



# Threat Assessment of Lake Ecosystems: A Review of Sediment-Contaminant Dynamics Lake Kivu

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## Abstract

Urban river pollution causes serious problems to the environment, sedimentation of shore, human health, and water scarcity. This study compared the sediments at the weir level of rivers in the city of Bukavu, Lake Kivu basin in the Democratic Republic of Congo between 2003 and 2021. To do this, Google earth images from 2003 and 2021 were used and data was processed by the cartographic software ArcGIS 10.7.1. The rivers are at the base of the displacements of the sediments in Lake Kivu and in 2021 on these sediments of Lake Kivu are built homes anarchically. The invasion of the shore of the lake is not only the work of the rivers, in certain places the population of Bukavu brings piles of earth which it pours into the lake and thereafter it erects houses on these lands which it considers to be parcels. The authorities must protect this heritage which also contains a large quantity of methane gas which constitutes not only a threat but also and above all an opportunity for wealth for the country.

## Subject Areas

Environment

## Keywords

Sediments, Lake Kivu, Embankments, River Pollution, Urban River

## 1. Introduction

Sterner *et al.* (2022) [1] and Jenny *et al.* (2022) [2] show that, approximately 1.35 million tons of fish are harvested each year from the 25 largest lakes in the world by commercial or artisanal fisheries, with approximately 95% of this harvest coming from the African large lakes. Indeed, in developing countries and indigenous communities especially, the food provided by large lakes can represent key components of the diet. Aquaculture, a growing industry within the waters of several large lakes (e.g., [3]), also provides a source of protein to a growing human population, along with employment opportunities and economic benefits. However, large lakes can offer supplemental resources to human populations, or in some regions the necessary resources to sustain populations [4].

The excessive production of sediments, considered as a vector of environmental disturbances due to anthropogenic activities, is increasing in many regions of the globe and leading to various water pollutions [5].

In the Lake Kivu basin (specifically in Bukavu and its surroundings), there are enough aquatic systems that show signs of pollution resulting from human activities [6]. The sediment supplies of rivers in organic matter [7] [8] as in suspended inorganic matter [9] [10] [11], in Lake Kivu as elsewhere, underwent a drastic change a few decades ago. This is the direct consequence of the anarchic occupation of the slopes of different rivers in the city of Bukavu. The dynamism of the habitat and the development of a city depend on the natural increase of the population within the city and the rural exodus [12].

[9] found that  $84.26187 \text{ m}^3$ , on average, of suspended solids were carried by the Tshula River, one of the urban watercourses of the city of Bukavu, in the 8 months covered by his study. These sediments will result in an increase in the solid load (sediment flow) of the watercourses and the deposition of the sediments towards the lower latitudes, already at the level of the lake. Downstream, not only are these deposits a threat to the aquatic fauna and flora [13] but they are also a significant vector for modifying the morphology of the shore of Lake Kivu [9] [14] and upstream the uprooted sediments have a negative impact on food security because it is the fertile part of the soil that is subject to this erosion.

The work of [9] comparing two satellite images of the SNCC bay, one from 1973 and the other from 2008, showed that a drift of sediments about 100 m wide was made in 35 years, *i.e.* a sedimentation rate of about 3 m per year. While [9] observed in 2012 that the fact justifying rapid sedimentation of the Tshula River in Lake Kivu is the fact that from 100 to 300 meters from the coast, *i.e.* in the middle of the lake Kivu recognized for its steep coasts, the water only reaches the level of the belt of an adult man (1.20 to 1.30 m in height). We therefore realize that the Tshula River-Lake Kivu interface is characterized by significant alluvium of this first. Of different mass and densities, it came to stop there by setting up an alluvial plain of a shape similar to a triangular area. This delta, in which the bed runs over 162.9 meters in length, is between 0 and 1.60 meters above the level of Lake Kivu (1460 meters above sea level). This alluvial plain,

with an area of about 2.5 to 2.7 hectares reclaimed from the lake, is today densely inhabited by the urban population (places where small fishing canoes for *Limnothrissa miodon* and *Haplochromis dock*, culture of amaranths, Bar-restaurant with beach) [9].

Erosion in the watershed (upstream), which influences the turbidity of the watercourse [15] and the rapid sedimentary accumulation in the lake [9], is considered as a disorder that disturbs the balance of aquatic life and often attracts the attention of biologists.

