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# Using the Multi-metric Index of Biotic Integrity methodological approach to determine the major river catchment that most pollutes a lake

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*We present the Multi-metric Index of Biotic Integrity methodological approach that allows for the ranking of major river catchments based on pollution status in the Kenyan portion of Lake Victoria, Africa. The study has a broader applicability to all of Lake Victoria, other African Great Lakes, and all lakes that have riverine discharge. The method presented utilizes water quality and environmental data, local knowledge, and pre-existing literature. The parameters considered were sampled from 2016 to 2018 during the dry season (July sampling) and the wet season (March sampling). Separation power of Mann-Whitney U test ($p < 0.05$) qualified 11 discriminant metrics for both macroinvertebrate and fish samples into the scoring system of 1, 3 and 5 in the formulation of final Multi-metric Index of Biotic Integrity methodological approach. Rivers in the northern section had lower Multi-metric Index of Biotic Integrity methodological approach scores, as compared to southern counterparts. The Multi-metric Index of Biotic Integrity methodological approach ranking herein was validated by community perceptions on pollution levels. River Nzoia catchment emerged as the most polluted, followed by River Yala, River Kuja, and Sondu-Miriu. Siltation, domestic washing, litter and refuse emerged as the main agents of pollution. Management authorities ought to reinforce a balanced utilization of the vital water resources to minimize future impacts, and promote catchment wide practices that ensure ecological health sustainability of the lake ecosystem.*

*Keywords:* lake basin, river, management

## Introduction

Freshwater regional studies in ecology, hydrology, and socio-economics have been done in isolation in terms of catchments and components. This situation has made it impossible to provide an integrated and holistic description of the basin. For example, management efforts of Lake Victoria Basin (LVB) have been hampered by lack of clear holistic standards against which to judge the



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degree of biodiversity loss due to pollution and environmental degradation. Moreover, management priorities for the Lake Victoria catchment need to be based upon reliable assessments on the biological integrity of the inflowing rivers that potentially influence biodiversity, moderation of climate variation, ecological functioning of the lake and social well-being. This is because changes in the aquatic systems dynamics have been found to affect the community structure of biota which are assessed by indices and models as useful societal decision support tools for ecosystem health management (Aura et al., 2010; Masese et al., 2013). This calls for a robust, cost-effective and integrative approach of characterisation of the biological, physical, and chemical approaches that are linked to societal perceptions in the assessment and monitoring of LVB for improved management and conservation. In this regard, the development of a basin-wide Multi-metric Index of Biotic Integrity (MMIBI) that could be linked to societal inputs could demonstrate the utility in scientifically determining the extent of pollution impacts in relation to communal perceptions as a scientifically defendable rationale for developing guidelines for conservation and management.

An index of biotic integrity as a multi-metric approach, has gained unprecedented interest and growth (Karr and Dudley, 1981; Barbour et al., 1999; Raburu et al., 2009). Metric in this context, is defined as an attribute with empirical change in value based on one's study, along a gradient of human disturbance, e.g. land use changes or environmental condition change (Masese et al., 2013; Aura et al., 2017) in a given ecosystem. It is a system that integrates all the indicators in one model and it is therefore of paramount importance and has the potential to give a more detailed status of the ecological health of an aquatic ecosystem.

However, there is paucity of information on using MMIBI in ranking of major river catchments that drain into a lake in order to come up with sustainable management measures to ensure improved benefits for all water users. This can also mitigate downstream pollution effects on lake-river ecosystem health as river water is utilized for all water users. Therefore, there is need for information and data on the major river drainage systems of lakes such as Lake Victoria to understand the problems that are related to water quality changes, disruption of free fish movements, sustainable utilization of riverine associated wetland resources, impacts from river sand harvesting. Such information is useful for the protection of the river catchments and associated ecosystems as hotspots of biological diversity and for the sustainability of the lake basin. The current study developed an integrated MMIBI to determine the river catchment that pollutes Lake Victoria, Kenya the most as a prerequisite for further management and conservation measures of the ecosystem.

