International Journal of Biology Sciences 2023; 5(1): 171-181

International Journal of Biology Sciences

ISSN Print: 2664-9926
ISSN Online: 2664-9934
Impact Factor: RJIF 5.45
IJBS 2023; 5(1): 171-181
www.biologyjournal.net
Received: 13-02-2023
Accepted: 21-03-2023

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Biomonitoring using stream invertebrates in Kenya: A review of status, challenges and future prospects

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DOI: https://dx.doi.org/10.33545/26649926.2023.v5.i1c.161

Abstract
Biomonitoring refers to the use of living organisms to evaluate the ecological condition of the environment. Although aquatic biomonitoring using invertebrates has a long historical background in developed countries, its application in assessment of aquatic ecosystems in developing countries is relatively limited. The objective of this paper is to review the status, challenges and future prospects for invertebrate-based biomonitoring in Kenya. In Kenya, stream invertebrates are increasingly being applied in biomonitoring of running water ecosystems. However, there are challenges that hinder the biomonitoring process such as a lack of published identification keys, scarcity of information on the ecology and distribution of Kenyan stream invertebrates and a lack of a nation-wide biomonitoring programme. Potential future directions with regard to biomonitoring of Kenyan streams using invertebrates include publication of identification keys, establishment of a nation-wide biomonitoring programme using stream invertebrates as bioindicators, inclusion of stream biomonitoring in legislations and policies dealing with environmental monitoring and management, and allocation of more funds to research projects dealing with stream biomonitoring. In conclusion, invertebrate-based biomonitoring is important in evaluation of stream ecological conditions in Kenya. However, the challenges that hinder its application need to be addressed for its full potential to be realized.

Keywords: Bioassessment, tropical, anthropogenic disturbance, river, ecological condition

Introduction

Worldwide, freshwater constitutes 0.01% of all water resources and covers less than 1% of the earth's surface (Dudgeon *et al.*, 2006) [1]. Freshwaters are among the most threatened ecosystems of the earth and understanding their ecological condition is of paramount importance (Malmqvist and Rundle, 2002) [2]. Freshwater ecosystems are affected by anthropogenic impacts such as deforestation, agriculture, industries, damming and mining (Bashir *et al.*, 2020) [3].

The impact of anthropogenic stressors on stream ecosystems is an urgent challenge globally and dealing with it has become a key priority of sustainable development programs (Forio and Goethals, 2020) [4]. In many regions of the world, evaluating a range of physico-chemical parameters has permitted for water quality assessment (Robert *et al.*, 2020) [5]. Despite the fact that physico-chemical assessment is a long-established method for assessing the health condition of aquatic ecosystems, results may differ greatly over spatio-temporal scales (Kassegne and Leta, 2020) [6]. Therefore, to accurately evaluate changes in water quality, it is important to collect physico-chemistry data over extended time frames (Zaldívar *et al.*, 2008) [7]. This is disadvantageous because it is time consuming and costly. Therefore, cost-effective and rapid bioassessment techniques using bioindicators, such as aquatic macroinvertebrates, were developed (Holt and Miller, 2010) [8].

The response of aquatic invertebrates to environmental stressors associated with human activities has been widely evaluated in different countries around the world (e.g., Gezie *et al.*, 2017) [9]. Most benthic invertebrates spend a large part of their lifecycle in freshwater environments. They are potentially effective bioindicators of ecological conditions due to their ease of sampling and processing, widespread distribution, relatively long lifespans, high diversity and sensitivity to different types of stressors affecting freshwater environments (Li *et al.*, 2010) [10]. Additionally, they are important components in river food webs that provide a connection between coarse particulate organic matter (e.g. wood debris, periphyton) and higher trophic levels.

The historical background of aquatic invertebrates as biomonitors dates back to the beginning of the twentieth century (Cairns and Pratt, 1993) [11]. Actually, the idea of using aquatic invertebrates as biological indicators started in Europe with the research of Kolkwitz and Marsson (1902) [12]. Their method of biomonitoring aimed to relate organic contamination to abundance and distribution patterns of invertebrates in rivers.

Since that time, many biotic indices have been developed using different aquatic organisms, including invertebrate fauna, to evaluate river ecological conditions and water quality in different countries. Such biotic indices include the Trent Biotic Index in England (Woodiwiss, 1964) [13], the Chandler's Score in Scotland (Chandler, 1970) [14], the Biological Monitoring Working Party in the United Kingdom (Chesters, 1980) [15]. The River Invertebrate Prediction and Classification System was adapted for biomonitoring of aquatic ecosystems in Europe and the Australian River Assessment system was developed in the early 1990's as part of a national river health assessment program in Australia (Chessman, 1995) [16]. Biotic indices have also been developed in other regions of the world such as the USA (Hilsenhoff, 1987) [17], South America (Ferreira *et al.*, 2011) [18] and South Africa (Chutter, 1972) [19]. Macroinvertebrate-based biomonitoring of rivers is also undertaken using methods such as diversity indices, multimetric approaches, multivariate approaches, functional feeding groups, biological traits, molecular methods and assessment of contaminants bioaccumulation in indicator species.