An increasing number of anthropogenic activities, however, represent additional disturbances that lead to the acceleration of erosion and siltation processes and the input of fine sediments into the water column. The presence of excessive amounts of sediment influences the processes of heat transmission in the water column, which inevitably modifies the amount of dissolved oxygen [16] but also by limiting the penetration of light, the load turbidity reduces photosynthesis processes and can lead to phases of anoxia, particularly in lake systems [17]. Effects on aquatic organisms are generally grouped into two categories; direct effects: physiological disorders, behavioral changes and mechanical damage; and the indirect effects that result from an alteration of the habitat and their food resources. The level of susceptibility of different aquatic organisms can vary greatly between species and is dependent on their biological requirements.

This work analyzes the sediments between 2003 and 2021 at the level of the weirs of the rivers of the city of Bukavu, basin of Lake Kivu in the Democratic Republic of the Congo. Specifically, it is a question of identifying the main places where the modifications of the shore of the lake are observable, evaluating the zones and perimeters of sediments deposited by watercourses and deducting the sedimentation rate.

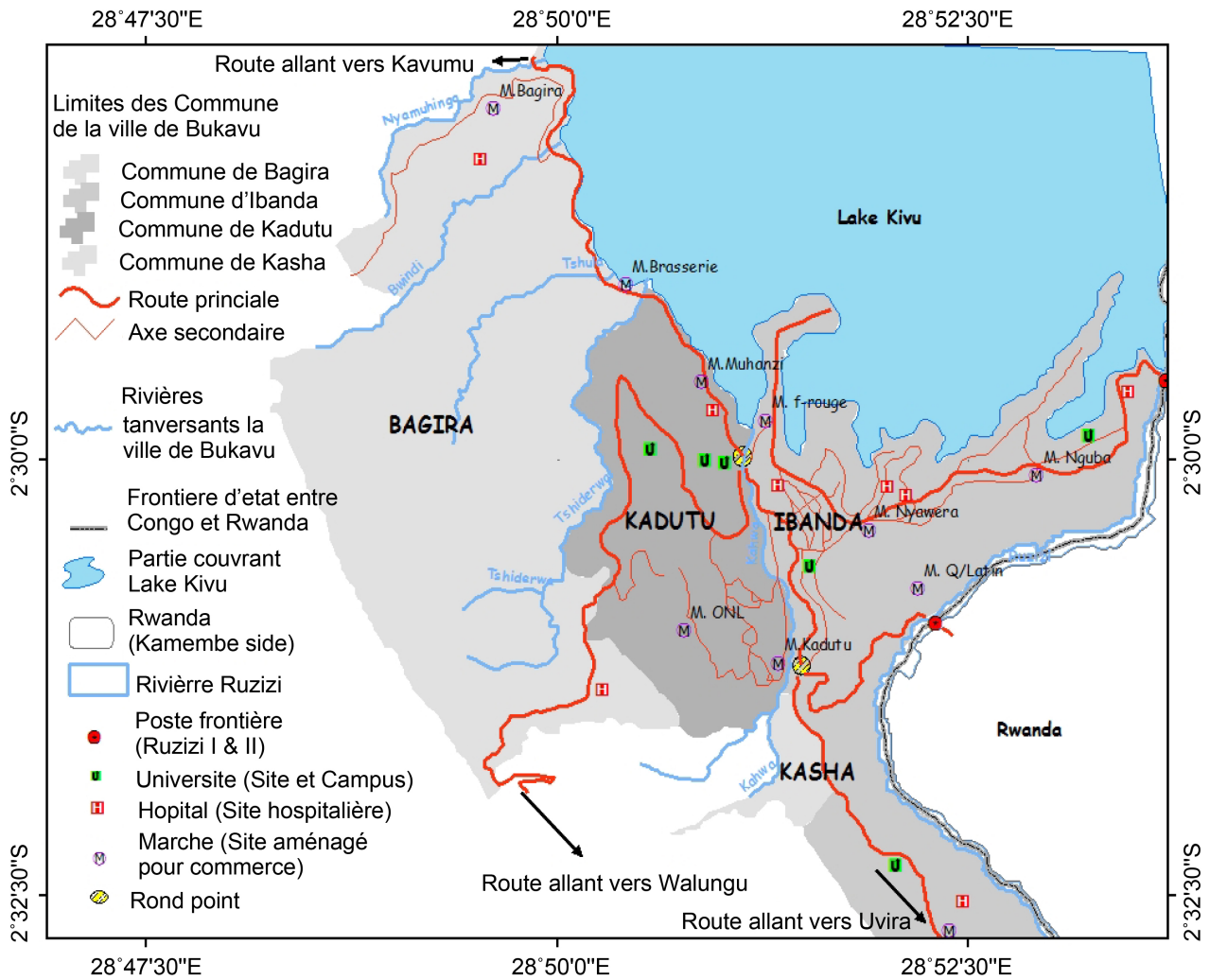
## 2. Methodology

To identify and define the problem related to the threats, a documentary research and, then a field visit to the points subject to the threats were carried out and the sampling of the geographical coordinates using the GPS (Garmin Map 64s) were made there (Figure 1).