# Methods

## Study area

The current study focused on the lower reaches of the rivers Nzoia, Yala, Sondu-Miriu, and Kuja as the representative major river catchments and most notable biodiversity hotspots for Lake Victoria (Figure 1). The level of representation was based on predominance of anthropogenic activities, distance variations, locality, type of river mouths and discharge levels. Rivers Nzoia and Yala constituted the northern section and Rivers Kuja and Sondu-Miriu were the southern representatives. River Nzoia is the largest river among them, with a length of 257 km and a catchment of 12,842 $km^2$, contributing about 15% of the total influx into the lake. The river originates from Mt. Elgon and Cherang'ani hills through Kitale plain, which forms part of the pre-Miocene period and has a slight southerly tilt with the principal drainage system eventually flowing into Lake Victoria near Port Victoria in Busia County (Government of Kenya, 2014). The river is important to a population of over 3.5 million people in Western Kenya. It supports an artisanal fishery, particularly during the rainy seasons (Balirwa and Bugenyi, 1980), acts as a source of water for livestock, irrigation, industries and domestic uses, besides the rich biodiversity (Graham, 1929). The river is threatened by catchment activities like conversion of wetlands into farms, urban developments, poor management of domestic and industrial wastes, and leaching of agrochemical residues causing decreased forest cover, increased soil erosion and river pollution (Yi et al., 2010). The effluents from factories along the river may not only alter fish

