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

Lake Kivu River Tributaries Physicochemical Characteristics and Status of Waters, Democratic Republic of Congo Side

Bgalwa M.[1*], Ndegeyi K.[1], Kalala A. O.[2], Ruhambya M. B.[3], Karume K.[4,5]

[1]Department of Biology, Centre de Recherche en Sciences Naturelles, Lwiro, Democratic Republic of Congo
[2]Department of Geomatics and Land Management, Geographic Information Sciences and Technology, Makerere University, Kampala, Uganda
[3]Department of Geography, Geo-informatics and Climatic Sciences, Makerere University, Kampala, Uganda
[4]Faculté des Sciences Agronomiques et Environnement, Université Evangélique en Afrique, Bukavu, Congo
[5]Centre de Recherche en Géothermie, Bukavu, République Démocratique du Congo

DOI: 10.36347/sajb.2023.v11i12.001 | **Received:** 01.03.2023 | **Accepted:** 12.04.2023 | **Published:** 01.12.2023

***Corresponding author:** Bgalwa M.
Department of Biology, Centre de Recherche en Sciences Naturelles, Lwiro, Democratic Republic of Congo

Abstract **Original Research Article**

Rivers often play a vital role in the transport of major natural chemicals entering through a variety of pathways, including atmospheric inputs, chemical weathering of minerals, mechanical erosion of rocks and soil particles, and soil leaching. Increased anthropogenic activities on the shoreline of Lake Kivu combined with existing land use practices may increase changes in river water quality and composition. Knowing the physico-chemical and biological contribution of each tributary of the lake is vital for the management of its biodiversity. This study aimed at determining the physico-chemical characteristics, water quality indices and identifying the polluted tributary rivers that feed Lake Kivu on the Congo side. The physicochemical characteristics were determined for each water sample following water quantity protocol for each analysis at the Malacology Laboratory of the Biology Department of Lwiro Research Center. Two pollution level indices were used to determine the level of organic pollution in watercourses. The physico-chemical characteristics of rivers vary from one river to another depending on the anthropogenic activities around the different sub-basins of these rivers. The state of the rivers presented here reveals that the majority of them are moderately polluted and others slightly polluted. No rivers were very heavily polluted or good in the Lake Kivu basin on the DR Congo side. There is a strong or moderate correlation between certain parameters and the water quality indices used in this study (LISEC and OPI). Due to increase in anthropogenic activities near watercourses, further research is needed and the combination of several complex analytical methods should be used in the future to better characterize these waters.

Keywords: Rivers, nutrients, Lake Kivu, Democratic Republic of Congo.

INTRODUCTION

The quality of surface waters around the world is governed by human activities and natural processes, including weathering, erosion, hydrological patterns, climate change, precipitation, industrial activities, agricultural land use, vegetation cover, wastewater discharges and human exploitation of water resources [1, 2]. While fresh water will be a scarce resource in the future, water quality assessment in most countries has become a critical issue [3-6]. Rivers often play a very vital role in transporting major natural chemicals entering through a variety of pathways, including atmospheric inputs, chemical weathering of minerals, mechanical erosion of rocks and soil particles, and soil leaching [7, 8]. They are also necessary for agricultural, industrial, domestic, hydroelectric, recreational and environmental activities [9]. The biogeochemistry of river waters are influenced by atmospheric inputs, basin lithology, anthropogenic inputs and climatic conditions [10]. Natural (erosion) and anthropogenic (agricultural discharges) activities affect surface water quality [11-13].

According to Finnveden *et al.*, [14], the population along the rivers discards crop waste, degradable solid waste and food waste which contributes to the increase of organic matter in surface waters. But also, it receives all the load of materials transported from the watershed and contributes to the biogeochemical cycles of the lake. Consequently, these agricultural, urban and industrial pollutants to rivers in various parts of the world has led to the deterioration of biodiversity and water quality in lakes receiving river water [15]. In recent decades, the assessment of river water quality has attracted scientific interest for its high demand for human consumption and aquatic health. It is important to understand that in addition to weather-induced changes and variations in river chemistry, human activities, urban, industrial and agricultural runoff, will also impact the quality of rivers in space and over time [16]. Understanding the physicochemical, biological and polluting contribution of tributaries to the lake is vital for the management of biodiversity in the receiving environment. In Lake Kivu watershed, few studies are made of the streams and other rural rivers that contribute to the supply of Lake Kivu. Studies have focused on the aspect of pollution of some rivers in the city of Bukavu and the city of Lwiro [17, 18] and some aspects of ecological characteristics [19]. Bagalwa [20] described the impact of land use on certain physico-chemical parameters along the Lwiro River and Wronski *et al.*, [21] studied the biological status of water quality and biodiversity in Rwandan rivers flowing into Lake Kivu. As for Muvundja *et al.*, [22], they analyzed the influence of hydrological variation in the watershed and the operation of the hydroelectric dam on the water level of the lake. Their studies provided good estimates of water quality, but contain substantial uncertainties about the state of water quality. On the other hand, Mupenzi *et al.*, [23] evaluated the spatial distribution of water quality of 23 Rwandan rivers in the eastern branch that flow into Lake Kivu and showed that the good water quality (low polluted) was located in areas dominated by forests while the bad and very bad (39%, 26%) classes of rivers (severely polluted) were influenced by the dominance of agricultural land. While the limnology and biogeochemistry of Lake Kivu have been well studied [24, 25], the spatial variability of water quality in the tributaries and catchments of the lake remains unknown especially in the western branch of the watershed of Lake Kivu in the DRCongo.

Increased anthropogenic activities on the Lake Kivu shoreline combined with existing land use practices may increase changes in water quality and composition [15]. Bagalwa *et al.*, [26] show that the increase in deforestation created by the search for agricultural land is one of the causes of pollution and sedimentation of Lake Kivu. This situation has been accelerated by the growth of population density, which is already high in the basin [20]. This deforestation causes soil erosion with a potential effect on biodiversity, habitats and the ecology of rivers and the receiving environment. Due to anthropogenic activities most of the world's rivers are now impacted. These changes can be considered as global water quality problems [27]. In Lake Kivu, biodiversity is currently threatened by a number of anthropogenic disturbances, the most important of which are increased nutrient loading, contamination, acidification and the invasion of alien species [28]. Ecological stress on the system results in deterioration of water quality and increased levels of biological productivity. However, changes in land use/cover, biogeochemistry and increasing urbanization have created global environmental stress expressed as climate change, runoff, erosion and landslides, atmospheric deposition, acidification and the invasion of alien species [29, 30]. All of these factors, alone and in combination, will negatively affect water quality in the receiving Lake Kivu. Moreover, these anthropogenic disturbances have had and will continue to have serious effects on natural systems and their biota [31]. The objectives of this study were 1) to determine the physico-chemical characteristics of water tributaries of Lake Kivu on the DR Congo side, 2) to compute the indices of the quality of these rivers, and 3) to identify the polluted tributary rivers at risk of impact Lake Kivu on the DR Congo side.

MATERIAL AND METHODS

Description of study area

Lake Kivu, one of the Central African Great Lakes in the Albertine Rift Region, is exceptional in that it has no major tributary to its heavily eroded basin, and it receives untreated sewage from 400 000 inhabitants of the city of Bukavu [32, 33]. Lake Kivu was formed as a result of volcanic activity in the region. It has an area of 2,370 km^2, of which approximately 1000 km^2 (42%) belongs to Rwanda and 58% to the Democratic Republic of Congo [34]. The lake is in the axial zone of the NNE-SSW oriented rift axis. The East African rift is characterized by topographical uplift and uplift of the rift shoulder. Topographical uplift redirects some drainage pathways away from rift lakes and rejuvenates others, making them more erosive. A dense drainage network supplies the lake with water [35]. The western half-graben located in D.R. Congo is much less known. The study was conducted on the shores of Lake Kivu, Bukavu-Goma. The 1200 km long shoreline of the lake is home to several large towns and villages, including Bukavu, Kabare, Kalehe, Sake and Goma in the DRC. Topographically, it consists of a large basin (main basin) and four smaller basins (from north to south: Kabuno Bay, Kalehe, Ishungu and Bukavu).