Then, mapping and remote sensing were done to have the evolution over time of sedimentary deposits caused by watercourses on the shore of Lake Kivu. To do this, Google earth images from 2003 and 2021 were used. Then again, the data was processed by the cartographic software ArcGIS 10.7.1. In it, the calculation of the surfaces and perimeters of the sedimentary deposits was carried out. The area of sediment deposited from 2003 to 2021 was taken divided by 18 as the number of years.

## 3. Results

The mapping of areas of Lake Kivu vulnerable to change due to sedimentary deposition is as follows.



**Figure 1.** Rivers visited in the city of Bukavu (Blue line).

### 3.1. Bukavu Bay (SNCC): Kahwa River

On the left, **Figure 2** shows the occupation of the waters of Lake Kivu in 2003 and on the right in 2021, Lake Kivu is invaded by sediments transported by the Kahwa River. The area of these sediments calculated in ArcGIS is 18773.100 m<sup>2</sup>, with a perimeter of 1068.520 m. Anarchic constructions are put in place at the location of the sediments (**Figure 3**).

### 3.2. Wesha River

Also, **Figure 4** below shows the occupation of water in 2003 (left) and sediment with anarchic constructions in 2021 (right). The area of these sediments calculated in ArcGIS is 2686.730 m<sup>2</sup>, with a perimeter of 374.894 m.

### 3.3. Tshula River

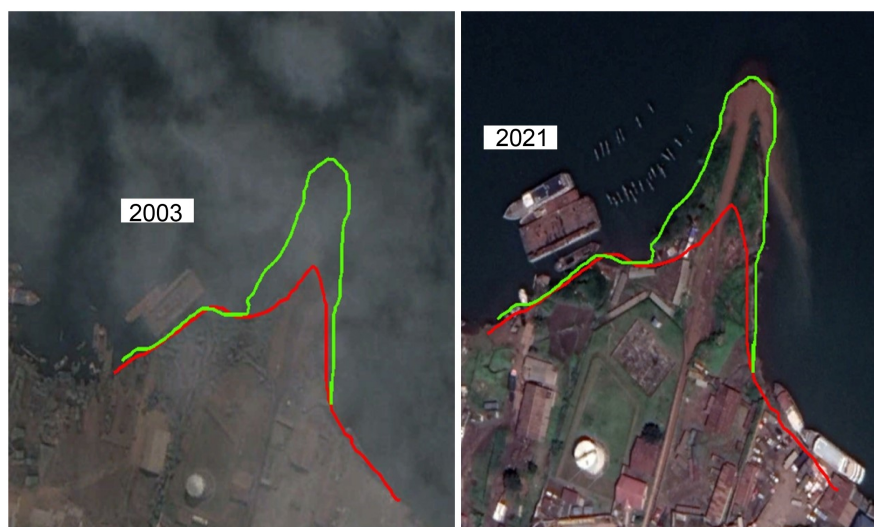
Tshula River presents the occupation of waters in 2003 (left) and of sediments with anarchic constructions in 2021 too (right). The area of these sediments



**Figure 2.** Bukavu bay: Kahwa River.



**Figure 3.** Anarchic constructions on the sediments deposited in the bay of Bukavu (SNCC).



**Figure 4.** The mouth of the Wesha River.

calculated in ArcGIS is 4745.520 m<sup>2</sup>, with a perimeter of 473.574 m (**Figure 5**).

