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Effectiveness and Compatibility of Non-Tropical Bio-Monitoring Indices for Assessing Pollution in Tropical Rivers - A Review

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Abstract In Tropical regions, bio-monitoring indices for assessing pollution in streams and rivers are not yet in place. As a result, indices that have been developed inconsistently in different non-tropical regions using their local macro-invertebrate species are adopted and used for assessing pollution in tropical rivers. In Africa, only one review on existing non-tropical bio-monitoring indices to assess river quality in southern Africa was previously reported in conjunction with comparisons with those developed in United States of America, Asia, Australia, Canada, and European countries. However, a comprehensive overview of the complete body of bio-monitoring applications of these indices to streams and rivers in tropical African countries, particularly East and Central Africa was not addressed. Similarly, comparisons of the different sampling techniques, taxonomic resolutions and sensitivity of bio-indicators' species that were used in different studies to develop the existing indices were not covered in that review. In that regard, this review work has highlighted the geographical compatibility, effectiveness, and capability of existing non-tropical bio-monitoring indices to assess pollution in tropical African rivers, in a view of improving bio-monitoring programmes. The need for tropical African regions to have or develop their own bio-monitoring index that will be more reliable than adopting indices from other geographical areas (i.e., non-tropical regions) is a supreme.

Keywords Macro-invertebrate, Bio-monitoring, Indices, Assessment, Tropical Rivers and Aquatic Pollution

1. Introduction

Conventional methods which rely on chemical aspects to assess river pollution are becoming less suitable in monitoring programmes as they cannot detect physical and biological stressors that occurred over time and at multiple scales [1-5]. As such, the concepts and principles of bio-monitoring indices, which are more efficient, effective, and of lower cost than the traditional methods have been developed and applied broadly around the world to assess river pollution. Nonetheless, this new initiative has exempted tropical region in favour of modifying and adopting the existing indices that have been developed for non-tropical regions using their local freshwater organisms. These bio-monitoring indices are normally developed for specific regions in order to account for regional variation using local biotic assemblages that exhibit regional variation based on organism's sensitivity or tolerance. Such variations might affect the capability, functioning, and reliability of the bio-monitoring indices developed for non-tropical regions when applied in tropical rivers. Likewise, modification of non-tropical bio-monitoring indices for use in tropical regions is usually hindered by incomplete taxonomical resolution and the barely known sensitivity levels of many tropical taxa [5].

This paper work presented a review on concepts, current use and anticipated future research directions of existing non-tropical bio-monitoring indices with a view of improving bio-monitoring programmes in Africa. The review focused on reliability and geographical compatibility of adopting non-tropical indices to assess water pollution in tropical African rivers. It also discussed the bottlenecks of adopting such indices while setting some basis for developing tropical bio-monitoring index in the near future.

1.1. Historical Background and Overview of Bio-Monitoring Indices

United Kingdom was the first nation to officiate the use of Rapid Bio-monitoring Methods (RBMs) for assessing river pollution in 1970. In response to criticisms about the inadequacy of the method, the Biological Monitoring

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Working Party (BMWP) index was developed in 1976 and recommended for use in river pollution surveys [6]. Later, a number of RBMs based on macro-invertebrates were developed and used worldwide as a response to the need in water management for quick and cost-effective methods for assessing water quality [7]. For instance in German, Kolkwitz and Marsson developed Saprobien or Saprobic System based on the Saprobien System in 1900s, followed by other developments in the United Kingdom [8, 9], North America [10], United States of America [11, 12], Canada [13], Australia [14], Mexico ([15], Thailand [16], Brazil [17], and Bolivia [18].

In southern region of Africa, the South African Scoring System (SASS) in South Africa [19-22], the Namibia Scoring System (NASS) in Namibia [23], the Okavango Assessment System (OKAS) in Okavango delta [24], and the Zambia Invertebrate Scoring System (ZISS) in Zambia [25] have been developed based on local freshwater macro-invertebrate families. NASS, OKAS, and ZISS have been modified from SASS5 index, which has been extensively tested in South Africa, and its capability and reliability proven for assessment of water quality and general river condition [7, 26, 27, 22].

On the contrary, ongoing efforts in southern tropical African countries regarding bio-monitoring indices development, testing, refinement, and validation are yet to be employed in rivers in tropical countries such as Kenya, Uganda, and Tanzania [5]. Apart from few ecological and taxonomical studies conducted in patches on the north-east of Africa [28, 29], in Kenya [30-33], Uganda [34, 35] and Tanzania [36, 37, 4, 38], there is no any effort that has led to the development of bio-monitoring indices in tropical African countries. The presence of technical, financial and logistical constraints have hindered the potential use of macro-invertebrate communities as indicators of water quality and thus, making bio-monitoring programs a remote possibility in tropical African region.