Sampling protocol and water analysis

Water samples were taken from the outlet of several tributary rivers of Lake Kivu with clean pre-sterilized 500 ml bottles from the Congolese side. The bottles were aseptically opened five centimeters (5 cm) below the water surface, rinsed with the first set of water samples, then filled with the required water sample, and the bottle closed aseptically. These were carried out between 7:00 a.m. and 12:00 p.m. (late morning to early afternoon by which human activities resumed), and carried out in two different sampling periods, rainy season and dry season, precisely at always the same geographic coordinates. Samples were transported to the laboratory under ice and stored at approximately 4°C until ready for analysis.

The physical and chemical properties were determined for each water sample according to the analytical methods, carried out at the Malacology

Laboratory of the Biology Department of Lwiro. Two pollution level indices were used to determine the level of organic pollution in rivers. These include the Index of the Interuniversity Laboratory for Education and Communication Sciences (LISEC) [36] and the Organic Pollution Index (OPI) [37, 38]. The first was determined based on DO saturation (%), BOD, ammonium and phosphate and the second was based on BOD, nitrites, ammonium and phosphate. Five quality classes are proposed for the values of this index as presented in Table 1.

Table 1: Indexes classes of water pollution according to LISEC and OPI

OPI		LISEC
>4.6	Null pollution	4 – 6
4.6 – 4	Slightly pollution	6 – 10
4 – 3	Moderately pollution	10 – 14
3 – 2	Strongly pollution	14 – 18
< 2	Very strongly pollution	18 – 20

Statistical Analyses

Normality of data was tested and proved before ANOVA test was carried out to compare OPI and LISEC indexes of all the rivers. Correlation between chemical variables, water quality indexes and land use/cover change were analyzed in Past via the Pearson correlation coefficient.

RESULTS

Variation of Physicochemical Parameters in River Tributaries of Lake Kivu, DR Congo Side

Rivers originates from a slightly disturbed mountain region contained low concentrations of nutrients and was nearly saturated with dissolved oxygen (DO), except river Kahuwa, passing through high populated Bukavu city. The physicochemical characteristics of the rivers are present in Table 2.

Table 2: Physical chemical variables of water at different sampling sites along Lake Kivu

River Name	Temp	pH	EC	TDS	OD	% Oxygen	BOD_5	COD	TH	CaH	MgH	Ca	Mg	CO_3^-	Alkalinity	TSS	TP	TN	NH_4
Lwiro	16.6	7	220	100	7.4	71.0	2.4	31.1	75.18	26.85	48.33	0.60	0.65	0	25	0.2	0.11	5.39	4.04
Nkene	23.6	7	270	120	7.5	82.0	2.5	28.9	179.00	60.86	118.14	1.36	1.58	0	30	0.5	0.15	5.36	4.02
Tchoga	21.4	7.1	220	100	6.9	79.0	1.9	28.6	110.98	32.22	78.76	0.72	1.06	0	30	0.6	0.15	4.84	3.63
Cirhanyobowa	17.7	7.2	130	50	4.4	42.0	1.4	32.2	89.50	12.53	76.97	0.28	1.03	0	14	0.2	0.14	6.82	5.12
Nyabarongo	18.1	7.2	180	80	5.5	53.0	0.5	31.8	119.93	14.32	105.61	0.32	1.42	0	31	0.2	0.14	3.76	2.82
Lokola	17.9	7.2	70	30	3.8	42.0	0.8	28	71.60	19.69	51.91	0.44	0.70	0	18	0.1	0.12	6.94	5.21
Luzira	16.9	7.1	70	20	7	73.0	2.0	27.8	68.02	17.90	50.12	0.40	0.67	0	17	0.3	0.09	7.00	5.25
Sangano	19.8	7	40	10	4.6	55.0	1.6	28.3	55.49	10.74	44.75	0.24	0.60	38	83	0.5	0.12	4.55	3.41
Trukakangala	22.6	6.9	140	60	7.5	93.0	2.5	29	87.71	44.75	42.96	1.00	0.58	0	25	0.6	0.17	0.80	0.60
Nyalumbumbo	23.4	7.1	190	90	5.5	58.0	0.5	28.7	114.56	59.07	55.49	1.32	0.74	0	28	0.4	0.09	4.67	3.51

Chirumba	21.5	7.4	310	150	8.8	103.0	3.8	30	179.00	78.76	100.24	1.76	1.34	0	39	0.5	0.14	2.63	1.97
Chibira	18.2	7.4	50	20	4.8	53.0	1.8	31.7	34.01	17.90	16.11	0.40	0.22	0	9	0.4	1.01	7.07	5.30
Lukungula	24.1	7	120	50	5	60.0	2.0	24	75.18	26.85	48.33	0.60	0.65	0	19	0.6	0.12	5.76	4.32
Cishavu	20	7	80	30	3	33.0	0.0	30	78.76	25.06	53.70	0.56	0.72	0	14	0.2	0.11	6.41	4.81
Nyamukubi	18.4	7	80	30	4	42.0	1.0	29.5	68.02	16.11	51.91	0.36	0.70	0	16	0.1	1.04	7.84	5.88
Pungulu	19.4	7.8	80	30	2	22.0	0.0	30	69.81	28.64	41.17	0.64	0.55	0	12	0.1	0.07	7.64	5.73
Kambulula	23.1	7.7	50	20	7.7	92.0	2.7	28.7	59.07	14.32	44.75	0.32	0.60	0	14	0.2	0.09	7.99	5.99
Ndindi	20.3	6.9	70	30	1.7	11.0	0.7	28.2	28.64	17.90	10.74	0.40	0.14	0	25	0.3	0.07	7.08	5.31
Mutabona	18.8	6.9	110	50	8	97.0	3.0	30	51.91	35.80	16.11	0.80	0.22	0	18	0.2	0.07	5.71	4.28
Mukwija	19.1	7.8	580	280	4	43.0	1.0	30.8	78.76	68.02	10.74	1.52	0.14	0	90	0.1	0.21	2.34	1.76
Lurumba	18.1	7.8	100	40	6.7	74.0	3.7	29.5	179.00	25.06	153.94	0.56	2.06	0	17	0.1	0.15	5.98	4.48
Mubambiro	17.3	6.4	1180	580	3.3	31.0	0.3	34.1	105.61	55.49	50.12	1.24	0.67	0	153	0.1	0.16	2.81	2.11
Kihira	19.1	6.4	1200	590	2.5	32.0	1.5	34.1	329.36	80.55	248.81	1.80	3.34	0	171	0.4	0.13	2.62	1.96
Ngaleko	17.1	7.4	800	390	3	31.0	0.0	34.1	340.10	19.69	320.41	0.44	4.30	0	109	0.2	0.18	1.92	1.44
Shasha	17.4	7.7	720	350	1.4	31.0	0.4	31.5	221.96	37.59	184.37	0.84	2.47	0	100	0.1	0.19	2.60	1.95
Mweya	17.3	7.4	130	60	5	52.0	3.0	31.2	227.33	50.12	177.21	1.12	2.38	0	30	0.1	0.16	5.39	4.05
Nyabibale	17.5	7.4	360	170	3.5	52.0	1.5	32.8	94.87	84.13	10.74	1.88	0.14	0	58	0.4	0.16	4.91	3.69
Budindi	20.4	7.3	520	250	1.2	22.0	0.2	29.5	179.00	51.91	127.09	1.16	1.70	0	72	0.2	0.21	3.55	2.66
Cilalo	19.5	7.3	350	170	4	44.0	1.0	31.5	207.64	80.55	127.09	1.80	1.70	0	54	0.3	0.13	3.28	2.46
Mubimbi	17.9	7.3	140	60	2.5	32.0	0.5	31.4	179.00	39.38	139.62	0.88	1.87	0	23	0.3	0.10	6.71	5.04
Makelele	17.6	7.3	140	60	4.3	32.0	2.3	30.9	144.99	39.38	105.61	0.88	1.42	0	24	0.2	0.14	7.55	5.67