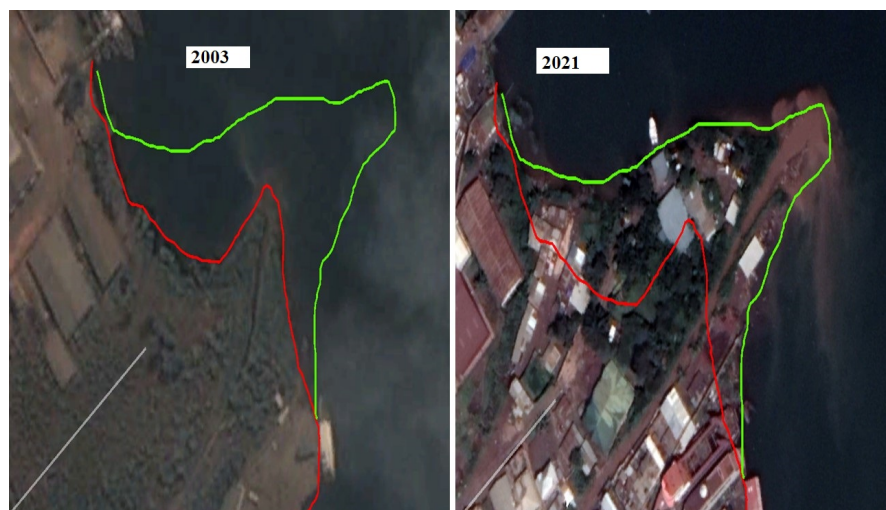
### 3.4. Mugaba River (Bwindi)

On the Mugaba River (Bwindi), the area of these sediments calculated in ArcGIS is 6834.720 m<sup>2</sup>, with a perimeter of 617.370 m. **Figure 6** presents the occupation of waters in 2003 (left) and of sediments with anarchic constructions in 2021 too (right).

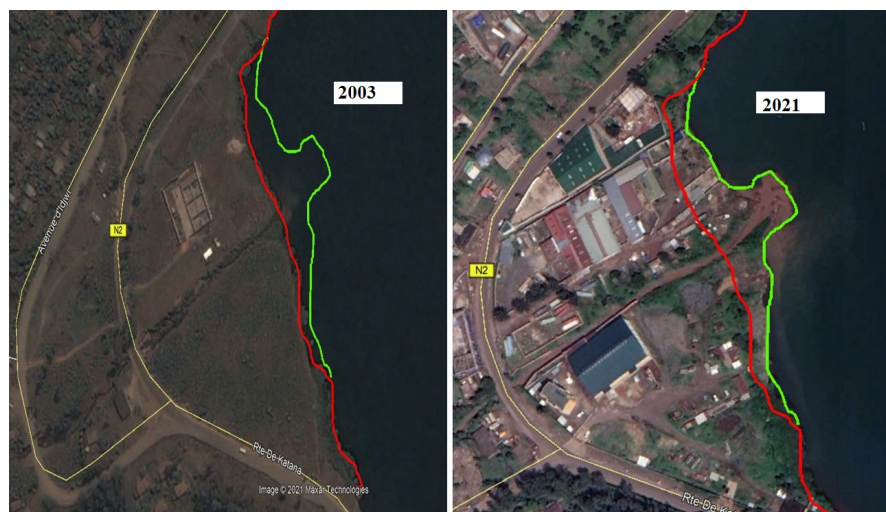
### 3.5. Nyamuhinga River (Towards Kazingo)

Again, on the Nyamuhinga River (Towards Kazingo), the area of these sediments calculated in ArcGIS is 4730.950 m<sup>2</sup>, with a perimeter of 617.370 m. Also, **Figure 7** below shows the occupation of water in 2003 (left) and sediment with anarchic constructions in 2021 (right).

**Table 1** presents the watercourses studied, the surface areas of the sediments



**Figure 5.** The mouth of the Tshula River.



**Figure 6.** The mouth of the Mugaba River.



**Figure 7.** The mouth of the Nyamuhinga River.

**Table 1.** Sediment area and Perimeter of watercourse.

Name of watercourse	Sediment area (m <sup>2</sup> )	Perimeter (m)
Kahwa	18773.100	1068.520
Wesha	2686.730	374.894
Tshula	4745.520	473.574
Mugaba	6834.720	617.370
Nyamuhinga	4730.950	467.204

and their perimeters.