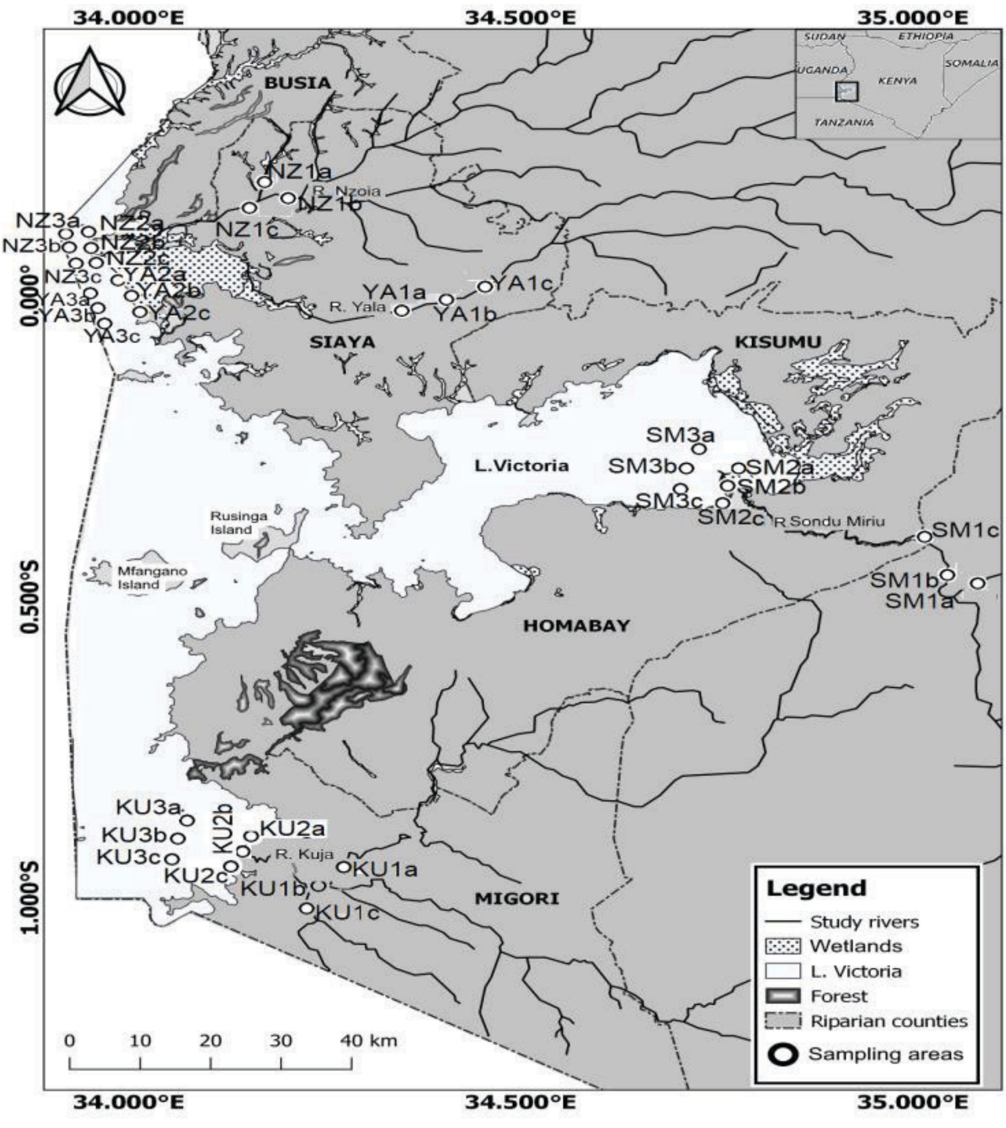


**Figure 1.** Location of the study sites within the stations of (a) River Kuja (KU), (b) River Sondu-Miriu (SM), (c) River Yala (YA), and (d) River Nzoia (NZ). Sampling sites included River Kuja: KU1a, b, c – River Kuja upstream channel; KU2a, b, c – Kuja River mouth before discharge; KU3a, b, c - Kuja River mouth after discharge. Sondu–Miriu: SM1a, b, c – River Sondu-Miriu upstream; SM2a, b, c – River Sondu-Miriu river mouth before discharge; SM3a, b, c – Sondu-Miriu River mouth after discharge. River Yala: YA1a, b, c - River Yala upstream; YA2a, b, c - Yala River mouth before discharge, YA3a, b, c – Yala River mouth after discharge. River Nzoia: NZ1a, b, c - River Nzoia upstream, NZ2a, b, c –Nzoia River mouth before discharge, NZ3a, b, c - Nzoia River mouth after discharge.

species composition but is also likely to affect the behaviour of fish (Balirwa, 1979). At the same time, these activities have the potential to compromise the water quality of the river water, which may affect the fisheries community structure and human health downstream.

## Development of a Multi-metric Index of Biotic Integrity approach

Information on schematic representation of the criteria used in the MMIBI are shown in the Supplementary Material 1 (see SM1 in the supplementary file to the online version of this article). It was made up of characterization of sampling site, data collection of physico-chemical parameters, macroinvertebrates and fish as indicators of pollution, MMIBI development, and validation using significant physico-chemical parameters. The methodology was further validated using community perceptions on pollution of ranking sources.

## Sampling sites for indicators of pollution

Sampling sites for measurements of all indicator parameters followed a longitudinal transect from upstream and downstream of the river channel, and based on the major land-cover or land-use activity (Raburu et al., 2009; Aura et al., 2017), to the lake–river interface before discharge, and another site after discharge into the lake (Masese et al., 2013). Sampling occurred in the July for the dry season and in March for the wet season sampling in 2016 - 2018. Triplicate samples were collected objectively with consideration of the various microhabitats (the riffle, the pool and the run) (Aura et al., 2010). Where possible, both sides of the riverbanks and the mid-section of the river channel were sampled by boat. Due to lack of significant variations between microhabitats and seasons, replicate samples were averaged per station.

Before sampling for physico-chemical, flora and fauna characteristics, general environmental observations about the stations like the maximum depth of the sampling site, time of sampling, weather conditions, station features and Global Positioning System (GPS) location coordinates were noted.

## Physico-chemical parameters

In situ physico-chemical longitudinal profile measurements can provide insight into the pollutants from river catchments that are entering the lake (Okely et al., 2010). Standard methods were used for in situ data collection and sampling (APHA, 2005). Portable electronic water quality meters were used to collect data on the physico-chemical parameters. The main physical and chemical parameters measured electronically consisted of temperature (°C), dissolved oxygen (DO, mg $l^{-1}$), and pH using OAKTONR, Model pH/Mv/◦C METER, Singapore), and conductivity (using OAKTONR, Model WD-35607-10, Singapore, µS $cm^{-1}$). Water transparency was measured with a standard Secchi disk. Water samples for nutrient fractions were collected directly from sampling stations using pre-treated 1 Litre polyethylene sample bottles. The bottles were labelled, filled, preserved using sulphuric acid and stored in cooler boxes at temperatures of about 4 °C, for further laboratory analysis using photometric methods for total nitrogen (TN, µg $l^{-1}$) and total phosphorus (TP, µg $l^{-1}$) according to APHA (2005).