Hundu	20.7	7.2	70	30	2	22.0	0.0	31.3	141.41	35.80	105.61	0.80	1.42	0	13	0.2	0.13	8.27	6.20
Nyamasasa	20.4	7.2	100	40	2.5	33.0	0.5	31.2	139.62	41.17	98.45	0.92	1.32	0	20	0.2	0.13	6.68	5.01
Kibimbi	20.3	7.2	80	30	3.8	44.0	1.8	30	64.44	25.06	39.38	0.56	0.53	0	13	0.4	0.11	7.33	5.49
Lwango	20.7	7.1	90	40	5.8	67.0	3.8	30.4	71.60	41.17	30.43	0.92	0.41	0	19	0.2	0.14	6.31	4.73
Mukana	20.3	7.2	60	20	3.5	44.0	1.5	30	46.54	21.48	25.06	0.48	0.34	0	13	0.2	0.15	8.39	6.30
Burundi	25.3	7	150	60	6.1	73.0	4.1	31.5	102.03	57.28	44.75	1.28	0.60	0	27	0.3	0.15	6.41	4.81
Bidagasa	20.6	7	70	20	8	90.0	3.0	32.5	102.03	23.27	78.76	0.52	1.06	0	13	0.1	0.15	5.81	4.36
Mahyuza	39.7	7.5	1220	600	3.8	61.0	1.8	31.4	73.39	59.07	14.32	1.32	0.19	0	200	0.1	0.18	3.38	2.54
Nyaburasha	19.5	7.6	380	180	3.7	44.0	1.7	24.8	302.51	82.34	220.17	1.84	2.95	0	64	0.1	0.17	2.26	1.70
Mirumba	20.2	7.6	50	20	4.5	55.0	2.5	21	193.32	14.32	179.00	0.32	2.40	0	23	0.4	0.19	6.91	5.18
Mushweshwe	17.5	7.2	60	20	3.2	32.0	1.2	27.9	85.92	30.43	55.49	0.68	0.74	0	16	0.3	0.11	8.51	6.39
Karungula	19.7	6.9	90	40	4.2	44.0	2.2	10.6	112.77	26.85	85.92	0.60	1.15	0	21	0.2	0.15	7.96	5.97
Garanywa	18.5	6.9	80	30	3	32.0	1.0	19.2	94.87	25.06	69.81	0.56	0.94	0	15	0.3	0.13	7.48	5.61
Nyamugwe	18.7	6.9	230	110	5.8	65.0	3.8	8.8	105.61	48.33	57.28	1.08	0.77	0	27	0.2	0.18	4.74	3.56
Nachibudundu	19.1	7.5	280	130	4.5	43.0	2.5	9.1	152.15	66.23	85.92	1.48	1.15	0	47	0.1	0.20	3.86	2.89
Kashashomwa	19.3	7.5	200	90	4.3	43.0	2.3	8.3	161.10	73.39	87.71	1.64	1.18	0	29	0.5	0.22	6.94	5.21
Mushuva	18.1	7.4	100	40	1.8	21.0	0.8	7.9	146.78	35.80	110.98	0.80	1.49	0	22	0.2	0.18	6.77	5.08
Mpungwe	17.4	7.3	90	30	1.5	21.0	0.5	8.6	102.03	30.43	71.60	0.68	0.96	0	22	0.1	0.19	7.19	5.39
Kakombo	20.3	7.2	110	50	6	66.0	4.0	8	132.46	32.22	100.24	0.72	1.34	0	24	0.1	0.19	6.60	4.95
Cirehe	20.2	7.2	120	50	1.1	11.0	0.1	8	102.03	37.59	64.44	0.84	0.86	0	29	0.2	0.33	7.96	5.97

Murundu	20.2	7.1	110	50	2.7	33.0	0.7	8.2	93.08	26.85	66.23	0.60	0.89	0	25	0.1	0.30	6.97	5.23
Nyamuhinga	21.9	6.9	250	120	3.5	46.0	1.5	6.3	94.87	57.28	37.59	1.28	0.50	0	39	0.4	0.81	18.71	14.03
Mugaba	21.6	6.9	150	70	2.4	34.0	0.4	7.7	121.72	53.70	68.02	1.20	0.91	0	31	0.5	0.32	6.37	4.78
Chula	22.4	6.9	240	110	4.4	46.0	2.4	7.7	114.56	44.75	69.81	1.00	0.94	0	44	0.4	0.51	7.60	5.70
Wesha	23.2	6.9	210	90	2.7	35.0	0.7	7.4	123.51	53.70	69.81	1.20	0.94	0	36	0.5	0.30	5.86	4.40
Kahuwa	24.4	6.9	870	420	1.4	12.0	0.4	1.7	284.61	73.39	211.22	1.64	2.83	0	120	1.2	0.76	21.04	15.78

Note: Temp: Temperature (ºC); BOD_5: 5-day's biochemical oxygen demand (mg/L); COD: chemical oxygen demand (mg/L); DO: dissolved oxygen (mg/L); TDS: Total Dissolved Sediment (mg/L), EC: Electrical Conductibility (µS/cm2), TH: Total Hardness (mg/L), CaH: Calcium Hardness (mg/L); MgH: Magnesium Hardness (mg/L); Ca: Calcium (mg/L); Mg: Magnesium (mg/L); CO_3^-: Carbonate (mg/L); TSS: Total Suspended Solid (g/L); TP: Total Phosphorus (µmole/L); TN: Total Nitrogen (µmole/L); NH4: Ammonium (µmole/L).

The highest temperature was recorded in Mahyza River (39.7 ºC) while the lowest was recorded in Lwiro River (16.6 ºC). pH is an important parameter in the assessment of water quality. The pH value in the analyzed water samples ranged from 6.4 to 7.8. The electrical conductivity (EC) of the collected samples ranged from 1220 to 40 µS/cm. The highest TDS value was observed in Mahyza River. The EC in river samples correlates with the concentration of total dissolved solids (TDS). The acceptable value of TDS is 500 mg/l. The TDS range of the analyzed water samples varied between 600 and 10 mg/l. Some rivers have a TDS that exceeds the water quality standard. Calcium and magnesium are essential nutrients for humans and help maintain the structure of plant cells and soils. Calcium can easily dissolve from carbonate rocks and limestones or be leached from soils. The acceptable limits of Ca^{2+} and Mg^{2+} are 75 mg/l and 30 mg/l respectively. The estimated Ca^{2+} content of the collected water samples ranged from 1.88 to 0.24 mg/l and the Mg^{2+} concentration ranged from 4.29 to 0.144 mg/l, as shown in Table 2. Ca^{2+} concentrations and Mg^{2+} in the sampled rivers are below the acceptable limit. Higher concentrations of Ca^{2+} and Mg^{2+} were observed in Nyabibale and Ngaleko rivers respectively. The total hardness of the analyzed water samples ranged from 340.1 to 28.64 mg/l in $CaCO_3$. The acceptable limit of total hardness is 200 mg/l. Carbonates and alkalinity in rivers are mainly present in association with Ca^{2+} and Mg^{2+}. The carbonate content of the analyzed water samples ranged from 3.8 mg/l to 0.0 mg/l and the alkalinity content ranged from 200 mg/l to 9 mg/l, as shown in Table 2. carbonate concentration in most water samples was zero except the Sangano River. The acceptable limit of alkalinity is 200 mg/l. Only the Mahyza river has the limit concentration and the other rivers were below the standard. During the sampling period, total suspended solids (TSS) varied from 1.2 to 0.1 g/L in the rivers. The highest TSS concentration was recorded in Kahuwa River. Changes in DO, BOD_5, COD, Ammonium, Total Nitrogen (TN) and Total Phosphorus (TP) were observed in the rivers during the sampling period. The DO varied from 8.5 to 1.1 mg/L in the rivers with 21.1% of rivers with a DO greater than 6 mg/L; 52.6% of rivers with a DO between 6 and 3 mg/L and 26.3% with a DO below 2 mg/L. The DO was close to zero in some rivers. BOD_5 values varied between 4.1 and 0 mg/l during the sampling period. High values were recorded in the Burundi River while the lowest in the Hundu River. Similarly, COD values were between 34.1 and 1.7 mg/l in Mubanbiro, Kihira and Kahuwa rivers respectively. Nutrient phosphorus and nitrogen were assessed in river samples and showed variations. In general, rivers flowing through town and major cities have a higher concentration than rivers coming for other places. High TPs were recorded in Nyamukubi (1.04 µmole/L) and Kahuwa (0.76 µmole/L) rivers while the lowest were recorded in the Ndindi and Mutobona rivers (0.07 µmole/L). For TN, the concentration range was between 21.06 and 0.8 µmol/L in the Kahuwa River and the Trukakangala River.

