramount to improve the management of waters and, ameliorate the quality of life [5,6].

Ecological benefits of maintaining good water quality relates to the protection of aquatic and terrestrial life and direct maintenance of biodiversity. Water quality importance on human, ecological health and economic development is reflected in a number of water quality indices, employing various mathematical and statistical methods that have been proposed and implemented by many agencies [7,8]. The strengths of using water quality indices as opposed to the evaluation of individual water quality variables are mainly on the ability of indices to reduce the bulk of information into single to convey the data in a simplified and understandable manner [9]. Notwithstanding the attention that water quality indices have received in the empirical and practitioners' literature, no single widely accepted method has emerged and, all currently used indices are restricted in their applicability and scope [7,10].

Freshwater bodies in Rwanda have been inventoried recently, and 861 rivers were identified, totaling 6,462 km in length [11,12]. Two major water basins drain those rivers; the Nile River Basin that covers 67% and delivers 90% of the national waters and the Congo River Basin which covers 33% of Rwanda's territory and receives 10% of the total national waters [13]. Recently, Wronski et al. [12] and Sekomo et al. [14] used physicochemical and bacteriological methods to report on the surface water quality of Rwandan rivers and described numerous inorganic and two bacteriological variables taken at 33 sampling sites across the country. Similarly, Wronski et al. [12] studied the biological status of water quality and biodiversity in Rwandan rivers draining into the Lake Kivu; Muvundja et al. [15] analyzed the influence of hydrological variation in the catchment and hydropower dam operation to the lake water level. Their studies in press give good estimates of water quality, but contain substantial uncertainties the state of water quality. In addition, a broad spatial view is missing and water quality indices are necessary in increasing participation since they are capable of reducing the jargon from water quality information; making water quality to be understood not only by water resources professionals but also by all stakeholders and the general public [9].

Whereas the limnology and biogeochemistry of the Lake Kivu have been well studied [16,17], spatial variability of water quality in the tributaries and catchments of the Lake remains unknown. Therefore, the objectives of this study are (1) to assess the water quality in 23 Rwandan rivers draining into the Lake Kivu, using the National Sanitation Foundation Water Quality Index (NSFWQI) and the River Pollution Index (RPI); (2) to determine the influence of land use types to the water quality of rivers and (3) to create maps showing spatial patterns of water quality in the Lake Kivu basin area. This study will help to recognize the spatial variation of water quality for further enhanced water quality management.

2. Materials and methods

2.1. Description of the study area

The Lake Kivu basin lies in the border between Rwanda and Democratic Republic of Congo in the tropical zone. The delineated study area, located on the Rwandan side of the Lake Kivu basin (Fig. 1) covers an area of about 3,483.088 km^2 and comprises 1,008.47 km^2 (29%) of the water surface and 2,474.61 km^2 (71%) of other land covers. Elevation varies from 1,389 m in the shores of the Lake Kivu increasing toward 4,483 m in the east catchment on the Congo Nile ridge and the volcanic range with a mean slope of 30.5% (Fig. 1). The Lake Kivu basin experiences a tropical climate with a mean annual rainfall of 1,314.4 mm, a mean annual temperature of 19°C and two rainfall seasons per year (March to May and September to December) [18]. Geologically, the basin is characterized by acrisols, andosols, ferralsols, cambisols and regosols [19].

Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model version 2 (30 m resolution) acquired from the United States Geological Survey EarthExplorer database [20] has been used to delineate the Rwandan side of the Lake Kivu by using the hydrology toolset of the ArcGIS software version 10.2.

2.2. Sampling and analysis

In this study, 23 Rwandan rivers and tributaries belonging to 23 sub-catchments were carefully selected. Each river was sampled once a month from September 2015 to August 2016 in order to cover the wet season (September–May) and the dry season (June–August), from the north (Rubavu district) to the south of the study area (Rusizi district). At all locations, samples were carefully obtained from well-mixed water that was indicative of the main flow of the river at the sampling cross-section [21]. Physical properties of the water samples such as pH, temperature (T; °C) and dissolved oxygen (DO; mg/L) were carried out in situ using a combined pen-type pH/thermometer (ATC Pometer), handheld conductivity tester EC-1382A (Kelilong Electron) and with YSI professional Plus handheld multiparameter instrument calibrated with standard solutions, respectively. The laboratory analyses for major chemical constituents were conducted according to the standard laboratory procedures [22–24]. In the studied rivers, NSFWQI was used to evaluate water quality, and for understanding the tendencies of water pollution, RPI was selected.