## Macroinvertebrates

Several authors have noted that macroinvertebrates respond to changes in water chemistry, with areas of poor water quality recording lower densities than pristine environments (Masese et al., 2012; Aura et al., 2010). Macroinvertebrates samples were collected using a scoop net (1 $m^2$ covered bottom, with a 0.5 mm mesh size), and a brush was used to scrape on stony surfaces and collected in a bucket. The samples were sorted and analysed as per methods described by Merritt and Cummins (1997) on the suppositions that the US determination keys have previously been applied in the region (e.g. Raburu et al., 2009; Aura et al., 2010); and that the coarse taxonomic resolution still gives a good basis for the discrimination ability of the MMIBI.

## Fish

Fish are good indicators of water quality because of their sensitivity to pollution (Mora et al., 2008). At the upstream sites, electro-fishing was undertaken using a generator-powered electrofisher (Smith-Root Type VI-A) at the same zone with other sampled parameters on an average of 30 minutes depending on accessibility and the shoreline characteristics during base-flows and high-flow periods. At the river mouths, two fleets monofilament gillnets (mesh sizes 0.5” - 2”) were set parallel and perpendicular to the shoreline and away from direct water flow but within the river-lake inter-phase. The nets were soaked for two hours before retrieval after which the fish were sorted into species level and biological measurements done according to standard operating procedures for biological monitoring as described by Windell

(1968) and Hyslop (1980).

## Multi-metric Index of Biotic Integrity methodological approach and data analyses

Macroinvertebrates and fish mean (± SE) relative abundance, dominance, Shannon-Wiener diversity index (H'), and the beta diversity index were analysed based on methods suggested by Karr and Dudley (1981), Aura et al. (2010, 2017) and Masese et al. (2012, 2013). The classifications into metrics as interpretations of community responses to different types of stressors in the lake region consisting of functional feeding groups (FFG), richness, composition and tolerance was based upon literature of previously used aquatic ecosystems around the world (i.e. Karr and Chu, 1997; Richards et al., 1997; Barbour et al., 1999; Karr and Chu, 2000) and in an African context to suit local conditions (Kibichii et al., 2007; Aura et al., 2010, 2017; Masese et al., 2013).

The physico-chemical data collected were compared using the non-parametric Kruskal-Wallis one-way ANOVA to examine the uncertainty and spatial variations between sites. This is because data were not normally distributed and attempts to normalize the data by transformations were unsuccessful. The reference site varied per comparison to accommodate variations of high fauna and flora diversity due to environmental conditions of the adjacent land use in relation to the pollution of impaired sites (Masese et al., 2013; Aura et al., 2018b). Data were pooled due to lack of monthly and annual variations ($p > 0.05$) in physico-chemical parameters, macroinvertebrate and fish abundances (Aura et al., 2017). The MMIBI development used the methods suggested by Raburu et al. (2009), Aura et al. (2010) and Masese et al. (2012, 2013) but with a combination of both macroinvertebrate and fish community responses to different types of stressors in the region that were mainly due to site variations, land use and pollution. In this case, we evaluated the ability of attributes to separate each sampled site from a reference site using Mann–Whitney U tests. Potential metrics for MMIBI scoring were identified when the tests showed significant differences ($p < 0.05$ in more than two cases of sampled sites pair-wise comparison) between site groups.

A scoring criterion of 1, 3 and 5 with the thresholds of median-ranges for each metric of 25$^{th}$ and 75$^{th}$ percentiles based on the control site was used, which has been commonly used in Index of Biotic Integrity (IBI) assessments (Raburu et al., 2009; Aura et al., 2010, 2017). For each metric expected to decrease with pollution, values below the 25$^{th}$ percentile were scored as 1. Values between the 25$^{th}$ and 75$^{th}$ percentiles were scored as 3, and values above the 75$^{th}$ percentile were scored as 5. The scores for each metric were summed up in order to arrive at the final MMIBI value for each sampling site for either macroinverbrates or fish assemblages. The highest expected value of 55 points served as a benchmark for the four-class scheme based on the distribution of MMIBI scores, which were used as the threshold for the pollution–response relationships (Paulsen et al., 2008) of MMIBI scores. The study used integrity classes of excellent, good, fair, and poor as quantitative levels to come out with a scenario that could easily be interpreted by the policy makers (Aura et al., 2010). The highest and lowest threshold ranges of > 46 and < 30 points were used to avoid a large deviation from all the MMIBI final values (see SM2 in the supplementary file to the online version of this article). On the other hand, the middle ranges were based on the higher (> 46) and lower (< 30) threshold integrity class ranges with an equal class size, and at the same time to avoid much deviation from the actual description of the representative sampled sites.