Water quality assessments using LISEC and OPI indexes

In this study, the LISEC and OPI indexes are computed for all rivers tributaries in the DR Congo side of Lake Kivu. The evaluation of these indexes reveals that there are some rivers, which are polluted at different classes compared to the normal of each index (Figure 1).

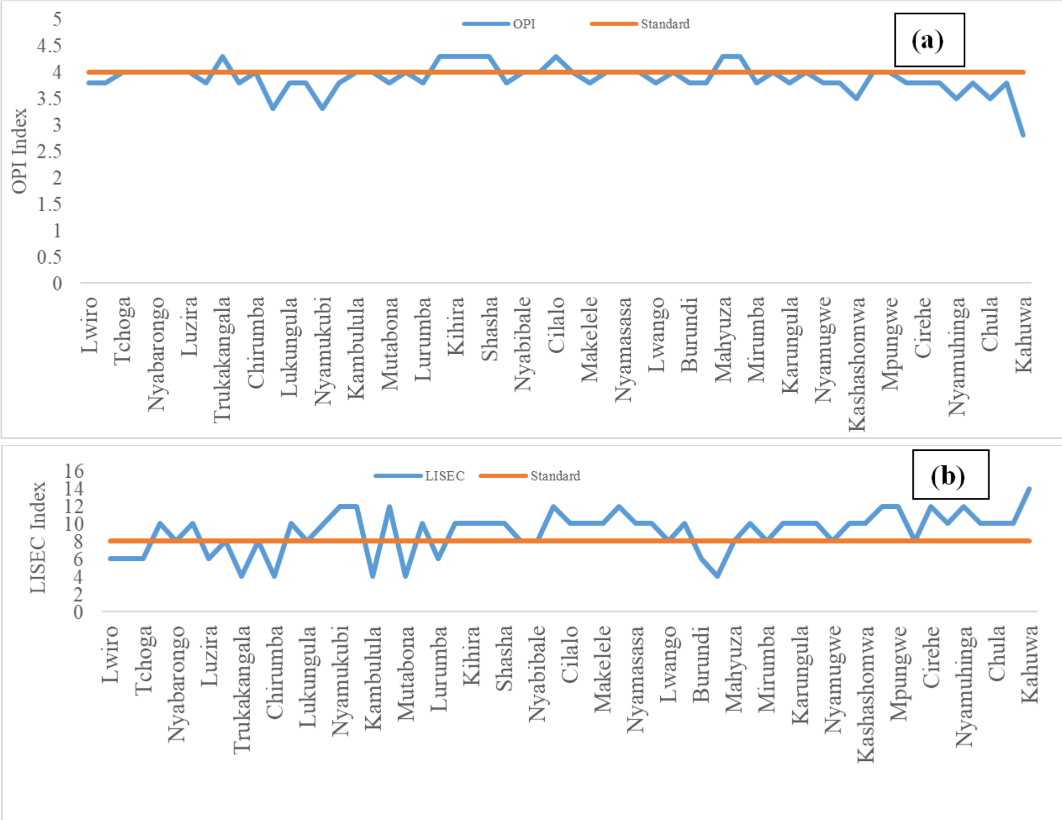

Figure 1: OPI (a) and LISEC (b) indexes evaluation in the river's tributaries of Lake Kivu, DR Congo side (OPI: Organic Pollution index, LISEC: "Laboratoire Interuniversitaire des Sciences de l'Education et de la Communication" Index).

The OPI and LISEC indices vary from one river to another with significant differences ($p<0.05$). High OPI of 4.5 indicate slightly polluted water and 2.8 indicate heavily polluted water. Some rivers have OPI values below the norm in the basin. For the LISEC index, a high value of 14 indicates heavily polluted water and a low value of 4 indicates slightly polluted water. IPO was assessed at all sampling sites, One river (Kahuwa River), indicates severely polluted water quality and moderately polluted water quality in 27 rivers, while slightly polluted water in 29 rivers. While the LISEC index also reveals severely polluted water quality in 1 river (Kahuwa River), moderately polluted water quality in 31 rivers, while slightly polluted water quality in 25 rivers, as shown in Fig. 2.

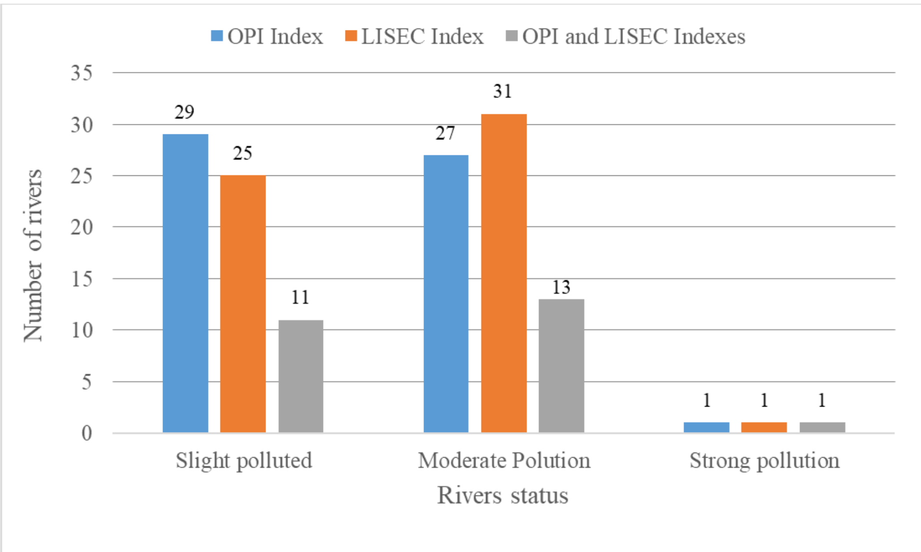

Figure 2: Status of rivers pollution using OPI and LISEC indexes

The comparative analysis of OPI and LISEC results reveals almost similar trend in variation of water quality at all sampling locations. To classify the status of water pollution in the river's tributaries of Lake Kivu in DR Congo side, the indices data and the status of rivers are shown in Table 3.

Table 3: Indices of pollution and status of rivers tributaries of Lake Kivu, DR Congo side