Biomonitoring of aquatic ecosystems is more commonly undertaken in the developed countries than in the developing countries. However, there is an increase in the number of biomonitoring programs in developing countries due to the requirements to establish monitoring standards by environmental laws and policies, due to increase in habitat modifications affecting aquatic ecosystems (e.g., mining, damming, overfishing) or as a prerequisite for disease vector control initiatives (e.g., schistosomiasis, African sleeping sickness) (Thorne and Williams, 1997) [20]. Biomonitoring is especially ideal for developing countries given that the equipment needed for use are not expensive or complicated.

Despite the importance of biomonitoring programs in developing countries, such as Kenya, various challenges hinder its establishment. Such challenges include a lack of adequate trained personnel with sufficient taxonomic knowledge, a lack of research funds and a lack of identification keys, among others. Due to a lack of well-established national biomonitoring programs and protocols, developing countries cannot achieve significant improvements of their aquatic ecosystems condition and the actions they undertake may be inadequate to produce effective aquatic restoration programs. The aim of this article is to review the status, challenges and future prospects for macroinvertebrate-based biomonitoring in Kenya. The article provides crucial information to river ecosystem managers and policy makers on the current biomonitoring practices, challenges that hinder biomonitoring and potential future prospects in the field of aquatic biomonitoring in Kenya.

Literature Search

The databases Web of Knowledge, Google Scholar and Scopus were searched for publications on biomonitoring of stream ecosystems in Kenya. Papers were searched using terms such as biomonitoring, bio assessment, monitoring, assessment, invertebrates, macroinvertebrates, zoobenthos, stream, river, Kenya. Additionally, the literature searches were improved by scrutinizing the references of articles dealing with invertebrate-based biomonitoring for more literature. A total of 61 articles were found. Out of these articles, four articles were exempted from further evaluation since the studies did not explicitly deal with biomonitoring using stream invertebrates (e.g., Dobson *et al.*, 2003) [21]. The 57 articles that focused on invertebrate-based biomonitoring were read in detail and information such as season of study, disturbance, level of invertebrate's identification and keys, and response of invertebrates to disturbance was recorded. The summarized articles are available as supplementary information from the author.

Status of Invertebrate-based Biomonitoring in Kenya

Most invertebrate-based biomonitoring studies in Kenya have focused on specific anthropogenic disturbances affecting streams such as agriculture, deforestation, organic pollutants, urbanization, grazing, human settlements and water abstraction (e.g., Aera *et al.*, 2019) [22]. Some of the studies that were reviewed only evaluated invertebrates during one season and focused on a single biotope (e.g., riffle) (e.g., Minoo *et al.*, 2016; Aera *et al.*, 2019) [22, 23]. Other studies did not mention the season when sampling was done or the aquatic biotopes that were sampled (e.g., Abong'o *et al.*, 2015; Oremo *et al.*, 2019) [24, 25].

Most studies were conducted in one watershed for a period lasting less than one year and were mainly based at Kenyan Universities. These studies were either conducted by postgraduate students or academic staff.

Most studies identified macroinvertebrates to order, family or genus levels while few studies identified macroinvertebrates to the species level. Additionally, most studies used identification keys developed for other regions of the world, such as Northern Europe (e.g., Merritt and Cummins, 1997) [26], South Africa (e.g., Gerber and Gabriel, 2002) [27], Britain (e.g., Savage, 1989) [28], or did not mention the keys that were used during identification. Collection of macroinvertebrates was undertaken using different samplers (e.g., Hess and surber samplers, and D-frame dip net) and sampling periods (1-15 months).

Most studies evaluated the response of stream invertebrates to stressors using invertebrate-based indices such as density, Ephemeroptera, Plecoptera and Trichoptera (EPT) richness, diversity indices, taxa richness, functional feeding groups and multi-metric index of biotic integrity. However, few studies evaluated concentration of toxicants (e.g., heavy metals) in macroinvertebrates (e.g., Osano *et al.*, 2004) [29], biological traits (e.g., body size, mass) (e.g., Mathooko, 2002) [30] or applied stable isotopes analysis in biomonitoring (e.g., Masese *et al.*, 2018) [31].

Challenges and Future Prospects for Invertebrate-based Biomonitoring in Kenya

Stream ecosystems are affected by multiple disturbances concurrently and evaluation of the effect of specific disturbances on macroinvertebrates, as is the case with the reviewed studies, may not adequately explain the effect of multiple disturbances on stream ecological integrity. This is due to the fact that it is difficult to predict the impact of multiple disturbances because of complexity of interactions among disturbances. Disturbances may interact in additive or non-additive ways, where the combined impacts of multiple disturbances may be greater or smaller than what would be anticipated based on the impacts of single disturbances (Folt *et al.,* 1999) [32]. Recent studies have suggested that interactions between disturbances may account for between forty and seventy percent of all responses in stream ecological conditions (Folt *et al.,* 1999; Jackson *et al.,* 2016) [32, 33]. Additionally, the non-additive interactions may be as common as additive responses, suggesting that the impacts of multiple disturbances are more challenging to predict based on the impacts associated with single disturbances. Predicting the impacts of multiple disturbances may especially be difficult in field-based studies where specific disturbances are evaluated and manipulation of various environmental factors (e.g., nutrients, temperature, and sediment) may be difficult (Piggott *et al.,* 2015) [34]. Therefore, future studies evaluating the response of invertebrates to disturbances in Kenya should consider combining collection of field samples with mesocosm experiments where the effect of several environmental factors can be evaluated. This will help to gain a clearer understanding of the effects of multiple disturbances in stream ecosystems.