2.3. National Sanitation Foundation Water Quality Index

NSFWQI is the most widely used among water quality indices [25–27]. It has been applied to give a systematized method for assessing the water quality of various water bodies; then its results are used to determine healthy status of water bodies [26]. Calculation of NSFWQI relies on nine parameters including DO (mg L^{-1}), biochemical oxygen demand (BOD_5, mg L^{-1}), nitrate (NO^-_3, mg L^{-1}), phosphate (PO_4, mg L^{-1}), fecal coliform bacteria (CFU/100 mL), turbidity (NTU), suspended solids (SS, mg L^{-1}), temperature (°C) and pH. Each parameter has been given weights (Wi) as indicated in Table 1, then after, numerical ranges of NSFWQI are classified into five categories such as very bad (0–25), bad (25–50), medium (50–70), good (70–90) and excellent (90–100). The NSFWQI is expressed mathematically as:

$$\text{NSFWQI} = \sum_{i=1}^{p} \text{WiIi} \quad (1)$$

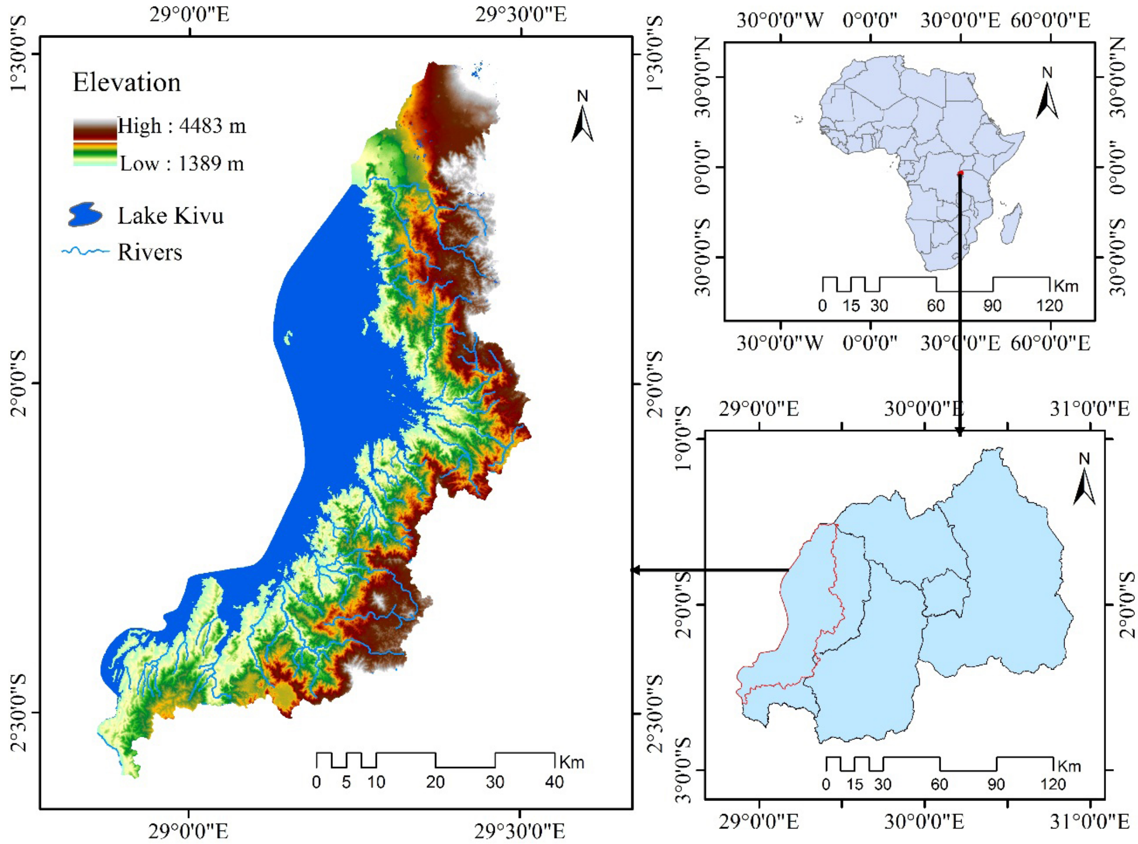

Fig. 1. Location map of the study area, covering the Rwandan side of the Lake Kivu Basin.