	OPI	**Status**	**LISEC**	**Status**		**OPI**	**Status**	**LISEC**	**Status**
Lwiro	3.8	Moderately	6	Slightly	Mubimbi	4	Slightly	10	Moderately
Nkene	3.8	Moderately	6	Slightly	Makelele	3.8	Moderately	10	Moderately
Tchoga	4	Slightly	6	Slightly	Hundu	4	Slightly	12	Moderately
Cirhanyobowa	4	Slightly	10	Moderately	Nyamasasa	4	Slightly	10	Moderately
Nyabarongo	4	Slightly	8	Slightly	Kibimbi	4	Slightly	10	Moderately
Lokola	4	Slightly	10	Moderately	Lwango	3.8	Moderately	8	Slightly
Luzira	4	Slightly	6	Slightly	Mukana	4	Slightly	10	Moderately
Sangano	3.8	Moderately	8	Slightly	Burundi	3.8	Moderately	6	Slightly
Trukakangala	4.3	Slightly	4	Slightly	Bidagasa	3.8	Moderately	4	Slightly
Nyalumbumbo	3.8	Moderately	8	Slightly	Mahyuza	4.3	Slightly	8	Slightly
Chirumba	4	Slightly	4	Slightly	Nyaburasha	4.3	Slightly	10	Moderately
Chibira	3.3	Moderately	10	Moderately	Mirumba	3.8	Moderately	8	Slightly
Lukungula	3.8	Moderately	8	Slightly	Mushweshwe	4	Slightly	10	Moderately
Cishavu	3.8	Moderately	10	Moderately	Karungula	3.8	Moderately	10	Moderately
Nyamukubi	3.3	Moderately	12	Moderately	Garanywa	4	Slightly	10	Moderately
Pungulu	3.8	Moderately	12	Moderately	Nyamugwe	3.8	Moderately	8	Slightly
Kambulula	4	Slightly	4	Slightly	Nachibudundu	3.8	Moderately	10	Moderately
Ndindi	4	Slightly	12	Moderately	Kashashomwa	3.5	Moderately	10	Moderately
Mutabona	3.8	Moderately	4	Slightly	Mushuva	4	Slightly	12	Slightly
Mukwija	4	Slightly	10	Moderately	Mpungwe	4	Slightly	12	Slightly
Lurumba	3.8	Moderately	6	Slightly	Kakombo	3.8	Moderately	8	Slightly
Mubambiro	4.3	Slightly	10	Moderately	Cirehe	3.8	Moderately	12	Slightly
Kihira	4.3	Slightly	10	Moderately	Murundu	3.8	Moderately	10	Moderately
Ngaleko	4.3	Slightly	10	Moderately	Nyamuhinga	3.5	Moderately	12	Moderately
Shasha	4.3	Slightly	10	Moderately	Mugaba	3.8	Moderately	10	Moderately
Mweya	3.8	Slightly	8	Slightly	Chula	3.5	Moderately	10	Moderately
Nyabibale	4	Slightly	8	Slightly	Wesha	3.8	Moderately	10	Moderately
Budindi	4	Slightly	12	Moderately	Kahuwa	2.8	Severely	14	Severely
Cilalo	4.3	Slightly	10	Moderately					

Legend: Slightly: Slightly pollution; Moderately: moderate pollution and Severely: strong pollution

The status of rivers tributaries of Lake Kivu in DR Congo side presented in table 3 reveals that some rivers are moderately polluted and others are slightly polluted. No rivers were very strongly polluted or with pristine status in the Lake Kivu basin in DR Congo side.

Correlation between physicochemical parameters and water quality indexes

To identify the most significant parameter of water quality and its correlation with other parameters, correlation matrix studies were done. In this study, the correlation matrix of 19 variables and 2 WQI value for the 57 water samples for rivers tributaries of Lake Kivu in DR Congo side was computed using Past software and is presented below in Table 4.

Table 4: Canonical correlation coefficients between physical chemical variables of water and organic index (LISEC and OPI) at sampling sites

	Temp	**pH**	**EC**	**TDS**	**OD**	**%O2**	**BOD**	**COD**	**TH**	**CaH**	**MgH**	**Ca**	**Mg**	**CO3-**	**Alkal**	**TSS**	**TP**	**TN**	**NH4**	**OPI**	**LISEC**
Temp	1																				
pH	-0.03***	1																			
EC	0.31	-0.15	1																		

	TDS	OD	% O2	BOD5	COD	TH	CaH	MgH	Ca	Mg	CO3-	Alkal	TSS	TP	TN	NH4
Temp	0.31	0.08*	0.21	0.12	-0.08*	-0.10	0.24	-0.20	0.24	-0.20	-0.02***	0.37	0.26	0.06**	0.07*	0.07*
pH	-0.14	-0.02***	0.02***	0.04***	0.13	0.11	-0.03***	0.13	-0.03***	0.13	-0.08***	-0.12	-0.32	-0.12	-0.15	-0.15
EC	1.00	-0.24	-0.18	-0.21	0.13	0.50	0.52	0.39	0.52	0.39	-0.10	0.96	0.09*	0.05***	-0.20	-0.20
TDS	1	-0.24	-0.18	-0.21	0.13	0.50	0.52	0.39	0.52	0.39	-0.10	0.96	0.08*	0.05***	-0.20	-0.20
OD		1	0.96	0.78	0.27	-0.21	-0.07**	-0.21	-0.07**	-0.21	0.02***	-0.27	0.05***	-0.17	-0.24	-0.24
%O2			1	0.77	0.28	-0.20	-0.01***	-0.22	-0.01***	-0.22	0.04***	-0.19	0.06**	-0.17	-0.28	-0.28
BOD				1	0.00***	-0.08*	0.08*	-0.12	0.08*	-0.12	0.00***	-0.21	0.00***	-0.10	-0.10	-0.10
COD					1	-0.04***	-0.14	0.00***	-0.14	0.00***	0.05**	0.12	-0.25	-0.33	-0.48	-0.48
TH						1	0.47	0.96	0.47	0.96	-0.14	0.45	0.16***	-0.02	-0.11	-0.11
CaH							1	0.20	1	0.19	-0.19	0.46	0.27***	0.03	-0.11	-0.11
MgH								1	0.20	1.00	-0.09*	0.34	0.09*	-0.03***	-0.09*	-0.09*
Ca									1	0.19	-0.19	0.46	0.27***	0.03	-0.11	-0.11
Mg										1	-0.09*	0.34	0.09*	-0.03***	-0.09*	-0.09*
CO3-											1	0.14	0.15	-0.06**	-0.07**	-0.07**
Alkal												1	0.09*	0.04***	-0.21	-0.21
TSS													1	0.27	0.39	0.39
TP														1	0.51	0.51
TN															1	1
NH4																1
OPI																
LISEC																

	Temp	pH	EC	TDS	OD	%O2	BOD	COD	TH	CaH	MgH	Ca	Mg	CO3-	Alkal	TSS	TP	TN	NH4	OPI	LISEC
OPI	-0.03***	0.11	0.28	0.29	-0.03	0.05***	-0.14***	0.47	0.15	0.06**	0.15	0.06**	0.15	-0.04***	0.29	-0.43	-0.68	-0.71	-0.71	1	
LISEC	-0.15	-0.01***	0.15	0.15	-0.91	-0.95	-0.69	-0.36	0.16	0.06**	0.16	0.06**	0.16	-0.06**	0.16	-0.01***	0.38	0.41	0.41	-0.21	1

Correlation analysis is a preliminary descriptive technique to estimate the degree of association among multiple variables involved in the study. Therefore, a correlation matrix was computed, showing the degree of a linear association between any two of the parameters, and measured by the degree of correlation as a coefficient (R). R-value is used to identify the highly correlated parameters. Value of R ranges from > 0.7 or near to one indicating a strongest positive linear correlation between two parameters compared and 0.6 to 0.69 moderately correlated and 0.5 to 0.59 correlated. The correlation can be positive or negative. There are strong or moderate correlation between some parameters and the water quality index used in this study (LISEC and OPI). This correlation of each parameter with WQI was computed to study the linear association between each parameter with it.

DISCUSSION

The pH values of water samples were ranging between 7.1 and 8.8 in the river's tributaries of Lake Kivu basins in DR Congo side, which exhibit slightly alkaline water quality of rivers. This could be due to the presence of carbonates and bicarbonates of magnesium and calcium. The mean pH of Rivers is between the minimum limit of pH (6.5 to 8.5) for drinking water guideline suggested by WHO [39] and aquatic biodiversity life standard [40]. The EC of water is a useful and easy indicator of its salinity or total salt content. In the present study, the mean EC of the rivers in the basin were less than 1000 µs cm-1, while the EC in the Lake Kivu was reported to be 1250 µs cm-1 [41]. Higher EC values (> 1000 µs cm-1) comparably to the Lake Kivu water were recorded in Mubambiro, Kihira and Mahyuza rivers. The highest TDS in the river Mahyuza revealed the salinity but other rivers were non-saline as classified by Robinove *et al.*, [42] and Rout and Sharma, [43].