During biomonitoring of streams using invertebrates, it is important to consider evaluation of invertebrates during different seasons because the distribution and composition of invertebrates are influenced by seasonal variability and this may affect various invertebrate-based indices that are applied in biomonitoring. For example, Stark and Phillips (2009) [35] evaluated the seasonality of invertebrate-based indices such as taxa richness, %EPT richness and the macroinvertebrate community index. All the indices portrayed a statistically significant seasonal variability in the studied streams. Sporka *et al.* (2006) [36] investigated the effect of seasonal variation on invertebrate metrics and showed that about 30 out of 76 metrics showed statistically significant differences between months. Another field study evaluated seasonal changes of invertebrate communities in a river receiving non-point source insecticide pollution and showed that the abundance of Ephemeroptera was significantly increased from the wet to the dry season. Abundance of the aforementioned taxon significantly decreased at the study site receiving non-point source pollution and there was a significant interaction between study sites and season for the three most common mayfly taxa (Bollmohr and Schulz, 2009) [37]. Therefore, the season of sampling can have a confounding effect when interpreting invertebrate-based biomonitoring results, and is thus an important factor that should be considered by future biomonitoring studies in Kenya.

Future biomonitoring studies in Kenya should consider sampling different stream biotopes (e.g., riffles, pools, vegetation) because differences in invertebrate's taxa abundance and composition between different biotopes can affect biomonitoring results. For example, Dallas (2007) [38] evaluated the effect of biotope availability on benthic invertebrates and found that differences in biotopes in terms of individual taxa and invertebrates assemblage resulted in variability in the resultant South African Scoring System (SASS) scores. Differences in invertebrates assemblage was greater among biotopes than between study sites and all the three metrics that were investigated (i.e., SASS score, number of taxa and average score per taxon) differed significantly among biotopes. Another study evaluated the effect of biotopes on macroinvertebrate community structure in streams and found that about 120 taxa were obtained from all the sampled biotopes, but not all invertebrates taxa were obtained from each stream. Invertebrates' taxonomic richness differed significantly among biotopes (Baker *et al.,* 2016) [39]. The observed differences in invertebrates' assemblage demonstrate the importance of considering different biotopes when sampling invertebrates from different streams.

Studies covering large spatio-temporal scales should be considered by future biomonitoring research projects in Kenya because the results of short-term studies (e.g., <1 year) may differ from those of studies covering longer periods (e.g., 10-20 years) of time. For example, Voelz *et al.* (2000) [40] evaluated the temporal and spatial trends in benthic macroinvertebrates data collected for a period of 15 years and showed that the composition and abundance of lotic macroinvertebrates assemblage remained comparatively constant over the 15-year period. However, during shorter time periods (i.e., 1 year), there was a significant reduction in macroinvertebrates density and taxa richness within the studied sites after high discharge and heavy spring runoff. The scarcity of large-scale macroinvertebrate data in Kenya represents a field in which volunteer scientists (i.e., citizen scientists, Edwards *et al.,* 2018) [41] could significantly contribute to stream ecosystems monitoring and management.

The fauna of many Kenyan streams are not well known and this makes it difficult to identify many taxa up to the species level. Additionally, there is a paucity of published invertebrates identification keys (Ochieng *et al.,* 2019) [42]. This indicates that the taxonomic knowledge of macroinvertebrates is still not very well developed and the taxonomic keys that can be used during identification of macroinvertebrates are not readily available. The keys that are available could possibly be unpublished and are either owned by individual people or institutions of high learning and research, hindering their accessibility by many people. In future, there is need to describe and inventorize the local invertebrate fauna (e.g., Mathooko, 1998) [43] because most species are still not well known. Additionally, there is need to compile comprehensive invertebrate identification keys to aquatic insects. An online database on the distribution, abundance, ecology and temporal characteristics of macroinvertebrates can also be useful to future studies focusing on benthic macroinvertebrates in Kenya. Training of personnel in taxonomic identification of invertebrates is also important in development of biomonitoring studies.

A nation-wide biomonitoring program initiated the relevant government agencies can be helpful in coming up with consistent methods for biomonitoring of streams in Kenya. Consistency in the field and laboratory methods used by different institutions can make it easier to combine multiple data sets and enable large-scale biomonitoring (Buss *et al.,* 2015) [44]. Biomonitoring at large spatial scales is increasingly becoming important because global issues such as climate change require data collected over large areas.

In many regions of the world, such as Kenya, the biomonitoring indices that are used for assessing the ecological effects of disturbances in stream ecosystems are not yet well established. Therefore, indices that have been developed for other regions of the world, using their local macroinvertebrates, are typically used in biomonitoring of streams (Elias *et al.,* 2014) [45]. Utilization of indices developed for other regions is challenging because macroinvertebrate taxa portray regional variations, making the resultant indices to be less compatible when applied in biomonitoring of streams. For example, some stone flies (e.g., Perlidae) are rarely found in Kenya whereas they are abundant in temperate zones (Masese and Raburu, 2017) [46]. Therefore, it is necessary to evaluate the sensitivity of invertebrate-based biomonitoring indices developed for other regions of the world and modify them so that they match local conditions. For example, Masese and Raburu (2017) [46] assessed the performance of the EPT index in biomonitoring of tropical streams and found that the performance of the EPT index improved greatly when the invertebrates belonging to the Baetid, Caenid and Hydropsychid families were removed. The three aforementioned invertebrate families are relatively tolerant to organic pollution, are widely distributed and have high abundances in disturbed study sites. In summary, utilization of indices developed for other regions of the world will require a clear understanding of the ecology of local taxa, such as tolerance, so that such indices can be modified before adoption.