2. Review on Non-Tropical Bio-monitoring Indices Applications in Tropical Regions

2.1. Sampling Techniques

A number of ecological and taxonomical studies together with those used to develop bio-monitoring indices have been conducted within the same or different climatic-regions using different sampling protocols and sampling tools. These include the frequently used sampling protocols (quantitative, semi-quantitative, and non-quantitative) and tools (substrates Hess samplers, surber sampler, substrate corer, grab sampler, and kick-net samplers) in developing Rapid Bio-monitoring Methods (RBMs). The use of these sampling techniques interchangeably in the same or different studies may either produce data of unknown quality or yield conflicting data interpretations, even at the same ecoregions or biotopes. As a result, element of doubt may arise regarding the precision of developed bio-monitoring tool, if the produced data were used to develop that particular index.

2.1.1. Sampling Protocols

Different studies have been done using different types of sampling protocols to collect macro-benthic assemblage samples from different biotopes [12, 20, 17]. These include quantitative method that used to collect benthic assemblage samples for developing BalkaN Biotic Index, Chutter's Biotic Index, Family-level Biotic Index, Quantitative Macro-invertebrate Community Index, and Hilsenhoff's Biotic Index. Both semi-quantitative and non-quantitative (qualitative) protocols were jointly employed to collected specimen during the development of Biological Monitoring Working Party Score System, Indice Biologique Global Normalisé, South African Scoring System, Version4 (SASS4), South African Scoring System, Version5 (SASS5), Namibian Scoring System, Version 1 (NASS), and Okavango Scoring System, Version 1 (OKASS) of Botswana [39, 22]. Likewise, none-quantitative (qualitative) method was preferred in Iberian BMWP, Florida Index, Beck's Biotic Index, Macro-invertebrate Community Index, Stream Invertebrate Grade Number – Average Level Biotic Index, and Trent Biotic Index development whereas, semi-quantitative protocol opted to develop Stream Invertebrate Grade Number – Average Level Weighted Biotic Index, Semi-Quantitative MCI, Rivers of Vaud Index, Rivers of Vaud Index, 1995 Version, Indice Biotique, Average Chandler Biotic Score, and Chandler's Biotic Score [39, 22].

Generally, sampling variability among replicate samples collected from one site, at one time, and of similar biotope may lead to incorrect interpretation of data and conclusions [40]. Environment Canada's Reference Condition Approach [13], the US Environment Protection Agency [12] and the South African Scoring System in South Africa [20] for example have used a single-composite-sample method as their sampling protocol. This sampling protocol involves sampling of dominant habitats or biotopes at a site and combining them into an overall site composite sample. As a result, only one-composite-sample per site is obtained and there is no replication [41]. Moreover, sampling variability becomes more critical in this protocol as single sample is expected to provide comparative information of reference conditions. This is due to the fact that, a sample is continuously collected from a particular habitat or biotope over either a fixed period of time (e.g. 2-5 min in stones) or fixed distance (2 m for marginal vegetation) or fixed area (1 m^2 for aquatic vegetation) in such a way that the sample is a composite as it is being collected rather than collecting discrete replicate samples, which are then used to give one biotope sample [41, 40].

Another major concern in the use of single-sample per biotope is the possibility of not collecting all macro-invertebrates taxa occurring at a site hence affecting the biotic index metrics. With single composite sample protocol, under expected number of taxa from study sites are likely due to the small sample size collected from few sample areas (habitats). In order to compile relatively complete taxa lists at a given area, taxonomic studies should sample macro-invertebrate assemblages from more areas of different habitat types. Similarly, the use of standardized protocol together with available taxonomic knowledge is more recommended as they can easily govern the differentiation of site conditions or macro-invertebrate composition in the same biotope.

2.1.2. Sampling Tools

Existing Rapid Bio-monitoring Methods (RBMs) developed in/for the same climatic regions (i.e., temperate or mediterranean) have been found use different field-based sampling tools of different diameters and retention sizes (often varies from 250μm to 1000μm). The most commonly used sampling tools for collecting macro-benthic assemblages include kick (hand) net, substrate Hess sampler, surber sampler, grab net, and stovepipe coring device. In New Zealand, surber sampler was used in collecting macro-benthic assemblage for developing Macro-invertebra te Community Index (MCI) and Quantitative MCI (QMCI) while both surber sampler and hand-net of 500 μm were used in France for developing Indice Biologique Global Normalise (IBGN). In southern part of Africa, the macro-benthic assemblages that used to develop South African Scoring System (SASS) in South Africa [19-22], the Namibia Scoring System (NASS) in Namibia [23], the Okavango Assessment System (OKAS) in Okavango delta [24] and the Zambia Invertebrate Scoring System (ZISS) in Zambia [25] were collected using hand-net of 1000 μm mesh size. In Brazil, Ferreira *et al.*, [43] used surber sampler of 0.09 m^2 and 250 μm mesh size while Stone *et al.*, [44] used stovepipe coring device in Southern Illinois (USA) before Elias [4] opted for substrates Hess sampler in Tanzanian rivers to collect macro-benthic assemblages. Hand net of different mesh sizes and diameters were also used in North America [10] and United Kingdom [8, 9] while both hand-net of 250 μm mesh size and grab net used in Australia [14].