The present study revealed that DO in the basins of Lake Kivu, DR Congo side ranged from 5.2 to 7.6 as also found in other basins in the region. The dissolved oxygen reveals the changes occurring in the biological parameters due to aerobic or anaerobic phenomenon and indicates the condition of Water Rivers for accommodating aquatic as well as human life [44]. The aquatic life is disturbed by low DO [45]. To ensure better aquatic life in the water body, DO should range between 4 and 6 mg/L [46] for survival of aquatic life. Oxygen saturation ranged between 11 – 103 % in the different rivers in the basin. And the BOD_5 had a range of 0.8–4.9 mg/L as also reported by Jung *et al.*, [47] in the Nakdong River, which is an important drinking water resource for southeastern Korea for data collected at 28 tributaries.

The high value of TSS might be attributed to the sediments from the nearby areas and water flow, which mixed up the nonliving matter like silt and sand at the bottom of the river during wet season. The high values of TSS have been also reported in other rivers during wet season [18, 48] as also indicated by Chleng *et al.*, [49]. Rivers in Lake Kivu basin, the TSS range from 100 to 1.200 mg/L, higher than the limit from water set by WHO [39]. The highest mean TSS of 1200 mg/L was measured in the river Kahuwa. The other rivers with high TSS (<500 mg/L) were Tchoga, Trukakangala, Lukungula, Wesha, Mugaba, Karhashomwa, Chirumba, Sangano and Nkene.

The highest value of total hardness was recorded in Kihira, Ngeleko, Cilala, Kahuwa and Nyarubasha rivers exceeding the standard limit. According to Durfor and Becker [50] and Rout and Sharma, [43] classification, these rivers are very hard. The high values of alkalinity might be due to excessive input of organic waste as well as enriched wastewater from agricultural and domestic area [51]. Due to the effect of the point source pollutant and runoff, the total phosphorus in a river continues to be mixed regularly thereby causing eutrophication in rivers. Phosphorus is a key limiting factor, and higher concentration causes eutrophication anytime depending on climate change and hydraulic conditions as observed by Lee *et al.*, [52].

In this study, TN concentration in river Kahuwa was higher than those in other rivers in the basin. TN concentration in Kahuwa river was confirmed in previous studies due to the influence of the non-point source pollution of the surrounding arable land [17, 53]. The anthropogenic factor has an important role in the formation and the influence of leakage in water processes on rivers of this hydrographical system. Activities such as household discharges and municipal sewage are the main sources of TN in water environment in general [54-56]. Zhu *et al.*, [55] have found that urban rivers are more easily being impacted by anthropogenic activities since residents are more densely distributed and industrial activities are far more rampant especially with the development of urbanization in China. The main pollution parameters to be considered for surface water quality management, in this study were classified as primary factors in Lake Kivu basin as also obtained by Jung *et al.*, [47]. Based on the above analysis, it was found that Water Rivers are in the polluted category and therefore, it is not suitable for drinking [39]. However, to draw meaningful information, it is essential to classify the overall water pollution status at each river.

The study conducted by Mishra and Kumar, [57] in river Narvada in India using Comprehensive Pollution Index (CPI) and Heavy metal Pollution Index (HPI) showed also moderately pollution as observed in rivers tributaries of Lake Kivu on DR Congo side. Liu [58] showed that the pollution of surface water in Honghe River Watershed was mainly the agricultural non-point source pollution. It mainly included pollutions from livestock and poultry industry, aquaculture industry, planting industry, and rural domestic sewage. Thus, from the matrix, the parameters influencing significantly the level of water quality of an area are evaluated according to Kothari *et al.*, [59]; Bhutiani *et al.*, [60] and Bellizzi *et al.*, [61]. Dunca [62] found that rivers in the heavily modified basin have had a moderate ecological potential as also found in this study. Some parameters are strongly correlated with others as well as water quality index used to evaluate the quality of river tributaries of Leke Kivu on DR Congo side.

Water quality indexes are the most efficacious approach used to define the suitability of water quality assessment of different water resources, predominantly rivers [63-65]. The multiple environmental parameters are effectively combined and converted into one value, which reveals the water quality status. According to the status of rivers in the Lake Kivu basin on DR Congo side, it is shown that the LISEC and OPI indexes reveal that water is moderately polluted in general. These indexes could be used to predict satisfactory and acceptable water quality trends in a river. However, it is to be noted that there is no single standard water quality index reported yet, which could be universally applied to assess the water quality in a water body in the basin and the region.

CONCLUSION

This study provides a better understanding of the state of water quality and the main pollutants of river tributaries of Lake Kivu basin on the DR Congo side. The physico-chemical characteristics of the different rivers vary from one river to another following the anthropic activities around the different sub-basins of the rivers. The state of the rivers presented here reveals that the majority of the river tributaries of Lake Kivu on the DR Congo side are moderately polluted and others are slightly polluted. No river was very heavily polluted or good in the Lake Kivu basin on the DR Congo side. The results obtained in this study can be used as a scientific basis for water resources management and research on water ecology in the Lake Kivu basins. They can also contribute to global research on water security. Given the increase in anthropogenic activities near rivers, more research is needed and the combination of several complex analytical methods should be used in the future to characterize these waters. It is believed that these results could be very useful for pollution control strategies, as well as for future planning and management of the watershed; in addition, they are also useful for further research on water quality simulation and validating simulation accuracy in watershed space.

ACKNOWLEDGEMENTS

We wish to express our gratitude to the following: Bazibuhe, Barhakomerwa, and Kipongo from CRSN/Lwiro for they help to analyses the samples and the late Prof Baluku Bajope for providing financial support for field collection.

BIBLIOGRAPHY

1. Jarvie, H.P., Whitton, B.A. and Neal, C., 1998. Nitrogen and phosphorus in east coast British rivers: speciation, sources and biological significance. Science of the Total Environment, 210-211, 79–109. doi:10.1016/S0048-9697(98)00109-0
2. Ipeaiyeda A.R. and Obaje G.M., 2017. Impact of cement effluent on water quality of rivers: A case study of Onyi river at Obajana, Nigeria, Cogent Environmental Science, 3:1, 1319102, DOI: 10.1080/23311843.2017.1319102
3. Simeonov V., Stratis J. A., Samara C., Zachariadis G., Voutsa D., Anthemidis A., Sofoniou M. and Kouimtzis Th., 2003. Assessment of the surface water quality in Northern Greece. Water Research, 37, 4119–4124. doi: 10.1016/S0043-1354(03)00398-1.
4. Singh K. P., Malik A., Mohan D. and Sinha S., 2004. Multivariate statistical techniques for the evaluation of spatial and temporal variations in water quality of Gomti River (India): a Case Study. Water Res., 38, 3980–3992. https://doi.org/10.1016/j.watres.2004.06.011
5. Qadir A., Malik R. N. and Husain S. Z., 2008. Spatio-temporal variations in water quality of Nullah Aik-tributary of the river Chenab, Pakistan. Environmental Monitoring and Assessment, 140, 1–3, 43–59. doi.org/10.1007/s10661-007-9846-4
6. Chinhanga J. R., 2010. Impact of industrial effluent from an iron and steel company on the physico-chemical quality of Kwekwe River water in Zimbabwe. International Journal of Engineering, Science and Technology, 2, 7, 29–40. DOI:10.4314/ijest.v2i7.63754
7. Wetzel R. G., 2001. Limnology: Lake and Rivers Ecosystems (3rd edn). Academic Press; 1006.
8. Khan M. Y. A. and Wen J., 2021. Evaluation of physicochemical and heavy metals characteristics in surface water under anthropogenic activities using