Table 1
Weighting factor for each parameter in NSFWQI calculation and classes

Index parameter	Weight (Wi) of each parameter
Suspended solids	0.08
Turbidity	0.08
BOD_5	0.10
Nitrate	0.10
Temperature	0.10
Total phosphorus	0.10
pH	0.12
Fecal coliform	0.15
DO	0.17

Source: [28–30].

where Wi = weight (in terms of importance) associated with water quality parameter, Ii = sub index for *i*th water quality parameter and *P* = number of water quality parameters.

2.4. River Pollution Index

Based on its capacity to show the characteristics and extent of river pollution, RPI that has long served as a reference for managing river pollution [31], has been used in this study. Taiwan Environmental Protection Administration has also adopted RPI for monitoring water quality [32]. Using this index from four variables including the DO, BOD_5, SS and ammonium nitrogen (NH_3-N), obtained results were categorized into appropriate groups necessary for managing the pollution of rivers [28,33,34]. Variables used for determining RPI were converted into one of four index scores ($Si = 1$, 3, 6 or 10) and were selected based on Table 2. Eq. (2) was used to calculate RPI:

$$\text{RPI} = \frac{1}{4}\sum_{1}^{4} Si \quad (2)$$

where Si represents the index scores (Table 2).

2.5. Land use/land cover

In order to delineate the catchments of each river and obtaining land use and land cover (LULC) information in the studied area, two Landsat 8 images (path/row 173/61; 173/62 acquired in March 2017) delivered by the USGS global visualization were processed in ArcGIS 10.2 (ESRI 2013) [35]. These images were corrected radiometrically, the cloud shadows were masked, and the gap-filling algorithm was used to obtain a cloud-free image using ENVI software version 5.2 (Exelis Visual Informations, Inc., a subsidiary of Harris Corporation, Boulder, CO, USA) [35]. This software was also used for the classification of the LULC map of the Lake Kivu basin (Fig. 2) using the supervised maximum likelihood classification method [36,37], which is the most commonly used supervised classification method with remote

Table 2
Parameters and pollution levels according to River Pollution Index values

Index parameter	Water pollution levels			
	Unpolluted	Negligibly polluted	Moderately polluted	Severely polluted
DO (mg/L)	>6.5	4.6–6.5	2–4.5	<2
BOD_5 (mg/L)	<3	3–4.9	5–15	>15
NH_3-N (mg/L)	<0.5	0.5–0.99	1–3	>3
SS (mg/L)	<20	20–49	50–100	>100
Index score (Si)	1	3	6	10
RPI value	<2	2–3	3.1–6	>6

Source: [32,33].

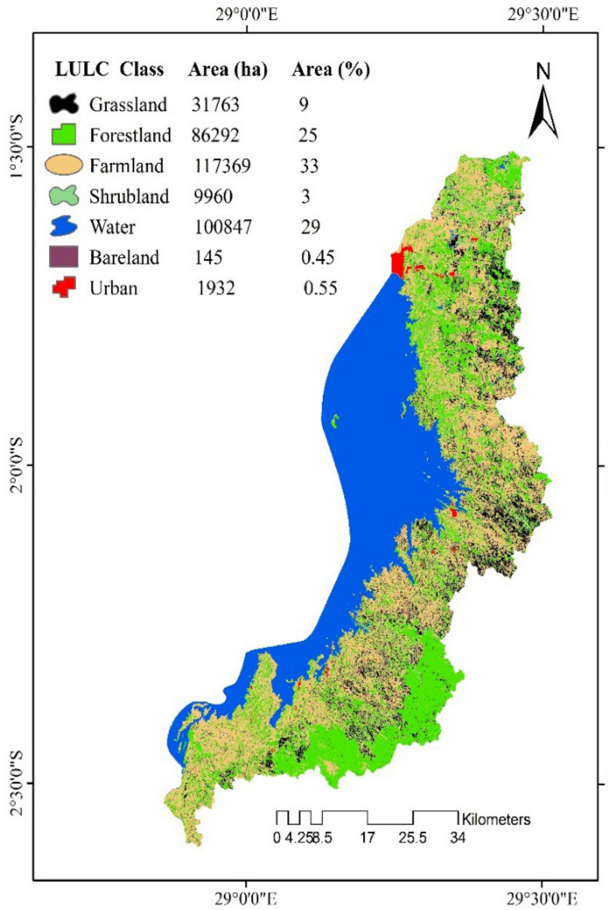

Fig. 2. LULC map for the Lake Kivu basin.

sensing imagery, due to its applicability and reliability for satellite image classification purposes [36,38]. The LULC map was classified into seven classes (Farmland, Forestland, Grassland, Shrubland, Bareland, Urban and water/Lake Kivu) according to the USGS classification scheme [39].