The study used Microsoft Excel 2016 for data entry and cleaning while SPSS version 21 (SPSS Inc., Chicago, IL, USA) and R version 3.5.0 (R Core team, 2014) were used for statistical analyses. The significance level was set at an alpha of 0.05.

## Validation of Multi-metric Index of Biotic Integrity methodological approach

The MMIBI of macroinvertebrates and fish assemblages were validated in order to establish the robustness of ranking of major river catchments in relation to lake pollution (Aura et al., 2010). This was undertaken using field data for community perceptions on major river catchment integrity classes of pollution of Lake Victoria. Respondent interviews using semi-structured questionnaires and participant observation were used. Field socioeconomics data was collected from 128 respondents that were purposely chosen. Those who stayed in close proximity to the river, depended on the river economically and socially, and had at least 20 years of continuous residence were preferred for interviews. This was based on the assumption that they could answer more accurately on the observed changes that the river system had experienced overtime. Snow-ball sampling technique was used when more information was required and reference was made to a key informant on certain river issues (Aura et al., 2018a). Friedman's test was used to perform a non-parametric analysis on the ranks of river catchments due to perceptions on pollutant levels. The null hypothesis (Ho) was set to indicate that there was no significant difference ($p < 0.05$) in the respondents' ranking of rivers based on the pollution of the lake.

# Results and discussion

## Physico-chemical parameters

Conductivity, TP and TN showed spatial variations (Kruskal-Wallis ANOVA; $p < 0.05$) which could be attributed to differences in pollution levels of the sampled sites (see SM2 in the supplementary file to the online version of this article). Generally, the highest mean (± SD) conductivity values were recorded at river mouths and with River Kuja upstream site recording the highest levels (KU1: 162.0 ± 3.0 µS $cm^{-1}$). River mouths recorded the highest TP and TN levels in all the sampled sites. The lowest levels of TP (< 70 µg $l^{-1}$) occurred in the upstream areas of Rivers Yala and Kuja. There were marked variations (Kruskal-Wallis ANOVA; $p < 0.05$) in mean (± SD) depth and mean (± SD) width. Organic and inorganic matter and mineral grain size showed gradual differences downstream. The in situ physico-chemical parameters and longitudinal profile measurements of these response variables provide insight into the water quality from river catchments that are entering the lake and for further inter-lake comparisons (Okely et al., 2010). The high conductivity, TN and TP levels could be related to increased nutrient enrichment in the lake due to increased anthropogenic activities and the nature of the bay (Masese et al., 2013).

## Multi-metric index of Biotic Integrity

The study was based on the lower reaches of Lake Victoria Basin that may capture the resultant effects of the representative major river catchment's pollution status and the possible impact on the lake. More adjustments for the MMIBI may be required in the future to compare the upper sections of the major river catchments and in relation to the lower sections. In the MMIBI developed, only those taxa that were considered to belong to the taxa richness, composition, tolerance and trophic or diet functions by consensus of most researchers and experts were used in this study (Copp et al., 1991; Karr and Chu, 1997; Barbour et al., 1999; Masese et al., 2013). Although, there is still a debate on the taxa groupings to pollution and anthropogenic influence (Aura et al., 2010). A total of 11 orders representing 36 families and 46 genera were found in the river mouth sites, with the highest and lowest number of genera recorded at NZ1 and NZ3 (19) and at SM1 (1), respectively (see SM3 and SM4 in the supplementary file to the online version of this article).

Of the metrics that were selected, 11 of them differed significantly ($p < 0.05$) between sampling sites and thus they were assumed to have discrimination among them and were excluded in the metric discrimination since both groups did not show significant relationships ($p < 0.05$) after pair-wise comparisons using Mann-Whitney U tests (see SM5 in the supplementary file to the online version of this article).