Despite the fact that identification of macroinvertebrates to the species level is a better estimate of true ecosystem biodiversity and produces better results in comparison with family level biomonitoring (Lenat and Resh, 2001) [47], many taxonomic indices developed around the world identify invertebrates up to the level of family rather than species (Elias *et al.*, 2014) [45]. Identification of invertebrates up to the family, or genus, level could be necessitated by the time, expense and potential misidentification of specimens at the species level (Chessman *et al.*, 2007) [48]. Future biomonitoring studies in Kenya should carefully consider factors such as level of invertebrate's identification necessary to distinguish varied levels of anthropogenic disturbances, costs associated with identification of invertebrates, level of expertise needed in invertebrates' identification, and the time needed for invertebrates' identification.

Although most studies in Kenya have focused on structural invertebrate-based indices (e.g., density, taxa richness), there has been an increase in application of functional indices such as biological and ecological traits (e.g., body shape, functional feeding groups) and molecular approaches (Li *et al.*, 2010) [10]. Future studies in Kenya should consider using functional indices to complement structural indices in biomonitoring of aquatic ecosystems to better detect anthropogenic disturbances in stream ecosystems.

One of the major challenges in biomonitoring of streams is establishment of reference sites which are devoid of present and historic anthropogenic disturbances. Many Kenyan river basins have been greatly modified by humans through disturbances such as deforestation, grazing and agriculture. This makes it difficult to establish reference sites that can be compared with the degraded sites. A potential solution to the challenge of establishing reference sites is the use of minimally disturbed condition concept (Stoddard *et al.*, 2006) [49] where reference sites are taken to be those sites without significant anthropogenic disturbances.

Despite the fact that many biomonitoring studies have been conducted in Kenya, there is a paucity of information on stream restoration projects. The relevant government agencies should use information generated by biomonitoring studies to implement restoration projects to protect stream ecosystems from further deterioration.

Biomonitoring of streams in Kenya should be guided by clear legislations and policies and the government should provide adequate funds to facilitate more long-term monitoring and management of stream ecosystems.

Table 1: Papers that applied stream invertebrates in biomonitoring of Kenyan rivers. IFS, Helb, N/a, EPT, KMFRI, MIBI refers to International Foundation for Science, higher education loans board, not available, Ephemeroptera, Plecoptera, Trichoptera, Kenya Marine and Fisheries Research Institute and Multimetric Index of Biotic Integrity

Reference	Season	Institution	Disturbance	Funding source	Sampler	Biotope	No. of sites/ watersheds	Study duration (months)	No. of taxa	Lowest Level of identification Keys	Other parameters	Invertebrate indices	Response to disturbance
Abongo *et al.* 2015 [24]	Wet, dry	University	Agriculture, deforestation, settlement, sewage, mining	IFS, Helb	D-frame dip net	N/a	26/1	8	13 orders (16 families)	Order, family; Quigley 1977 [55], Meritt and Cummins, 1996	Physico-chemical	abundance, EPT, Shannon diversity, family richness	Increase in tolerant taxa (e.g. tubificids, hirudinea), decrease in diversity, decrease in EPT taxa
Aera *et al.* 2019 [22]	dry	University	Organic pollutants	Rotary club of vienna	D-frame dip net	Riffle, pool, run	14/1	4	10 orders (18 families)	Order, family; Gerber and Gabriel, 2002 [27]	Physico-chemical	abundance, taxa richness, Margalefs diversity, Shannons diversity, species evenness, species similarity	Increase in tolerant taxa (e.g. chironomidae, decrease in diversity and taxa richness
Anyona *et al.* 2014	dry	University	Solid and liquid wastes, human settlement	East african community	D-frame dip net	N/a	08/1	1	8 orders	Order, family; Needham and Needham (1962), Egborge 1995	Physico-chemical, solid wastes	abundance, Evenness, Shannons diversity, taxa richness	Increase in tolerant taxa, reduction in EPT taxa, reduced evenness, density and diversity
Aura *et al.* 2010	Wet, dry	KMFRI	Agriculture, sewage, urbanization	East African wildlife society	D-frame dip net	Riffle, pool, run	07/1	5	13 orders (28 families, 31 genera)	Genus; Meritt and Cummins (1997), Mathooko 1998 [43]	Physico-chemical	Functional feeding groups, abundance, shannons diversity, EPT taxa, taxa tolerance, MIBI	Reduction of EPT taxa, increase in tolerant taxa, reduction in MIBI