2.6. Statistical analysis

Statistical analysis was performed to assess the correlation between LULC and water quality parameters to establish the degree of associability between the two variables using a Pearson correlation analysis.

Statistical package for the social sciences version 21.0 for windows was utilized by considering a Pearson correlation coefficient *r*, and correlation levels are shown in Table 3.

3. Results and discussion

3.1. Water quality

3.1.1. NSFWQI

NSFWQI was analyzed to get the state of water quality for Rwandan rivers draining into the Lake Kivu as illustrated in Table 4. Four rivers (Ruhanga, Kigoya, Cyunyu and Karundura) were classified as good quality (NSFWQI = 70–90) while five others (2nd, 3rd, 5th, 10th and 23rd) were classified as of medium (NSFWQI = 50–70). In addition, eight other studied rivers were classified as of bad quality (NSFWQI = 25–30), whereas the remaining other six rivers (6th, 12th, 14th, 15th, 21st and 22nd) were classified as very bad (NSFWQI = 0–25) in terms of quality. The statistical variation of water quality along the Rwandan side of the Kivu catchment is provided in Table 4, from north with the first river Sebeya to the south with the 23rd river Kadasomwa. Also, the spatial representation of water quality in the studied region is shown in Fig. 3(a).

The results showed that the good quality observed in the Ruhanga, Kigoya, Cyunyu and Karundura rivers was primarily due to the dominance of forestland (15.81, 18.02, 181.87 and 46.84 km^2) in their respective sub-catchments, which reduces the biological oxygen demand and increases dissolved oxygen in the respective catchments. However, attention was paid to rivers number 3, 17, 21 and 22, which fail to comply with good quality indicators even if forestland (5.31, 72.45, 0.13 and 44.25 km^2) dominates their sub-catchment. Several factors including the relative disturbances of other land uses within the basin and management practices that control water physico-chemistry [40] may crucially influence the quality of waters in these rivers. The remaining rivers of the catchment were identified into different classes of NSFWQI due to variations of measured parameters (Table A) as influenced by farmlands dominating the catchment. Exception is made to four rivers in which forestland dominates rather than farmland: two very bad rivers (21st and 22nd); one bad river (17th) and one river (3rd) of medium class. With regard to the results of this study in terms of NSFWQI values with adjacent LULC (Table 4), farmland negatively influences the water quality of rivers due to intensive fertilization during the farming seasons and agricultural runoff from soil erosion [41,42].

3.1.2. RPI

Based on RPI values presented in Table 4, three classes were obtained. Four rivers, namely Ruhanga, Kigoya, Cyunyu and Karundura (13th, 18th, 19th and 20th), were negligibly polluted while six others (2nd, 3rd, 5th, 10th, 15th and 23rd) were classified as moderately polluted.

Table 3
Interpretation of the level of a Pearson correlation

Correlation, *r*	Negative	Positive
None	–0.09 to 0.0	0.0–0.09
Small	–0.3 to –0.1	0.1–0.3
Medium	–0.5 to –0.3	0.3–0.5
Strong	–1.0 to –0.5	0.5–1.0

The remaining 57% of studied rivers were classified as severely polluted (Fig. 3).

The RPI values reflect the water quality parameters (Table A) function while LULC (grassland, forestland, farmland, shrubland, water, bareland and urban areas) in the sub-catchments is considered as a primordial factor influencing the status of waters as highlighted above.

The obtained pollution levels for RPI largely resulted from LULC (forestland and farmland) dominating the study area as similar to NSFWQI classes. The four rivers characterized by negligible pollution are surrounded by high forestland in their sub-catchments. In contrast, even if obtained classes according to NSFWQI values as presented in Fig. 3(a) are different from pollution levels indicated by RPI (Fig. 3(b)), the spatial distribution of water quality in the studied rivers shows similarity between two indices. All rivers (4) in 'good' class are negligibly polluted; five rivers in 'medium' class are all moderately polluted and thirteen rivers (nine bad and five very bad) are severely polluted. Moreover, Fig. 4 illustrates the consistency of NSFWQI not only with RPI but also with

Table 4
NSFWQI and RPI values in 23 Rwandan rivers and adjacent LULC, slopes and rainfall