In the final MMIBI, Kuja River (KU) emerged with the highest average MMIBI for macroinvertebrates (36 points with moderate riverine ecosystem quality) and fish assemblages (41 points with good riverine quality), (Table 1 and 2). On the other hand, Rivers Nzoia and Yala recorded poor riverine quality. The aforementioned MMIBI findings coincided with local perceptions and knowledge (see SM6 in the supplementary file to the online version of this article). Siltation was largely blamed for increased flooding downstream which affected farms and houses, especially in Rivers Nzoia and Yala. Rivers Sondu-Miriu and Kuja moderate MMIBI scores could further be explained by siltation and domestic washing, and

**Table 1.** Development of MMIBI for ranking of major river catchments (Rivers: Nzoia – NZ, Yala – YA, Sondu-Miriu – SM, Kuja – KU) in relation to pollution status in the lower reaches of Lake Victoria, Kenya using **a)** Macroinvertebrates metrics and scoring criteria; and **b)** Fish metrics used and scoring criteria (system).

| **a) Macroinvertebrates** | **River Nzoia** | | | **River Yala** | | | **River Sondu-Miriu** | | | **River Kuja** | | | **Scoring criteria** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Metrics** | **NZ1** | **NZ2** | **NZ3** | **YA1** | **YA2** | **YA3** | **SM1** | **SM2** | **SM3** | **KU1** | **KU2** | **KU3** | **5** | **3** | **1** |
| Number Ephemeroptera taxa | 3 | 1 | 3 | 1 | 3 | 5 | 5 | 5 | 5 | 5 | 3 | 5 | 46-34 | 33-22 | <22 |
| Number Trichoptera taxa | 3 | 1 | 3 | 3 | 3 | 3 | 5 | 3 | 3 | 5 | 3 | 5 | >84 | 84-63 | <63 |
| Number Hemiptera taxa | 1 | 5 | 1 | 1 | 3 | 1 | 3 | 3 | 5 | 3 | 1 | 5 | 71-59 | 58-31 | <31 |
| Shannon diversity index | 3 | 3 | 5 | 3 | 1 | 5 | 1 | 1 | 5 | 3 | 3 | 3 | >3.05 | 3.05-2.7 | <2.7 |
| % Hemiptera | 1 | 5 | 3 | 1 | 3 | 3 | 3 | 3 | 3 | 1 | 1 | 3 | <0.40 | 0.40-0.60 | >0.6 |
| % Trichoptera | 1 | 1 | 1 | 1 | 5 | 3 | 1 | 1 | 1 | 3 | 1 | 1 | >30 | 15-30 | <15 |
| % Tolerant taxa | 3 | 1 | 1 | 1 | 5 | 5 | 1 | 1 | 3 | 3 | 5 | 3 | <32 | 32-42 | >42 |
| % Dominant taxon | 5 | 3 | 5 | 5 | 3 | 3 | 1 | 3 | 3 | 3 | 5 | 5 | >16 | 8-16 | <8 |
| % scraper | 3 | 3 | 1 | 5 | 1 | 3 | 1 | 3 | 5 | 1 | 3 | 3 | >21 | 9-21 | <9 |
| % shredders | 5 | 3 | 5 | 5 | 1 | 5 | 3 | 3 | 5 | 3 | 1 | 5 | >28 | 15-28 | <15 |
| % filterers | 3 | 1 | 1 | 1 | 1 | 1 | 5 | 3 | 1 | 5 | 5 | 5 | <9 | 9-17 | >17 |
| **Total MMIBI Score** | **31** | **27** | **29** | **27** | **29** | **37** | **29** | **29** | **39** | **35** | **31** | **43** | | | |
| **River MMIBI** | | **29** | | | **31** | | | **32** | | | **36** | | | | |
| **b) Fish** | **River Nzoia** | | | **River Yala** | | | **River Sondu-Miriu** | | | **River Kuja** | | | **Scoring criteria** | | |
| **Metrics** | **NZ1** | **NZ2** | **NZ3** | **YA1** | **YA2** | **YA3** | **SM1** | **SM2** | **SM3** | **KU1** | **KU2** | **KU3** | **5** | **3** | **1** |
| Number of *Barbus* sp. | 5 | 3 | 3 | 3 | 5 | 3 | 3 | 3 | 5 | 3 | 3 | 3 | >13 | 13-8 | <8 |
| Number of *Labeo* sp. | 1 | 3 | 5 | 1 | 3 | 5 | 3 | 1 | 3 | 5 | 3 | 3 | >24 | 24-13 | <13 |
| Number of *Clarias* sp. | 1 | 3 | 3 | 3 | 1 | 3 | 1 | 3 | 5 | 3 | 5 | 3 | <7 | 7-14 | 15-24 |
| Number of *Synodontis* sp. | 3 | 3 | 1 | 3 | 5 | 1 | 3 | 5 | 1 | 3 | 3 | 5 | <5 | 5-15 | >15 |
| Shannon diversity index | 1 | 3 | 5 | 3 | 3 | 5 | 1 | 3 | 5 | 5 | 3 | 5 | >3.05 | 3.05-2.7 | <2.7 |
| Beta diversity index | 5 | 3 | 5 | 3 | 3 | 5 | 3 | 3 | 5 | 5 | 1 | 5 | >0.50 | 0.30-0.50 | <0.30 |
| % Dominant taxon | 3 | 1 | 3 | 1 | 5 | 1 | 3 | 1 | 5 | 3 | 5 | 5 | >10 | 10-20 | <10 |
| % Insects remains | 1 | 3 | 3 | 3 | 1 | 3 | 3 | 5 | 1 | 1 | 3 | 3 | >30 | 30-20 | <20 |
| % Odonata | 3 | 3 | 1 | 3 | 3 | 5 | 5 | 3 | 3 | 5 | 3 | 3 | <10 | 10-16 | >16 |
| % Chironomids | 5 | 3 | 3 | 5 | 3 | 5 | 5 | 3 | 5 | 5 | 3 | 5 | <11 | 11-25 | >25 |
| % Plant remains/detritus | 3 | 3 | 5 | 5 | 3 | 5 | 5 | 5 | 5 | 3 | 5 | 5 | <15 | 15-30 | >30 |
| **Total MMIBI Score** | **31** | **31** | **37** | **33** | **35** | **41** | **35** | **35** | **43** | **41** | **37** | **45** | | | |
| **River MMIBI** | | **33** | | | **36** | | | **38** | | | **41** | | | | |