Aura *et al*. 2011	Wet, dry	KMFRI	Agriculture, sewage, urbanization	East African journal of ecology	D-frame dip net	Riffle, pool, run	07/1	5	13 orders (28 families, 31 gener)	Genus; Meritt and Cummins (1997), Mathooko 1998 [43]	Physico-chemical	abundance, taxon richness, shannons diversity, EPT taxa	Reduced taxa richness, increase in tolerant taxa, reduced EPT taxa and taxa richness
Aura *et al*. 2017	Wet, dry	KMFRI	Urbanization	IFS	D-frame dip net	Riffle, pool, run	17/1	4	11 orders (20 families, 22 genera)	Genus; Meritt and Cummins (1997),Mathooko 1998 [43], Ndaruga *et al*. 2004 [56], Kibichii *et al* 2007 [53]	Physico-chemical	Functional feeding groups, abundance, shannons diversity, EPT taxa, taxa tolerance, MIBI	Reduction of EPT taxa, increase in tolerant taxa, reduction in MIBI
Barnard and Biggs 1988 [50]	dry	Museum, university	N/a	Leicester university, royal society	net; surber	N/a	113/1	2	64 taxa	Genus; N/a	N/a	Abundance, taxa richness	N/a

Table 2: Papers that applied stream invertebrates in biomonitoring of Kenyan rivers. N/a, NERC, USAID, GWS, FIU, GLCRSP, FIC, MIBI refers to not available, natural environment research council, united states agency for international development, global water for sustainability, florida international university, global collaborative research support programme, flemish inter university council, multimetric index of biotic integrity.

Reference	Season	Institution	Disturbance	Funding source	Sampler	Biotope	No. of sites/ watersheds	Study duration (months)	No. of taxa	Lowest Level of identification/ Keys	Other parameters	Invertebrate indices	Response to disturbance
Dobson *et al*. 2002	Wet, dry	University	Agriculture, physical disturbances, urbanization	N/a	Hess/surber sampler	N/a	12/8	N/a	35 orders	Genus; unpublished keys, Johanson 1992 [57], Mathooko 1998 [43], Tachet *et al*. 1980 [58]	Physico-chemical	Functional feding groups, EPT taxa, abundance	N/a
Dobson *et al*. 2007 [51]	Wet, dry	University	N/a	NERC	Baited traps/ surber sampler	N/a	01/1	15	1 genus	Genus; N/a	Physico-chemical	N/a	N/a
Gichana *et al*. 2015 [52]	Wet, dry	university	Agriculture, urbanization	USAID, GWS, FIU	D-frame dip net	Pool, riffle run	07/1	5	11 orders (38 families)	Family; Gerber and Gabriel, 2002 [27]	Physico-chemical	abundance, EPT taxa, shannons diversity, taxon richness	Decrease in EPT taxa, increase in tolerant taxa, decrease in diversity, reduced taxon richness
Kibichii *et al*. 2007 [53]	Wet	University	Grazing, agriculture	GLCRSP	Hess sampler	Pool, riffle, run	111/1	5	70 families	Genus; Savage (1989), Edington and Hildrew (1995) [59], Wallace *et al*. (1990), unpublished key	Physico-chemical	abundance, taxon richness, shannons diversity, evenness, dominance	Decrease in EPT taxa, decrease in diversity, taxon richness and evenness
Kilonzo *et al*. 2014	Wet, dry	University	Agriculture	FIC, Netherlands Govt.	D-frame dip net	Pool, riffle	36/1	4	71 families	Genus; Macan 1977, Quigley 1977 [5], Johanson 1992 [57], Day *et al*. 2002 [60], de Moor *et al*. 2003, Merritt *et al*. 2008 [61]	Physico-chemical	abundance, taxon richness, shannons diversity, simpsons richness	Reduced density and taxon richness, increase in tolerant taxa and reduced EPT taxa
Kobingi *et al*. 2009 [54]	Wet, dry	University/research institute	Agriculture, sand harvesting, water abstraction, industries, settlement	N/a	D-frame dip net	N/a	16/1	6	23 families, 12 orders (23 genus)	Genus; Macan 1977, Meritt and Cummins 1996, Nilson 1996 [62], Quigley 1977 [55], Scholtz and Holm 1985 [63], Johanson 1992 [57], Mathooko 1998 [43], Meritt and Cummins 1996, Dobson *et al*. 2002	Physico-chemical	Shannons diversity, taxon richness, abundance, evenness, MIBI	Increase in pollution tolerant taxa and reduction in EPT taxa, reduced diversity, evenness, taxon richness and MIBI

Table 3: Papers that applied stream invertebrates in biomonitoring of Kenyan rivers. NCST refers to National council for science and technology

Reference	Season	Institution	Disturbance	Funding source	Sampler	Biotope	No. of sites/watersheds	Study duration (months)	No. of taxa	Lowest Level of identification/ Keys	Other parameters	Invertebrate indices	Response to disturbance
Lancaster *et al*. 2008 [64]	Wet, dry	University	N/a	NERC	N/a	N/a	111/1	14	1	Genus; N/a	Stable isotopes analyses	abundance	N/a
Masese and Raburu 2017 [46]	dry	University	Agriculture, human settlement	NCST	Surber sampler	Pool, riffle, vegetation	22/2	3	15 orders (84 families)	Order, family; Quigley 1977 [55], Meritt and Cummins 1996, Day *et al*. 2002	Physico-chemical	EPT abundance	Decrease in EPT richness