From this table, it appears that the Kahwa River has a large sediment area and perimeter, followed by Mugaba, then Tshula, again Nyamuhinga and finally Wesha.

#### 4. Discussion

The rivers are at the base of the displacements of the sediments in Lake Kivu as illustrated in **Figure 8**. [18] and [19], the wastewater effluents and soil erosion (coupled with heavy runoff and agricultural land-use practices) have a significant impact on nutrients in Lake Kivu tributaries.

But, the invasion of the shore of the lake is not only the work of the rivers, in certain places the population of Bukavu brings piles of earth which it pours into the lake and thereafter it erects houses on these lands which it considers to be parcels. There is also a lot of rubbish, household and industrial waste that is poured into Lake Kivu. These are nuisances to the environment (**Figure 9**).

In 2021 on these sediments of Lake Kivu are built homes anarchically. Thus, Samir and Ahobangeze [20] show that natural increase is another factor in the demographic growth of the city. Urban immigration is all the greater in that the average population density of the Bukavu hinterland is the highest in the country. According Majoro *et al.* [21] and Muvundja *et al.* [22], surface water plays a



**Figure 8.** The coloring of the Kakombo River following siltation due to the sediment load resulting from erosion in the catchment area.



**Figure 9.** Illustration of a wild deposit for the extension of the plot at the edge of the lake.

significant role in the development of a country and individual citizens as sources of food, water, transport, hydropower and recreation. Zou *et al.* [23] show that the development of urban environments generates increasing flows of pollutants into aquatic environments from urban drainage networks and storm water management systems. In addition, urban runoff can alter the chemical quality of watercourses, as it entrains suspended sediments with adsorption. N and P nutrients, as well as other pollutants that accumulate on roads and parking lots during periods of low rainfall [24] [25]. Waste in charge and wastewater or leachate have led to diffuse water pollution [26] [27]. Thus, Muvundja *et al.* [22] reported high concentration of sediments in water retrogrades the economy of a country and the polluted water affect the livelihoods of people living in the vicinity and can kill aquatic life. Again, [28] reported in globally, soil erosion increases the amount of sediment transported in rivers at a rate of 2.3 billion tons per year.



## 5. Conclusions

The bays are ideal places for the reproduction of fish, given their physico-chemical characteristics (they are relatively calm places, sheltered from turbulence). Unfortunately, the rivers carry sediments which come to invade these places with all kinds of pollution (physical and biochemical); which will have a negative impact on the lake ecosystem. Their habitat being thus threatened following this modification, the fish will migrate and seek a favorable habitat (perhaps towards Rwanda). Man is thus impacted because the ecosystem services provided by the lake will decrease. This is one of the direct consequences of anarchic constructions in the watersheds of rivers. Man commits anthropogenic actions in the watershed, there is thus excessive production of sediments and rich in nutrients. The nutrients contained in the sediments can lead to eutrophication which can lead to the proliferation of aquatic plants (sometimes toxic). This phenomenon will thus limit the penetration of the sun's rays into the bottom of the lake. Following this the heat of the bottom of the lake is found modified but also the photosynthetic activity, and the fish will seek a refuge. Following the migration of fish, the services rendered by the lake ecosystem to man are reduced, thus impacting it.

The authorities must protect this heritage which also contains a large quantity of methane gas which constitutes not only a threat but also and above all an opportunity for wealth for the country.

## Conflicts of Interest

The author declares no conflicts of interest.