Rivers[a]	NSFWQI	RPI	Land use land cover (km^2)[b]							Slope	Rainfall
			LU1	LU2	LU3	LU4	LU5	LU6	LU7		
1	29.7	6.5	57.1	104.80	115.99	15.02	1.51	0.096	3.050	31	1,214
2	57.7	5.5	0.3	2.91	3.62	0.25	0.08	0.000	0.000	28	1,095
3	63.7	5.5	0.3	5.31	3.52	0.50	0.04	0.000	0.000	29	1,137
4	26.7	7.25	2.1	13.74	17.90	1.56	0.25	0.010	0.000	29	1,189
5	67.7	5.5	2.7	13.12	34.85	1.28	0.03	0.370	0.000	22	1,456
6	24.1	6.5	15.4	32.08	78.94	4.38	0.87	0.050	0.000	34	1,195
7	33.0	6.25	20.7	25.43	78.15	5.07	0.29	0.009	0.000	36	1,176
8	39.2	6.25	29.3	14.01	39.47	5.08	0.08	0.011	0.000	31	1,182
9	46.4	6.25	20.9	12.45	42.03	2.75	0.00	0.001	0.009	37	1,235
10	54.5	5.75	8.5	9.87	21.91	2.69	0.02	0.013	0.368	37	1,268
11	45.7	7.75	0.0	0.01	0.10	0.00	0.00	0.000	0.016	19	1,263
12	15.4	6.5	3.7	6.30	12.34	1.19	0.04	0.000	0.125	34	1,302
13	83.9	2.75	1.7	15.81	7.35	0.30	0.05	0.007	0.000	23	1,453
14	18.6	8.25	2.3	3.97	9.73	0.69	0.05	0.000	0.055	35	1,315
15	23.7	6	12.1	9.95	36.71	2.30	0.02	0.042	0.097	37	1,350
16	46.0	7.75	2.0	3.66	9.19	0.42	0.02	0.002	0.000	35	1,305
17	40.0	8.25	21.8	72.45	60.68	5.89	0.03	0.018	0.170	33	1,414
18	71.8	2.75	5.5	18.02	4.24	0.60	0.02	0.004	0.117	29	1,400
19	84.7	2.75	30.8	181.87	66.34	5.94	0.06	0.065	0.423	35	1,531
20	85.0	2.75	5.8	46.84	34.78	0.87	0.05	0.015	0.124	30	1,506
21	18.7	6.75	0.0	0.13	0.10	0.00	0.00	0.000	0.000	26	1,502
22	20.9	6.25	11.7	44.25	38.98	1.13	0.03	0.024	0.196	25	1,480
23	53.1	5.75	1.0	6.17	19.96	0.39	0.02	0.016	0.031	23	1,419

[a]Rivers: 1, Sebeya; 2, Burehe; 3, Gashashi; 4, Nkora; 5, Koko, 6, Muregeya; 7, Musogoro; 8, Nyabahanga; 9, Gisayo; 10, Kiraro; 11, Nyabitare; 12, Magarama; 13, Ruhanga; 14, Kiboga; 15, Nyarubandwa; 16, Gisuma; 17, Kirimbi; 18, Kigoya; 19, Cyunyu; 20, Karundura; 21, Kamiranzovu; 22, Gasayo; 23, Kadasomwa.
[b]LU1, grassland; LU2, forestland; LU3, farmland; LU4: shrubland; LU5, water; LU6, bareland; LU7, urban land.