										[60], de Moor *et al*. 2003, Stals and de Moor 2007 [67]			
Masese *et al*. 2009a [65]	Wet, dry	University	Agriculture, settlement	USAID	Surber sampler	Pool, riffle, runs	66/1	6	13 orders (50 families)	Genus; Macan 1977, Scholtz and Holm 1985 [63], Meritt and Cummins 1996, Nilson (1996, 1997) [62], Johanson 1992 [57], Mathooko 1998 [43]	Physico-chemical	Taxa richness, abundance, shannons diversity, evenness, EPT richness	Reduced abundance, reduced taxon richness and EPT richness, increase in tolerant taxa, reduced diversity and evenness
Masese *et al*. 2009b [65]	dry	University	Agriculture, settlement, urbanization,mining, water abstraction, grazing	USAID	Surber sampler	riffle	98/1	3	14 orders (45 families)	Genus; Macan 1977, Scholtz and Holm 1985 [63], Meritt and Cummins 1996, Nilson (1996, 1997) [62], Johanson 1992 [57], Mathooko 1998 [43]	Physico-chemical	Taxa richness, functional feeding groups, abundance, tolerance, MIBI	Reduced taxa richness, EPT taxa, diversity and MIBI. Increase in tolerant taxa
Masese *et al*. 2014b [66]	Wet, dry	University	Agriculture, settlement	Dutch ministry of foreign affairs	D-frame dip net	Riffles, pools	24/1	5	109 taxa	Genus; Day *et al*. 2002 [60], de Moor *et al*. 2003, Stals and de Moor 2007 [67], Meritt *et al*. 2008	Leaf litter decomposition, physico-chemical parameters	Abundance, functional feeding groups, taxa richness	Reduced taxa richness and shredders abundance
Masese *et al*. 2014 [66]	Wet, dry	University	Agriculture, settlement	Dutch ministry of foreign affairs	D-frame dip net	Riffles, pools	20/1	2	109 taxa	Genus; Day *et al*. 2002 [60], de Moor *et al*. 2003, Stals and de Moor 2007 [67], Meritt *et al*. 2008	Physico-chemical, gut contents	Functional feeding groups, abundance, biomass, taxa richness	Decreased shredder abundance, invertebrates biomass, taxa richness. Increased scrapers abundance
Masese *et al*. 2018 [31]	Wet, dry	University	Agriculture, grazing settlement, deforestation	Dutch minist. Fore. affairs	D-frame dip net	N/a	16/1	7	106 taxa	Genus; Meritt *et al*. 2008	Physico-chemical, stable isotopes	Functional feeding groups, density	N/a

Table 4: Papers that applied stream invertebrates in biomonitoring of Kenyan rivers. N/a, ÖAAD refers to österreicher akademischer austauch dienst

Reference	Season	Institution	Disturbance	Funding source	Sampler	Biotope	No. of sites/watersheds	Study duration (months)	No. of taxa	Lowest level of identification/ Keys	Other parameters	Invertebrate indices	Response to disturbance
Mathooko 1995	Wet, dry	University	N/a	NCST	Sampling baskets	riffle	81/1	12	11 taxa	Genus, family	physico-chemical	abundance, shannons diversity, evenness, species richness	N/a
Mathooko 1997	Wet, dry	Research institute	Artificial physical disturbance	ÖAAD	Hess sampler	riffle	91/1	8	N/a	Genus	physico-chemical	abundance, species richness	Decreased density and species richness
Mathooko 1998 [43]	Wet, dry	University	Artificial physical disturbance	ÖAAD	Hess sampler	riffle	91/1	8	6 families	Genus;N/a	N/a	Biomass, abundance	Decrease in biomass and density
Mathooko 2000	Wet, dry	University	Artificial physical disturbance	ÖAAD	Hess sampler	riffle	91/1	8	7 taxa	Genus; N/a	N/a	Abundance, species richness	Decrease in density and species richness
Mathooko and Mavuti 1992	Wet, dry	University	N/a	NCST	Substrate basket, drift sampler nets	riffle	97/1	12	13 orders	Genus, family, order;N/a	physico-chemical	abundance, taxa richness	N/a
Mathooko and Mavuti 1994	Wet, dry	University	N/a	N/a	Drift sampler nets	N/a	91/1	12	11 orders	Genus, family, order; N/a	N/a	abundance	N/a
Mathooko and Otieno 2002	Wet, dry	university	N/a	N/a	D-frame dip net	N/a	91/1	7	11 orders	order	Physico-chemical, wood decomposition	Shannons diversity, abundance, taxa richness	N/a
Mathooko *et al*. 2000	dry	University, research institute	N/a	N/a	N/a	N/a	91/1	2	N/a	N/a	Physico-chemical	abundance, functional feeding groups	N/a

Table 5: Papers that applied stream invertebrates in biomonitoring of Kenyan rivers