multivariate statistical methods, Garra River, Ganges Basin, India. Environ. Eng. Res., 26, 6, 200280. Doi.org/10.4491/eer.2020.280
9. Tena T. M., Mudenda F., Nguvulu A., Mwaanga P. and Gathenya J. M., 2021. Analysis of River Tributaries' Streamflow Contribution Using WEAP Model: A Case of the Ngwerere and Kanakatampa Tributaries to the Chongwe River in Zambia. Journal of Water Resource and Protection, 2021, 13, 309-32. DOI: 10.4236/jwarp.2021.134019
10. Bricker O. P. and Jones B. F., 1995. Main factors affecting the composition of natural waters. In: Salbu, B., Steinnes, E. (Eds.), Trace Elements in Natural Waters. CRC Press, Boca Raton, FL, 1-5.
11. Khan M. Y. A., Gani K. M. and Chakrapani G. J., 2016. Assessment of surface water quality and its spatial variation. A case study of Ramganga River, Ganga Basin, India. Arab. J. Geosci., 9, 28. DOI 10.1007/s12517-015-2134-7
12. Kumar R., Chauhan A. and Rawat L., 2017. Physico-chemical analysis of surface and ground water in selected sites of Dehradun, Uttara-khand, India. J Environ Anal Toxicol 6:420. DOI: 10.4172/2161-0525.1000420
13. Khan A., Khan H. H. and Umar R., 2017. Impact of land-use on ground-water quality: GIS-based study from an alluvial aquifer in the western Ganges basin. Appl. Water Sci., 7, 8, 4593–4603. DOI 10.1007/s13201-017-0612-7
14. Finnveden G., Hauschild M. Z., Ekvall T., Guinée J., Heijungs R., Hellweg S., Koehler A., Pennington D., Suh S., 2009. Recent developments in life cycle assessment. J. Environ. Manag., 91, 1–21.
15. Karume, K., Bagalwa, M., Bagula, E., Yalire, M., Habakaramo, P., Byamukama, J. and Mushagalusa, N., 2019. Water Quality in and around Lake Edward Basin of the Greater Virunga Landscape, D. R. Congo Side. Journal of Environmental Protection, 10, 1174-1193. https://doi.org/10.4236/jep.2019.109070
16. Ye L., Li D. F., Tang T., Qu X. D. and Cai Q. H., 2003. Spatial distribution of water quality in Xiangxi River, China. Chin J Appl Ecol., 14, 1959–1962
17. Bagalwa M., Majaliwa J.G.M., Mushagalusa N. and Karume K., 2013. Estimation of transported pollutant load from small urban Kahuwa river micro-catchment in Lake Kivu, Democratic Republic of Congo. Journal of Environment Science and Engineering B 2, 460 – 472.
18. Bagalwa M., Majaliwa J. G. M., Kansiime F., Bashwira S., Tenywa M. and Karume K., 2015. Sediment and nutrient loads into river Lwiro, in the Lake Kivu basin, Democratic Republic of Congo. Int. J. Biol. Chem. Sci., Vol. 9, 3, 1678 – 1690. DOI: 10.4314/ijbcs.v9i3.46
19. Marlier G., 1952. Eudes hydrologiques dans les rivières du Congo Oriental. Annales du Musée Royal du Congo Belge Tervuren (Belgique). Série in N0 8, Sciences Zoologiques, 21, 65p.
20. Bagalwa M**.,** 2006. The Impact of land use on water quality of the Lwiro River, Democratic Republic of Congo, Central Africa. African Journal of Aquatic science, 31, 1, 137 - 143. doi.org/10.2989/16085910609503881
21. Wronski T., Dusabe M. C., Apio A., Hausdorf B. and Albrecht C., 2015. Biological assessment of water quality and biodiversity in Rwandan rivers draining into Lake Kivu. Aquatic Ecology, 49, 3, 309–320. https://doi.org/10.1007/s10452-015-9525-4
22. Muvundja F. A., Wüest A., Isumbisho M., Kaningini M. B., Pasche N., Rinta P. and Schmid M., 2014. Modelling Lake Kivu water level variations over the last seven decades. Limnologica, 47, 21–33. https://doi.org/10.1016/j.limno.2014.02.003
23. Mupenzi C., Lia L., Nahayo L., Amanambu A. C., Kayiranga A., Karamage F., Ndayisaba F., Nyesheja E. M. and Nsengiyumva J. B., 2017. Spatial pattern assessment of Lake Kivu basin rivers water quality using National Sanitation Foundation Water Quality and Rivers Pollution Indices. Desalination and Water Treatment, 95, 118–127.
24. Morana C., Darchambeau F., Roland F. A. E., Borges A. V., Muvundja F., Kelemen Z., Masilya P., Descy J.-P. and Bouillon S., 2015. Biogeochemistry of a large and deep tropical lake (Lake Kivu, East Africa: insights from a stable isotope study covering an annual cycle. Biogeosciences, 12, 4953–4963. doi:10.5194/bg-12-4953-2015
25. Borges A. V., Morana C., Bouillon S., Servais P., Descy J.-P. and Darchambeau F., 2014. Carbon cycling of Lake Kivu (East Africa): Net autotrophy in the epilimnion and emission of CO2 to the atmosphere sustained by geogenic inputs, PLoS ONE, 9, e109500, doi:10.1371/journal.pone.0109500, 2014.
26. Bagalwa M., Majaliwa M. J. G., Kansiime F., Bashwira S., Tenywa M., Karume K. and Adipala E., 2016. Land use and land cover change detection in rural areas of river Lwiro Micro-catchment, Lake Kivu, Democratic Republic of Congo. Journal of Scientific Research & Reports, 9, 2, 1 – 10. DOI: 10.9734/JSRR/2016/15850
27. Meybeck, M. and Helmer R., 1989. The quality of rivers: From pristine stage to global pollution. Global and Planetary Change, 1, 4, 283–309. DOI: 10.1016/0921-8181(89)90007-6
28. Bronmark C. and Hansson L. R., 2002. Environmental issues in lakes and ponds: current state and perspectives. Environmental Conservation, 29, 3, 290–306. https://www.jstor.org/stable/44520612
29. Galloway J. N., Schlesinger W. H., Levy H., Michaels A. and Schnoor J. L., 1995. Nitrogen fixation: anthropogenic enhancement-environmental response. Global