refuse that were common in all the studied rivers, despite the fact that litter was minimal in River Kuja. Furthermore, Friedman's test indicated significant difference in the ranking of rivers based on the pollutants ($F_r = X^2$ (8, N = 4) = 11.57, p = 0.00) in which River Yala recorded a mean rank of 6.22, followed by River Nzoia (5.01), River Sondu-Miriu (4.03), and River Kuja (3.13). The order coincided with the ranking of rivers discharging into Lake Victoria with respect to perceived pollution status and with the MMIBI scoring, but with Rivers Nzoia and Yala swapping positions.

# Conclusions

Thus, MMIBI developed the order of ranking based on pollution status from most polluting to the least polluting was River Nzoia > River Yala > River Kuja > River Sondu-Miriu which coincided with

**Table 2.** Suggested threshold values of riverine ecosystem integrity classes for final Multi-metric Index of Biotic Integrity (MMIBI) development showing the classification level and ranges for ranking pollution levels in the lower reaches of Lake Victoria, Kenya during the study period.

| Integrity class | Description | Ranges |
|---|---|---|
| 1: Excellent | High quality and clear water (can see the bottom based on turbidity and depending on depth); very low level of pollution and degradation. | > 46 |
| 2: Good | Good water quality; slight pollution characteristics and degradation | 39 - 46 |
| 3: Moderate | Moderate water quality; significant pollution levels and degradation | 31 - 38 |
| 4: Poor | Poor water quality; major/heavy pollution and degradation | < 30 |

community perceptions. The current study forms a potential candidate in the ranking of the major river catchments pollution influence on lake ecosystems. We therefore recommend the application of the approach herein in other biodiversity hotspots in other lake ecosystems to act as a proof of concept for balanced utilization of the vital water resources to minimize future impacts, and promote catchment wide practices that ensure sustainability of the ecological health of the diverse ecosystems.

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## Supplementary material

Supplemental material for this article can be accessed on the publisher's website.

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