## References

- [1] Sterner, R.W., Keeler, B., Polasky, S., Poudel, R., Rhude, K. and Rogers, M. (2020). Ecosystem Services of Earth's Largest Freshwater Lakes. *Ecosystem Services*, **41**, Article ID: 101046. <https://doi.org/10.1016/j.ecoser.2019.101046>
- [2] Jenny, J.-P., Anneville, O., Arnaud, F., Baulaz, Y., Bouffard, D., Domaizon, I., Bocaniov, S.A., Chèvre, N., Dittrich, M., Dorioz, J.-M., Dunlop, E.S., Dur, G., Guillard, J., Guinaldo, T., Jacquet, S., Jamoneau, A., Jawed, Z., Jeppesen, E., Krantzberg, G. and Lenters, J. (2020) Scientists' Warning to Humanity: Rapid Degradation of the World's Large Lakes. *Journal of Great Lakes Research*, **46**, 686-702. <https://doi.org/10.1016/j.jglr.2020.05.006>
- [3] Jia, B., Tang, Y., Tian, L., Franz, L., Alewell, C. and Huang, J.H. (2015) Impact of Fish Farming on Phosphorus in Reservoir Sediments. *Scientific Reports*, **5**, Article No. 16617. <https://doi.org/10.1038/srep16617>
- [4] Carpenter, S.R., Benson, B.J., Biggs, R., Chipman, J.W., Foley, J.A., Golding, S.A., Hammer, R.B., Hanson, P.C., Johnson, P.T.J., Kamarainen, A.M., Kratz, T.K., Lathrop, R.C., McMahon, K.D., Provencher, B., Rusak, J.A., Solomon, C.T., Stanley, E.H., Turner, M.G., Vander Zanden, M.J., Wu, C.-H. and Yuan, H. (2007) Understanding Regional Change: A Comparison of Two Lake Districts. *BioScience*, **57**, 323-335. <https://doi.org/10.1641/B570407>
- [5] Zirirane, D., Bagalwa, J.J., Isumbisho, M., Mulengezi, M., Mukumba, I., Bora, M.,

- Mucheso, J.M., Lukamba, A., Iragi, G., Irengé, B., Kibangu, F. and 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*, **14**, Article No. 15365. <https://doi.org/10.4000/vertigo.15365>
- [6] Bagalwa, M., Majaliwa, J.G.M., Kansime, 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. *International Journal of Biological and Chemical Sciences*, **9**, 1678-1690. <https://doi.org/10.4314/ijbcs.v9i3.46>
- [7] Pasche, N., Dinkel, C., Müller, B., Schmid, M., Wüest, A. and Wehrli, B. (2009) Physical and Biogeochemical Limits to Internal Nutrient Loading of Meromictic Lake Kivu. *Limnology and Oceanography*, **54**, 1863-1873. <https://doi.org/10.4319/lo.2009.54.6.1863>
- [8] de Morais, C.P., Tadini, A.M., Bento, L.R., Oursel, B., Guimaraes, F.E.G., Martin-Neto, L., Mounier, S. and Milori, D.M.B.P. (2021) Assessing Extracted Organic Matter Quality from River Sediments by Elemental and Molecular Characterization: Application to the Tietê and Piracicaba Rivers São. *Applied Geochemistry*, **131**, Article ID: 105049. <https://doi.org/10.1016/j.apgeochem.2021.105049>
- [9] Birembano, B.R. (2012). Inondations et sédimentation dans les basses terres du littoral du lac Kivu à Bukavu: Cas du bassin versant de la Tshula, Mémoire de DEA, UPN Kinshasa.
- [10] Hirslund, F. (2012). An Additional Challenge of Lake Kivu in Central Africa—Upward Movement of the Chemoclines. *Journal of Limnology*, **71**, Article No. e4. <https://doi.org/10.4081/jlimnol.2012.e4>
- [11] Kulimushi, M.S., Mugaruka, B.T., Muhindo, S.W., Michellier, C. and Dewitte, O. (2017) Glissements de terrain et éléments à risque dans le bassin versant de la Weshu (Bukavu, RD Congo). Landslides and Elements at Risk in the Weshu Watershed (Bukavu, DR Congo). *Geo-Eco-Trop*, **41**, 233-248.
- [12] Nzuzi, F.L. (2008) Kinshasa, Ville et Environnement. L'Harmattan, Paris, 282 p.
- [13] Tramblay, Y., Saint-Hilaire, A., Ouarda, T.B.M.J., Moatar, F. and Hecht, B. (2010) Estimation of Local Extreme Suspended Sediment Concentrations in California Rivers. *The Science of the Total Environment*, **408**, 4221-4229. <https://doi.org/10.1016/j.scitotenv.2010.05.001>
- [14] Sadiki, A., Bouhlassa, S., Auajjar, J., Faleh, A. and Macaire, J.J. (2004) Utilisation d'un SIG pour l'évaluation et la cartographie des risques d'érosion par l'Équation universelle des pertes en sol dans le Rif oriental (Maroc): Cas du bassin versant de l'oued Boussouab. *Bulletin de l'Institut Scientifique, Rabat, section Sciences de la Terre*, No. 26, 69-79.
- [15] Lubis, K.S., Harahap, E.M., Rauf, A. and Hasibuan, Z.A. (2015) Dynamic Model of Suspended Sediment Concentration, River Discharge and Rainfall Intensity at Padang Watershed North Sumatra, Indonesia. *International Journal of Scientific & Technology Research*, **4**, 68-73.
- [16] Vachon, N. (2003) L'envasement des cours d'eau: Processus, causes et effets sur les écosystèmes avec une attention particulière aux Catostomidés dont le chevalier cuivré (*Moxostoma hubbsi*). Société de la faune et des parcs du Québec, Direction de l'aménagement de la faune de Montréal, de Laval et de la Montérégie, Longueuil, Rapport technique 16-13, vi + 49 p.
- [17] Gratiot, N. (2010) Impact des sédiments cohésifs sur l'écosystème. Hydrologie. Université Joseph-Fourier-Grenoble I, 2010. tel-00534075v2
- [18] Bisimwa, M.A., Mwanuzi, F. and Nobert, J. (2014) Water Quality Management in