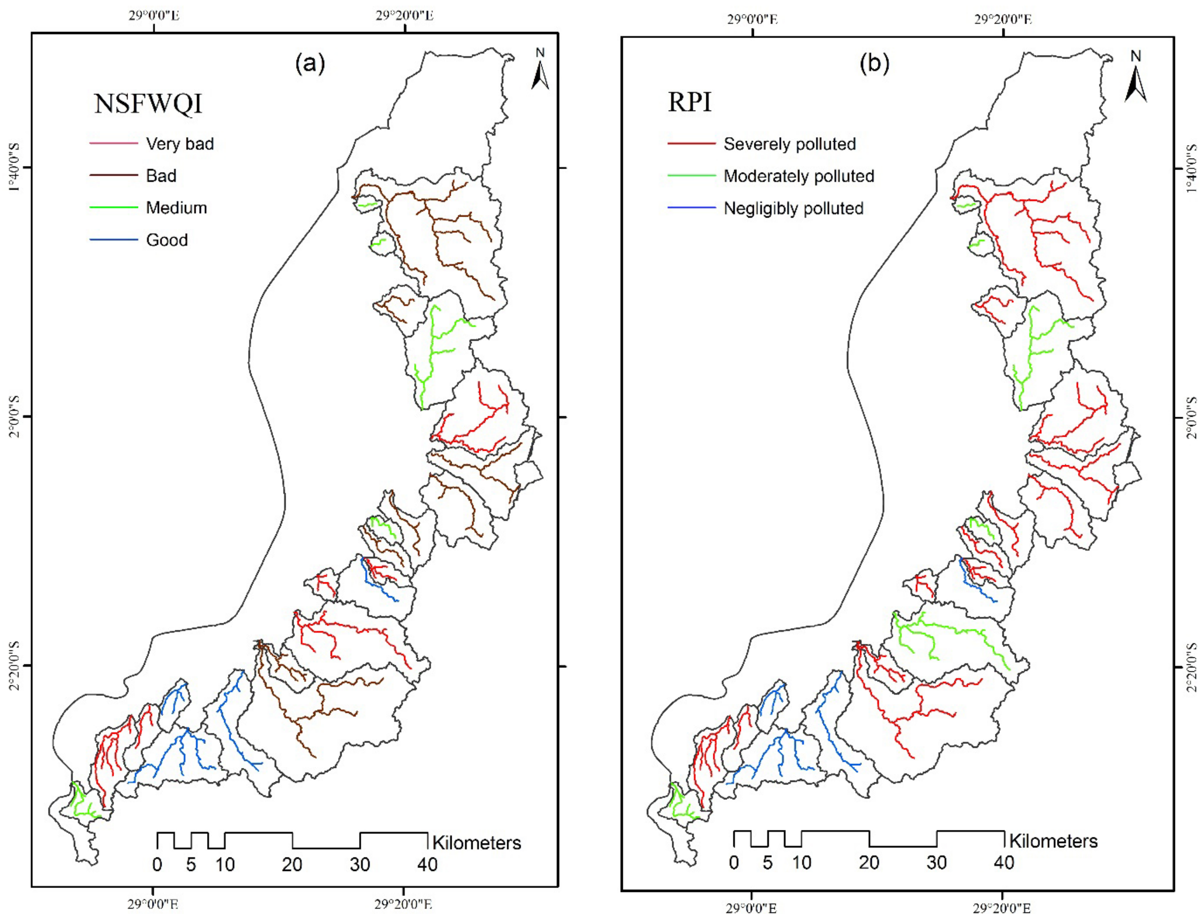

Fig. 3. Spatial distribution of NSFWQI (a) and RPI (b) in Rwandan rivers draining into Lake Kivu.

the other water quality indices, especially water quality indices for environmental contamination contributed by mineral processing [9]. As found for NSFWQI, farmland remains the primary land use type dominating severely polluted rivers. Therefore, agricultural activities constitute a significant source of river pollution owing to nutrients' runoff and various noxious substances from the use of fertilizers [43]. These results are congruent with previous findings on water quality deterioration influenced by agricultural activities as reported by [44,45].

Fig. 4. Comparison between NSFWQI and RPI.

3.1.3. Land use types

Seven LULC types, farmland, water, forestland, grassland, shrubland, urban areas and bareland (33%, 29%, 25%, 9%, 3%, 0.55% and 0.45%, respectively) as presented in Fig. 2, appear differently in Table 4 according to their presence (km^2) in sub-catchments of rivers.

Based on LULC results, water quality status is directly attributed to the dominants land use types such as farmland (33%) and forestland (25%). 'Bad' and 'very bad' water qualities (severely polluted rivers) are highly surrounded by agricultural activities apart from some exceptions (3rd, 17th, 21st and 22nd rivers' sub-catchments) in which forestland (5.31, 72.45, 0.13 and 44.25 km^2) was higher than farmland (60.68, 0.10 and 38.98 km^2).

Agriculture induced water quality degradation in studied tributaries coincides with major agricultural activities during the study period in the vicinity of the Lake Kivu. It has been exacerbated by the rising population pressure where about 83.4% of Rwanda's population primarily depends on a subsistence rainfed agriculture practiced on hill slopes without fallow due to land resource scarcity [46,47]. Runoff from these highly populated areas contains fertilizers, animal wastes and other non-point source pollution [48]. On the other hand, the quarter (25%) proportion of forestland spatially distributed in all over the studied areas is a fact alleviating the negative sides of farmland through high infiltration rates, litter layers that minimize exposed mineral soil and high dissolved oxygen concentration [49]. It was previously found that rivers with forest-dominated catchments were less eutrophic and had lower pollutants than rivers in no-forest dominated catchments [50].