Reference	Season	Institution	Disturbance	Funding source	Sampler	Biotope	No. of sites/watersheds	Study duration (months)	No. of taxa	Lowest level of identification/ Keys	Other parameters	Invertebrate indices	Response to disturbance
Mathooko *et al*. 2005 [68]	dry	university	drought	N/a	corer	pool	33/1	8	1 genus	Genus;	n.a	Biomass, abundance	Reduction in biomass and abundance
Mathooko 1995	Wet, dry	university	N/a	NCST	Sampling baskets	riffle	91/1	12	11 taxa	Genus, species; N/a	physico-chemical	Abundance, shannons diversity, evenness, taxa richness	N/a
Mathooko 1998a [43]	Wet, dry	university	Artifical physical disturbance	ÖAAD	Hess sampler	riffle	91/1	8	1 taxa	Species;N/a	N/a	Abundance	Reduced abundance
Mathooko 2001 [69]	Wet, dry	university	N/a	ÖAAD	Hess sampler	riffle	91/1	8	1 species	Species;N/a	physico-chemical	Abundance, biomass	N/a
Mathooko 2002 [70]	Wet, dry	university	Artifical physical disturbance	ÖAAD	Hess sampler	riffle	91/1	8	7 species	Species; N/a	N/a	Biomass, size, abundance	Reduction in biomass, size and abundance
Mbaka *et al*. 2014a [71]	dry	university	deforestation	N/a	Hess sampler	riffle	93/1	5	15	Family, order; N/a	Benthic organic matter, physico-chemical	Abundance, shannons diversity, functional feeding groups	Decrease in abundance, diversity and density of collectors, predators and filter feeders
Mbaka *et al*. 2014b [71]	dry	university	Agriculture, water abstraction	Egerton University	Hess sampler	riffle	93/1	4	14	Family, order; Gerber and Gabriel, 2002 [27]	physico-chemical	Abundance	Increase in sensitive taxa, reduced abundance
Mbaka *et al*. 2014c [71]	dry	university	Water abstraction, grazing, agriculture	Egerton university	Hess and D-frame dip net	Plant,stones, sand,mud	96/2	2	17	Order, family; Gerber and Gabriel, 2002 [27]	physico-chemical	Abundance, shannons diversity, taxa richness	decrease in diversity and taxa richness
Mbaka *et al*. 2016 [72]	dry	university	Human settlement, grazing	Egerton university	Hess sampler	riffle	93/1	2	17	Order, family; Gerber and Gabriel, 2002 [27]	physico-chemical	Abundance, shannons diversity, evenness, multimetric index, simpsons and margalefs diversity	Reduced abundance, diversity and multimetric index and EPT taxa

Table 6: Papers that applied stream invertebrates in biomonitoring of Kenyan rivers.

Reference	Season	Institution	Disturbance	Funding source	Sampler	Biotope	No. of sites/watersheds	Study duration (months)	No. of taxa	Lowest level of identification / Keys	Other parameters	Invertebrate indices	Response to disturbance
Mcclain *et al.* 2014	Dry, wet	Research institute, university	Water abstraction, agriculture	USAID	D-frame dip net/surber sampler	Pool,riffle, runs	96/1	5	34	Order,family;	Physico-chemical, riparian vegetation, fish	EPT taxa, taxa richness, diversity	Decrease in diversity, EPT taxa and taxa richness
M'Erimba *et al.* 2014 b [71]	Dry, wet	university	Sewer, settlements, grazing, deforestation	ÖAAD	Hess sampler	N/a	95/2	10	18	Order, family;N/a	Physico-chemical	Shannons diversity, taxa richness, dominance index, similarity index	Reduction in diversity, abundance, taxa richness, increased similarity
M'Erimba *et al.* 2014 [71]	dry	university	Agriculture, water abstraction, grazing, deorestation	Egerton university	Hess sampler, D-frame dip net	N/a	96/2	2	20	Family; Gerber and Gabriel 2002 [27]	Physico-chemical	EPT taxa, taxa richness, shannons diversity, abundance, functional feeding groups	Reduction in EPT taxa, richness, diversity and functional feeding groups
M'Erimba *et al.* 2018	dry	University	Grazing, agriculture	Egerton university	Drift net sampler	N/a	92/2	2	N/a	Order, family; Gerber and Gabriel 2002 [27]	Physico-chemical	Drift abundance	Increase in drift density
Minaya *et al*. 2013 [73]	dry	Research institute, university	Agriculture, settlements	USAID, dutch foreign ministry	D-frame dip net	N/a	25/1	2	N/a	Genus; Gerber and Gabriel, 2002 [27]	Physico-chemical	Abundance, taxa richness	Increase in sensitive taxa, reduction in EPT taxa

Minoo *et al*. 2016 [23]	dry	Research institute, university	Aquaculture effluents	Aquafish innovation lab, USAID	Surber sampler	riffle	99/1	9	N/a	Order, family; Day *et al*. 2002 [60], de Moor 2003, Stals and de Moor 2007 [67], Merritt *et al*. 2008 [61]	N/a	Abundance, taxonomic richness, shannons diversity, EPT taxa, functional feeding groups, Indice biologique global normalize (IBGN)	Increase in abundance, reduced richness, diversity, IBGN values and EPT taxa
Mureithi *et al*. 2017	dry	university	N/a	N/a	Drift net sampler	Riffle, pool	91/1	3	26	Order, family; Gerber and Gabriel, 2002 [27]	N/a	Drift abundance	N/a

Table 7: Papers that applied stream invertebrates in biomonitoring of Kenyan rivers. TWAS, CEWERM, SASS refers to the world academy of sciences, centre of excellence for water and environmental management of Masinde Muliro University of Science and Technology, South African scoring system