- Lake Kivu Basin, DR Congo: Estimation of Nutrient and Sediment Loading into Lake Kivu from Bukavu Sub-basin. Lambert Academic Publishing, Germany, 128 p.
- [19] Lina, A.A., Buregeza, H., Mindele, U., Bouezmarni, M. and Vassel, J.-L. (2015) Parasitological Loads of Rivers Crossing the City of Bukavu, Democratic Republic of Congo. *International Journal of Innovation Science and Research*, **19**, 412-422
- [20] Samir, C., Ahobangeze, N. (1981). Evolution et structure de la population de Bukavu. *Cahiers d'Outre-Mer*, **34**, 43-56. <https://doi.org/10.3406/caoum.1981.2969>
- [21] Majoro, F., Wali, U., Munyaneza, O., Naramabuye, F., Bugenimana, E. and Mukamwambali, C. (2020) Sediment Transport and Its Impacts on Lake Kivu, Gihira Water Treatment Plant and Various Hydropower Plants along Sebeya River in Rwanda. *Journal of Water Resource and Protection*, **12**, 934-950. <https://doi.org/10.4236/jwarp.2020.1211055>
- [22] 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. <https://doi.org/10.1016/j.jglr.2009.06.002>
- [23] Zou, L., Xia, J. and She, D. (2018) Analysis of Impacts of Climate Change and Human Activities on Hydrological Drought: A Case Study in the Wei River Basin, China. *Water Resources Management*, **32**, 1421-1438. <https://doi.org/10.1007/s11269-017-1877-1>
- [24] Lu, W., Wu, J., Li, Z., Cui, N. and Cheng, S. (2019) Water Quality Assessment of an Urban River Receiving Tail Water Using the Single-Factor Index and Principal Component Analysis. *Water Supply*, **19**, 603-609. <https://doi.org/10.2166/ws.2018.107>
- [25] WWAP (United Nations World Water Assessment Programme) (2017) The United Nations World Water Development Report 2017. Wastewater: The Untapped Resource. United Nations Educational, Scientific and Cultural Organization, Paris, 174 p.
- [26] Ololade, O.O., Mavimbela, S., Oke, S.A. and Makhadi, R. (2019) Impact of Leachate from Northern Landfill Site in Bloemfontein on Water and Soil Quality: Implications for Water and Food Security. *Sustainability*, **11**, Article No. 4238. <https://doi.org/10.3390/su11154238>
- [27] Naveen, B.P., Sumalatha, J. and Malik, R.K. (2018) A Study on Contamination of Ground and Surface Water Bodies by Leachate Leakage from a Landfill in Bangalore, India. *International Journal of Geo-Engineering*, **9**, Article No. 27. <https://doi.org/10.1186/s40703-018-0095-x>
- [28] Syvitski, J.P., Smarty, J.V., Kettner, J.A. and Pamela, G. (2005) Impact of Humans on the Flux of Terrestrial Sediment to the Global Coastal Ocean. *Science*, **308**, 376-380. <https://doi.org/10.1126/science.1109454>