Apart from land use types influence on water quality, the high mean precipitation (1,314 mm/year) and the steep slope (30%) are the potential agents of runoff depth increase which further degrades water quality by introducing salt and other wastes into rivers. Previous studies suggested that higher slope variability leads to higher rates of erosion, which subsequently increases the rates of particulate matter entering into the water bodies [51]. However, the obtained indices for NSFWQI and RPI (Table 3) are not in compliance with those findings because in this study, pollution levels had no relationship with slope. It has been found that negligible, moderate and severe pollution was identified in rivers whose adjacent slope varied between 23% and 30%, 22%–37% of slope and 19% to 37%, respectively.

3.2. Relationship between land use types and water quality parameters

Correlation analysis for the average values of the water quality parameters and land use types (Table 5) revealed a number of observations (strong, medium and small only) described as follows, and organized by parameters.

A strong positive correlation was observed between turbidity and water, urban and shrubland. Turbidity was also fairly (medium) correlated with grassland and farmland, while a small correlation was found with regards to forestland. Similarly, a medium correlation was depicted between nitrate and grassland, farmland and urban areas. The correlation of pH was positively medium with shrubland and water. Positively but at a small level correlated with grassland and farmland. Biological oxygen demand was negatively correlated at medium level with forestland. Small negative correlations with grassland and farmland but positive with water. Temperature was only negatively correlated with water at medium level. The remaining land use types correlate negatively at small level.

DO, total phosphorus (TP) and SS, small correlations were observed with grassland, forestland, shrubland, water and urban area for DO; forestland, water, bareland and urban for TP and bareland for SS.

Turbidity was positively and strongly correlated with water due to the downward emplacement of 'open water' land cover, widely distributed under hilly areas as shown in Table 4. Additionally, this may be explained by accumulation of sediments due to lack of ponds that could act as filters of water draining down into the Lake Kivu tributaries. On the other hand, the correlation with urban area is caused by urban sprawl which is commonly becoming a dominant feature for the area as a corollary of high population density [52]. Inappropriate growth of urbanization lacking basic infrastructure such as paved roads and parking lots increases the bare land areas influencing erosion toward the lake shores [53].

Thus, urbanized areas influence a variety of water quality of tributaries by shortening the time to flood peaks, causing increases in discharges and higher surface runoff. In the absence of other competing factors, the increase of farmland would be expected to strongly and positively correlate with an increase of turbidity since farmlands are more prone to erosion [54]. Such correlation was not observed in this study (medium correlation) indicating that other additive factors exerted more influence compensating for the increase in farmland and the state of turbidity (for example, the increase of forestland).

The observed correlation of nitrate and grassland resides on how nitrogen in grasslands is mineralized and accumulated in soils during dry periods. With the onset of rainy seasons, water begins to flow through the upper soil horizons, mobilizing the accumulated nitrate. Then, due to the dominance of free grazing technics in the studied area, the accumulated nitrate in upper soil horizon is easily eroded to down slope before new growth uptakes nutrients. In addition to grasslands, farmland and urban areas also correlate

Table 5
Results of Pearson correlation analysis between LULC types and water quality parameters

	Land use types (km^2)						
	Grassland	Forestland	Farmland	Shrubland	Water	Bareland	Urban
DO	0.121	0.257	0.094	0.103	0.136	–0.082	0.229
TP	0.002	–0.199	0.096	0.065	0.148	–0.15	–0.162
FC	–0.124	0.218	–0.12	–0.181	–0.308	0.203	–0.145
pH	0.286	–0.094	0.285	0.318	0.321	0.072	0.099
Nitrate	0.331	–0.014	0.336	0.264	0.061	–0.184	0.409
BOD	–0.174	–0.378	–0.16	–0.039	0.15	0.044	0.018
Temp	–0.274	–0.259	–0.234	–0.245	–0.397	–0.11	–0.351
SS	0.002	–0.045	–0.058	0.013	0.08	–0.173	0.076
Turbidity	0.427*	0.166	0.399	0.533**	0.748**	–0.023	0.620**

**0.01 significance.
*0.05 significance.
N = 23.

with nitrate. Farmland influence is explained by inappropriate use of inputs mostly chemical fertilizers such as urea and NPK which are vastly used in the study area [48]. The correlation between nitrate and urban areas suggests that the increasing urbanization near rivers may lead to an increase in the concentration of nitrate, thus lowering the water quality. Such a positive correlation of urban areas with nitrate was also observed by Huang et al. [55].