However, application of these different sampling tools and protocols might produce errors and uncertainty to data collected in the same climatic ecoregions or biotopes [41], underscoring the question of accuracy in bio-monitoring programs. In Mediterranean climatic regions for example, sampling tools used to collect macro-invertebrate assemblages to develop both South Africa Scoring System (SASS) and Iberian Peninsula indices were different in respect to their mesh sizes [42]. The influence of sampling tools of different mesh sizes on collected taxa may vary seasonally in response to size, temperament of habitat and development stage of a particular taxon. Therefore, organisms in stressed habitats (or temporary steams) and at earliest development stages, they cannot be retained by samplers of larger mesh sizes as opposed to others due to their small body sizes.

On the other hand, kick (hand) net was recommended over surber sampler by Daniel and Erika [45] regarding its ability of collecting macro-invertebrate assemblages. Similarly, macro-benthic samples collected with the kick method had significantly higher richness and BMWP scores in relation to surber sampler [45]. The surber technique often underestimates macro-invertebrate richness (5-25% less families than in kick net) and also is not an adequate device for streams with more than 30 cm depth because of difficulties in handling it in rocky and pebble-bottomed streams, commonly found in tropical and mountainous areas [45]. Additionally, inability to apply some of sampling devices (i.e., Surber and Hess sampler) to deep rivers meant that certain river stretches would not be sampled for any environmental impact using these devices [46]. Against that backdrop, hand-net, surber sampler, grab net, substrate Hess sampler, and sediment corer should be re-assessed for their effectiveness before any of them be recommended as a suitable sampling device.

2.2. Conflicting Features of Bio-Indicators' Species and Metrics

Generally, the basic principle of existing bio-monitoring indices is that healthy rivers contain large numbers of different species at all levels of pollution tolerance while no single species dominates. Bio-monitoring indices rank macro-invertebrate species relative to their levels of pollution sensitivity. Macro-invertebrate families that are very tolerant to pollution score a lower rank and vice versa for more sensitive organisms. However, low EPT (Ephemeroptera, Plecoptera and Tricoptera) percentages may prove good indicator of increased anthropogenic waste run-off as families of Ephemeroptera (i.e., Heptageniidae), and Plecoptera (i.e., Perlidae), are known to be sensitive to low dissolved oxygen concentrations [47]. On other hand, it may not be an effective indicator of sediment pollution because some Tricopterans (i.e., Hydropsychidae), and Ephemeropterans (i.e., Caenidae), can thrive in heavily sedimented streams [47]. In that case, EPT percentage may not be the best measure of water quality if the two stressors occurred simultaneously and thus, there is a need of identifying macro-invertebrate families to the lowest taxonomic unit (i.e., genus or species level).

Another case is regarding the families that are considered to be sensitive to disturbance, while some taxa are considered somewhat facultative to disturbance. For example, the Mildges, Baetidae, Simuliidae, Ceratopogonidae and Orthocladiinae can frequently be collected at highly impacted sites as well as in reference sites [4]. Similarly, *Potomanthidae* families that are usually expected to be found in impacted sites due to their known low sensitive score, they have also been found in reference sites [4]. Such absence of precise clear-cut distinction between these organisms and disturbance (pollution gradients) requires taxonomic studies to identify specimen further to the resolution of species rather than family level.

2.3. Indices' Taxonomic Resolution

Although species level bio-monitoring indices produce great results in comparison with family level bio-monitoring indices, yet many taxonomic studies identify specimen to the resolution of family rather than species. These include the South African Scoring System, Version5 (SASS5); Namibian Scoring System (NASS); Okavango Scoring System (OKASS) of Botswana; and Biological Monitoring Working Party Score System (BMWP) mostly used in UK, Finland, and Sweden and Belgean Biotic Index (BBI) mostly used in Belgium. Others include Hilsenhoff's Biotic Index (HBI), Florida Index (FI), Chundler's Biotic Score (CBS), and Average Chundler's Biotic Score (Avg. CBS) all used in USA; Family Level Biotic Index (FBI) in USA and Chile; Danish Stream Fauna Index (DSFI) used in Denmark and Sweden; Macro-invertebrate Community Index (MCI), Quantitative MCI (QMCI), and Semi-Quantitative MCI (SQMCI) all used in New Zealand; Indece Biotio Esteso (IBE) for Italy; Indice Biologique Global Normalise (IBGN) for France; Iberian BMWP (IBMWP) mostly used in Italy and Spain; BalkaN Biotic Index (BNBI) of Serbia and Stream Invertebrate Grade Number-Average Level Biotic Index (SIGNAL) and Stream Invertebrate Grade Number-Average Level Weighted Biotic Index (SIGNAL-W) mostly used in Australia [22]. Only Indice Biotique (IB) that developed in France and Trent Biotic Index (TBI) in Australia were developed using macro-invertebrate data that classified up to species level [22].