Biogeochemical Cycles 9:235-252. https://doi.org/10.1029/95GB00158
30. Mack R. N., Simberloff D., Lonsdale W. M., Evans H., Clout M. and Bazzaz E, 2000. Biotic invasions: causes, epidemiology, global consequences and control. Issues in Ecology 5:1-20. https://doi.org/10.1890/1051-0761(2000)010[0689:BICEGC]2.0.CO;2
31. Sala O. E., Chapin III F. S., Armesto J. J., Berlow E., Bloomfield J., Dirzo R., Huber-Sanwald E., Huenneke L. F., Jackson R. B., Kinzig A., Leemans R. Lodge D. M., Mooney H. A., Oesterheld M., Poff L. Sykes M. T., Walker B. H., Walker M. and Wall D. H., 2000. Global biodiversity scenarios for the year 2100. Science, 287, 1770–1774. https://doi.org/10.1126/science.287.5459.1770
32. Basima L. B., Mbalassa M., Muhigwa B. and Nshombo M., 2006. Anthropogenic influences on the littoral zone biota of Lake Kivu, Bukavu Basin, D. R. Congo. Internationale Vereinigung für theoretische und angewandte Limnologie: Verhandlungen, 29:5, 2283-2288, DOI: 10.1080/03680770.2006.11903100
33. Olapade O. J., 2012. Anthropogenic pollution impact on microbial contamination of Lake Kivu, Rwanda. West African Journal of Applied Ecology, 20, 23-31.
34. Schmid, M., Tietze K., Halbwachs M., Lorke A., McGinnis D. and Wüest A., 2004, How hazardous is the gas accumulation in Lake Kivu? Arguments for a risk assessment in light of the Nyiragongo Volcano eruption of 2002, ActaVulcanol., 14/15, 115–121. https://archive-ouverte.unige.ch/unige:40722
35. Kakonkwe C., Rwabuhungu D. E. and Biryabireme M., 2020. Drainage Basin of Lake Kivu in the Western Rift of East Africa and Hazards Potential. Rwanda Journal of Engineering, Science, Technology and Environment, 3, 1, DOI: doi.org/10.4314/rjeste.v3i1.1S
36. Hachemi R. L. and Amarchi H., 2012. Impact of urban waste water reject on the quality of watercourse "Case of Oued Meboudja Est of Algeria ». Energy Procedia, 18, 587 – 593. doi: 10.1016/j.egypro.2012.05.071
37. Leclercq L. and Maquet B., 1987. Deux nouveaux indices chimique et diatomique de qualité d'eau courante. Application au Samson et à ses affluents (bassin de la Meuse belge). Comparaison avec d'autres indices chimiques, biocénotiques et diatomiques. Inst. roy. Se. nat. Belg., Document de travail, 38, 113 p.
38. Mezbour R., Reggam A., Maazi M. C. and Houhamdi M., 2018. Evaluation of organic pollution index and the bacteriological quality of the water of the Lake of birds (ELTarf East-Algerian). J. Mater. Environ. Sci., 9, 3, 971-979. DOI: 10.26872/jmes.2018.9.3.108
39. WHO (World Health Organization), 2011. Guidelines for Drinking-Water Quality, WHO Press, Geneva, Switzerland, 4th edition,
40. UNECE, 1994. Standard Statistical Classification of Surface Freshwater Quality for the Maintenance of Aquatic Life. In *Readings in International Environment Statistics.* United Nations Economic Commission for Europe: United Nations, New York and Geneva.
41. Muvundja A. F., Pasche N., Bugenyi W. B. F., Isumbisho M., Müller B., Namugize J. P., Rinta P., Schmid M., Stierli R. and Wüest A., 2009. Balancing Nutrient Inputs to Lake Kivu. Journal of Great Lakes Research, 35, 406-418. doi.org/10.1016/j.jglr.2009.06.002
42. Robinove C. J., Langford R. H. and Brookhart J. W., 1958, Saline water resource of North Dakota, In US Geological Survey Water Supply, Paper No. 1428, pp 72.
43. Rout C. and Sharma A., 2011. Assessment of drinking water quality: A case study of Ambala cantonment area, Haryana, India. International journal of environmental sciences, 2, 2, 933 -945
44. Chang H., 2005. Spatial and temporal variations of water quality in the Han River and its tributaries, Seoul, Korea, 1993-2002.
45. Cox B. A., 2003. A review of currently available instream water-quality models and their applicability for simulating dissolved oxygen in lowland rivers. The Science of the Total Environment, 314-316, 335–377. doi: 10.1016/s0048-9697(03)00063-9.
46. Gupta N., Pandey P. and Hussain J., 2017. Effect of physicochemical and biological parameters on the quality of river water of Narmada, Madhya Pradesh, India. Water Science, 31, 11–23. https://doi.org/10.1016/j.wsj.2017.03.002
47. Jung K.-Y., Cho S., Hwang S.-Y., Lee Y., Kim K. and Na E. H., 2020. Identification of high-priority tributaries for water quality management in Nakdong River using neural networks and grade classification. Sustainability, 12, 9149. doi.org/10.3390/su12219149
48. Ndahama N., Bagalwa M., Batumike C., Ndegeyi K., Zirirane N., Bahizire K. and Buzenga M., 2014. Impact de l'agriculture sur la variabilité journalière des sédiments en suspension et leur flux dans la rivière Cirhanyobwa, Lac Kivu, République Démocratique du Congo. International Journal of Innovation and Applied Studies, 7, 4, 1391-1399. http://www.ijias.issr-journals.org/
49. Chleng Y. S., Theany R., Sokheng L., Candra E. and Kongken P., 2018. Assessment of physical properties of the rivers water in Phnom Penh and its suburban area. The bulletin of Cambodian chemical society, 9, 29-35.
50. Durfor C.N. and Becker E., 1964. Public water supplies of the 100 largest cities in the United States. In Geological Survey Water Supply, U.S.

Government Printing Office, Washington, Paper No. 1812, pp. 364.
51. Sharma A., Bora C. R. and Shukla V., 2013. Evaluation of Seasonal Changes in Physico-chemical and Bacteriological Characteristics of Water from the Narmada River (India) Using Multivariate Analysis. Nat. Resour. Res., 22, 283-296. https://doi.org/10.1007/s11053-013-9204-x
52. Lee S.-H., Jung S.-G., Park S.-M. and Lee B.-D., 2018. Evaluation of the tributaries by influence index on the mid-lower portion of the Nakdong River basin. Environ. Eng. Res., 23, 2, 150-158. doi.org/10.4491/eer.2017.067
53. Zirirane D., Bagalwa M., Isumbisho M., Mulengezi M., Mukumba I., Bora M., Mucheso J.M., Lukamba A., Iragi K. G, Irenge B., Kibangu F., & Kamangala R., 2014. Évaluation comparée de la pollution des rivières Kahuwa et Mpungwe par l'utilisation des macroinvertébrés benthiques, *VertigO - la revue électronique en sciences de l'environnement* [En ligne], Volume 14 Numéro 3, 21p. http://vertigo.revues.org/15365 ; DOI : 10.4000/vertigo.15365
54. Qing X., Ren Y., Lu Z., Wang X., Pang R., Deng H., Meng L. and Ma H., 2005. Characteristics of Total Nitrogen and Total Phosphorus pollution and eutrophication assessment of Secondary River in Urban Changqing. Environ. Sci., 36, 7, 2446 – 2452.
55. Zhu S., Mostafaei A., Luo W., Jin B. and Dai J., 2019. Assessing water quality for urban tributaries of the three Gorges reservoir, China. Journal of Water Reuse and Dissemination, 9, 1, 105 – 114.
56. An J. M., Jung K. Y., Kim S., Lee H. J., Shin S. H., Yang D. S., Shin D. S. and Na S. M., 2017. Development and application of the Grid-Distributed Model for contribution rate analysis on non-point source pollution according to land use. J. Korean Soc. Water Environ., 33, 78–89 https://doi.org/10.15681/KSWE.2017.33.1.78
57. Mishra S. and Kumar A., 2021. Estimation of physicochemical characteristics and associated metal contamination risk in the Narmada River, India. Environ. Eng. Res., 26, 1, 190521. doi.org/10.4491/eer.2019.521
58. Liu Q., 2012. Analysis of water pollutant load and application research on respective countermeasures in Hong River Watershed from upper reach of the Huaihe River. Thesis, Nanjing University.
59. Kothari V., Vij S., Sharma S. K. and Gupta N., 2021. Correlation of various water quality parameters and water quality index of districts of Uttarakhand. Environmental and Sustainability Indicators, 9, 100093. https://doi.org/10.1016/j.indic.2020.100093
60. Bhutiani, R., Ahamad, F., Tyagi, V. and Ram, K., 2018. Evaluation of water quality of River Malin using water quality index (WQI) at Najibabad, Bijnor (UP) India. Environ. Conserv. J. 19, 191–201. DOI: 10.36953/ECJ.2018.191228
61. Bellizzi, V., Nicola, L.D., Minutolo, R., Russo, D., Cianciaruso, B., Andreucci, M. and Andreucci, V.E., 1999. Effects of water hardness on urinary risk factors for kidney stones in patients with idiopathic nephrolithiasis. Nephron 81 (1), 66–70. doi: 10.1159/000046301.
62. Dunca A. M., 2018. Water Pollution and Water Quality Assessment of Major Transboundary Rivers from Banat (Romania). Hindawi Journal of Chemistry, Volume 2018, Article ID 9073763, 8 pages https://doi.org/10.1155/2018/9073763
63. Sutadian A. D., Muttil N., Yilmaz A. G. and Perera B. J. C., 2016. Development of river water quality indices—a review. Environ Monit Assess, 188, 58. doi: 10.1007/s10661-015-5050-0.
64. Mohebbi M. R., Saeedi R., Montazeri A., Vaghefi K. A., Labbafi S., Oktaie S. and Mohagheghian A., 2013. Assessment of water quality in groundwater resources of Iran using a modified drinking water quality index (DWQI). Ecol. Indic., 30, 28–34. DOI 10.1016/j.ecolind.2013.02.008
65. Iqbal K., Ahmad S. and Dutta V., 2019. Pollution mapping in the urban segment of a tropical river: is water quality index (WQI) enough for a nutrient-polluted river? Applied Water Science, 9,197, 16p.https://doi.org/10.1007/s13201-019-1083-9