4. Conclusion

This study assessed the spatial variability of water quality in the tributaries draining into the Lake Kivu in the western part of Rwanda by using two indices: NSFWQI and RPI. The results showed the existence of relationship between water quality, adjacent LULC and topography. It has been found that good water quality (negligibly polluted) was located in areas dominated by forestland and 39% bad and 26% very bad water quality of rivers equivalent to 56.5% of severely polluted rivers were influenced by the dominance of farmland. The findings highlight that 22% of rivers are counted in medium class corresponding to 26% moderately polluted rivers due to the disturbance of others land use types and factors such as topography (slope) and climate (tropical rainfall). Thus, this paper supports the integration of landscape analysis in order to understand the complexity of water quality of rivers. Based on the results contained herein, it is suggested that efforts to reduce pollution of the river system should be done especially in agricultural areas. In addition appropriate methods for conserving soil and water according to the LULC types with special attention to farmland are also highly recommended.

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Conflicts of interest

The authors declare no conflict of interest.

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Appendix

Table A
Calculated mean of water quality parameters in 1 year

No	Rivers	DO (mg/L)	TP (μmol/L)	FC (cfu/100mL)	pH	Nitrate (μmol/L)	BOD (mg/L)	Temp (°C)	SS (mg/L)	Turb (NTU)	NSFWQI	RPI
1	Sebeya	4.5	1.11	100	7.8	4.91	28.1	17.9	38.6	58.6	29.7	6.5
2	Burehe	4.3	1.99	300	7.5	3.21	27.2	18.2	27.6	47.3	57.7	5.5
3	Gashashi	3.8	2.61	350	7.9	0.9	30.9	20.4	22.1	29.7	63.7	5.5
4	Nkora	2.2	3.99	100	8.1	3.01	26.8	21.2	32	28.1	26.7	7.25
5	Koko	1.9	1.09	400	7.4	0.46	28	20.9	11	7.6	67.7	5.5
6	Muregeya	1.9	3.28	80	8.2	0.73	33.8	19.4	31.1	32.2	24.1	6.5
7	Musogoro	3.2	4.81	150	7.3	1.3	22.9	22.1	30.9	18.4	33.0	6.25
8	Nyabahanga	2.2	2.99	200	8.4	2.8	21.5	20.4	25.6	13.1	39.2	6.25
9	Gisayo	2.1	2.12	250	7.7	2.01	20.1	21	20.1	18.8	46.4	6.25
10	Kiraro	2.8	1.66	300	7.6	1.4	27.9	22.5	18.7	16	54.5	5.75
11	Nyabitare	1.4	2.01	250	7.1	4.2	19.7	23.1	18.8	8.6	45.7	7.75
12	Magarama	1.2	3.81	35	6.5	0.92	30.1	19.7	38.9	7.9	15.4	6.5
13	Ruhanga	6.6	1.07	500	7.2	0.96	14	19.7	9.8	12.1	82.3	2.75
14	Kiboga	1.1	3.09	50	6.8	3.91	34.8	24.1	37.4	6.3	18.6	8.25
15	Nyarubandwa	1.3	2.19	90	7.8	0.42	35.1	19.9	32.1	8.8	23.7	6
16	Gisuma	1.5	0.09	250	7.9	4.03	29.7	21.9	11.2	10.4	46.0	7.75
17	Kirimbi	1.4	0.28	200	7.7	3.11	26.1	23.6	31.9	11.6	40.0	8.25
18	Kigoya	6.6	0.79	400	6.9	0.91	35.6	20.6	19	18.8	70.8	2.75
19	Cyunyu	4.8	1.52	500	6.7	0.39	14.8	19.5	19	10	82.6	2.75
20	Karundura	5.2	1.11	450	6.5	0.49	14	18.9	19	12	75.1	2.75
21	Kamiranzovu	2.6	0.04	10	6	0.49	37.2	19	118	11.7	18.7	6.75
22	Gasayo	1.6	0.09	100	7.1	0.99	10	20.4	51	10.7	24.2	6.25
23	Kadasomwa	2.1	0.78	300	7.5	1.07	23.8	23.1	12	12.4	53.1	5.75

DO, dissolved oxygen; TP, total phosphorus; FC, fecal coliform; BOD, biological oxygen demand; Temp, temperature; SS, suspended solids; Turb, turbidity.