Reference	Season	Institution	Disturbance	Funding source	Sampler	Biotope	No. of sites/watersheds	Study duration (months)	No. of taxa	Lowest level of identification/ Keys	Other parameters	Invertebrate indices	Response to disturbance
Mureithi *et al*. 2018	dry	university	Settlements, agriculture, industries	N/a	Drift net	Riffle	91/1	3	23	Order, family; Gerber and Gabriel, 2002 Orut24a, de Moor *et al*. 2003, Day *et al*. 2003	Physico-chemical	Invertebrate drift	N/a
Ndaruga *et al*. 2004 [56]	Wet, dry	University, research institute	Settlements, agriculture, industries	Kenya museums society, kenyatta university	corer	N/a	96/1	7	26	Genus; Merritt and Cummins, 1996 [76]	Physico-chemical	Taxa richness, dominance, evenness, diversity, abundance, EPT taxa, functional feeding groups	Reduction in EPT taxa, decrease in diversity, increased abundance of grazers, predators
Odhiambo and Mwangi 2014 [74]	Wet, dry	university	N/a	N/a	Hess	N/a	91/1	9	10	Order, family; N/a	Coarse particulate organic matter	abundance	N/a
Oigara and Masese 2017 [75]	wet	university	N/a	N/a	D-frame dip net	Stones, mud, sand, vegetation	98/1	2	16	Order, family; Gerber and Gabriel, 2002 [27], Day and de Moor 2002, Day *et al*. 2002 [60], de Moor *et al*. 2003, Merritt *et al*. 2008 [61]	N/a	SASS, abundance, taxa richness	Reduced SASS scores, taxa richness and abundance
Oremo *et al*. 2019 [25]	N/a	university	Agriculture, grazing, urbanization, mining	TWAS, CEWERM	Plankton nets	N/a	912/1	N/a	3	Order, family; Voshell, 2002 [77]	Physico-chemical	N/a	N/a
Oruta *et al*. 2017 b	Dry, wet	University, water resources authority	Agriculture, grazing	N/a	D-frame dip net	Riffle, pool, run	99/1	12	73	Genus; Acûna *et al*. 2013, Australian Government, 2001, Mathooko 1998	Canopy cover	Abundance, taxa richness, shannons diversity, evenness	Reduced abundance, taxa richness, diversity, evenness
Oruta *et al*. 2017	Dry, wet	University, water resources authority	Agriculture, grazing	N/a	D-frame dip net	Riffle, pool, run	99/1	12	73	Genus; Acûna *et al*. 2013, Australian Government, 2001, Mathooko 1998 [43]	Physico-chemical	Taxa richness, abundance, evenness, shannons diversity	Reduced taxa richness, abundance, sensitive taxa and diversity

Table 8: Papers that applied stream invertebrates in biomonitoring of Kenyan rivers. SIDA-SAREC refers to Swedish International Development Agency, Department for Research

Reference	Season	Institution	Disturbance	Funding source	Sampler	Biotope	No. of sites/watersheds	Study duration (months)	No. of taxa	Lowest level of identification/ Keys	Other parameters	Invertebrate indices	Response to disturbance
Osano *et al*. 2004 [29]	Wet, dry	university	urbanization	Moi University	D-frame dip net	N/a	33/1	2	9	Species; N/a	Heavy metals	abundance	Increased concentration of heavy metals in invertebrates
Raburu *et al*. 2009 [78]	Wet, dry	university	Agriculture, settlements	N/a	D-frame dip net	Riffle, pool, run	22/2	6	15	Genus; Merritt and Cummins (1996) [76], Versuchen 1997, Mathooko 1998 [43]	Physico-chemical	Abundance, EPT taxa, MIBI, taxa richness, functional feeding groups	Reduced EPT taxa, MIBI, abundance, taxa richness and some feeding groups
Raburu *et al*. 2017 [46]	Wet, dry	university	Sewage effluents	NCST, SIDA-SAREC	D-frame dip net	N/a	77/1	9	33 genera	Genus; Day *et al*. 2002 [60], de Moor *et al*. 2003, Stals	Physico-chemical	Abundance, tolerance,	Increase in tolerant taxa,

										and de Moor 2007 [67], Merritt *et al*. 2008 [61]		biotic index, EPT taxa	reduced EPT abundance
Shivoga 2000	Wet, dry	university	agriculture	ÖAAD	Hess sampler	N/a	33/2	9	11	Order, family; N/a	Physico-chemical (conductivity)	Abundance, taxa richness	N/a
Shivoga 2001	Wet, dry	university	agriculture	ÖAAD	Hess sampler	N/a	77/2	12	115	Sub-family; Harding and Smith, 1974, Pinder 1978 [79], Wieder-holm 1983, Savage 1989 [28], Harrison 1991 [80], 1992, 1996, Versuchen 1997	Physico-chemical (hydrology)	Abundance, taxa richness	N/a
Tsisiche *et al*. 2018	wet	university	Agriculture, grazing	Glowswater scholars; FIU	Hess sampler	N/a	66/1	3	23	Family; N/a	Physico-chemical, litter decomposition	Abundance, functional feeding groups	Increase in collector gatherers and reduction in shredders abundance

Conclusion
In conclusion, there has been application of invertebrate-based biomonitoring to evaluate stream ecological conditions in Kenya. The challenges that hinder application of invertebrates in biomonitoring need to be urgently addressed to improve the monitoring and management of stream ecosystems. In future, there will be need to establish a national biomonitoring program which will guide evaluation of ecological conditions in streams. Training in identification of invertebrates, use of complementary approaches (e.g., molecular analyses), publication of identification keys and biomonitoring at large spatio-temporal scales are examples of crucial factors that need to be addressed to improve application of invertebrates in biomonitoring of streams in future.

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