The choice of suitable taxonomic resolution is a compromise between the cost of obtaining data at high taxonomic resolutions and the loss of data at lower resolutions [48]. About 6% of data can be lost by identifying taxa to family as opposed to species [48]. The cost saved in identifying macro-invertebrates to develop family level indices may not be justified if precision cannot be met by such indices at family level. Likewise, the cost expended to obtain species level indices may also not be warranted if cheaper family level indices can evaluate accurately the status of aquatic ecosystems. Moreover, the distribution patterns of all analysed macro-invertebrate samples collected from reference and degraded sites showed that the use of species level indices (or indices developed by best available taxonomic level) perform better at a practical (fine) scale in comparison to family level indices [49]. For the sake of data accuracy and precision, any index development for tropical climatic-region should be downscaled up to the lowest taxonomical unit.

2.4. Geographical Compatibility of Adopted Non-Tropical Indices to Tropical Regions

Macro-invertebrate assemblages exhibit regional variation and because bio-monitoring indices are developed based on organism's sensitivity or tolerance for specific regions in order to account for regional variation. The indices have been developed as a response to the need in water management for quick and cost-effective methods for assessing water quality [7]. The wide spread use of bio-monitoring indices have also been facilitated by regulatory authorities who appreciate the value of bio-monitoring data and information on water resource management. To date, a number of bio-monitoring indices have been developed (though in patchy form) by different countries around the world to assess the rivers' health status in aquatic ecosystems [19, 50, 12]. However, the absence of such indices in tropical and mountainous climatic-regions in fulfilment of effectiveness and efficiency regarding their application to wider area is still a problem. As a result, tropical regions are depending on existing non-tropical developed bio-monitoring indices, which are geographically incompatible in assessing river pollution. These indices have used indicator species metrics (individual taxa) that are only relevant to the geographical range related to the distribution of the indicator species. For example, a Stonefly family (Perlidae) is absent in mountainous and tropical regions but abundantly found in temperate and mediterranean biogeographical zones.

Moreover, *Osmerus epertanus* is profusely used as a qualified indicator in North Sea estuaries but not qualified to be used in mediterranean estuaries. Since these indices are area specific, existing non-topical indices require substantial refinement and calibration on a variety of scales before being applied for use in tropical climatic-regions. This is due to the fact that some macro-invertebrate species might occur abundantly in temperate but not in tropical or mediterranean climatic regions and vice versa. However, when they occur in all climatic regions, they tend to differ in diversity (for example, Plecoptera is a low diversity family in the tropics but of high diversity in temperate and mediterranean regions) and thus, nullify them as key metric during bio-monitoring index development. In that regards, locally available freshwater organisms of high diversity should considered in developing bio-monitoring index to represent that particular region after being downscaled up to the lowest taxonomic unit. This suggests that current prevalence of developing indices within a single or the same biogeographical zone indicates the spatially restricted relevance of most of existing bio-monitoring indices. In Tanzanian rivers for example, high diversified families of common Orders: Ordonata, Diptera, Coleoptera, Ephemeroptera and Tricoptera should only be used as key metrics in developing a new bio-monitoring index of that particular eco-region [4]. For attainment of fully developed tropical bio-monitoring indices that adhere to ISO standards, it requires committed and qualified experts, capacity building, government will and support to cater for field sampling and identification works.

3. Conclusions

Differences in climate, geology, longitude, and latitude between tropical and non-tropical countries may contribute to differences in the physical and chemical characteristics of rivers between the regions. Consequently, these differences can as well lead to variation in macro-invertebrate taxa composition and their sensitivity levels to disturbance and general ecosystem impairment from one geographical region to another. Such variation might affect the capability, functioning, and reliability of the existing non-tropical bio-monitoring indices when opted and applied in tropical rivers. In that regard, there is a risk of having unreliable findings when non-tropical bio-monitoring indices are applied or adopted to assess pollution in tropical rivers. Therefore, there is a need for tropical region to have or develop and validate their own indices that will be more reliable than adopting indices from other geographical areas which are inconsistence with regard to tools, research methods, taxonomic resolution and organisms involved in such studies. Additionally, field standard operating procedures and reference conditions for tropical rivers should also be developed and accredited by a recognized governing body or certified by ISO standard covering both surface and underneath benthic organisms.

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