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Original Research Article

Spatio-temporal macroinvertebrate multi-index of biotic integrity (MMiBI) for a coastal river basin: a case study of River Tana, Kenya

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ABSTRACT

In the wake of climate change events, spatio-temporal integrated ecosystem models and indices are useful decision support tools for ecosystem management. We developed a preliminary spatio-temporal macroinvertebrate multi-index of biotic integrity (MMiBI) in a major tropical river basin in Kenya. Separation power of Mann–Whitney *U* test ($p < 0.05$) qualified 11 metrics from triplicate macroinvertebrate samples collected seasonally in 33 microhabitats into the scoring system of 1, 3 and 5. Validation and strengthening procedure compared the final MMiBI with selected ($p < 0.05$) physico-chemical parameters and post-MMiBI fieldwork. Seasonal alternating pattern of MMiBI scores suggested that it was highly likely that temporal scores performance might rank lower as compared to spatial significance on ecosystem health delineation. Although a case study in a single river basin is presented, the indexing holistic approach can be of general use for any other coastal river basin as a low-cost biomonitoring tool as a prerequisite towards ecosystem sustainability of water resources.

1. Introduction

Socio-economic growth is dependent on intensification of human activities such as forestry and urbanization which leads to water resources' degradation (Mereta et al., 2012; Kibena et al., 2014). Yet water resources such as rivers are vital to support biodiversity and provide socio-economic benefits to humans (e.g., Hajkowicz, 2006). Indexing and modelling of aquatic resources using biomonitoring and bioassessment are essential to protect and improve water quality for ecology and hydrology management while responding to anthropogenic stressors (Dickens and Graham, 2002). Bioassessment and biomonitoring is recognized as pertinent aspects of water resources management as a tool for achieving sustainable riverine ecosystems (Ndaruga et al., 2004). Therefore, multi-metric indices that apply a holistic bioassessment approach of water resources for sustainability of ecosystems have become a popular tool for global assessment of aquatic resources (Aura et al., 2010).

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Prior water quality indices and models have been developed as biomarkers of ecosystem management for water resources sustainability (Masese and McClain, 2012). Globally (e.g., Karr and Chu, 1997, 2000) and at a regional level (e.g., Raburu et al., 2009; Aura et al., 2010; Gonzalo and Camargo, 2013), several models and indices integrating physico-chemical, hydraulic, and ecological water quality have been developed. Index of Biotic Integrity (IBI) stands out to be one of the best indices (Sabater et al., 2004) as it helps to gain a well-rounded perspective of the chemical, physical and biological conditions of a particular water resource. An Index of Biotic Integrity (IBI) is suitable because it satisfies the requirements that an index should be relevant, simple and easily understood by managers, scientifically justifiable, quantitative and acceptable in terms of cost (Aura et al., 2010).

Several global and regional studies on IBI have been developed to assess the ecosystem health of rivers (Kerans and Karr, 1994; Karr and Chu, 1997; Masese et al., 2009a,b; Raburu et al., 2009; Aura et al., 2010), but little information is available on coastal and seasonal aspects of such lotic systems. Due to limited field data, improvement of indices and models that are independent of high costs and climate change scenarios (e.g., studies on seasonal changes) are attracting renewed attention from ecologists, economists and managers to support water management for sustainability of such ecosystems (Smucker et al., 2015). Thus, there is an obvious need of biological indices for monitoring and scoring pollution and other types of degradation of African coastal lotic habitats to form the basis of global discussions on their temporal dynamics.

Little information is known on the holistic approach of water resources sustainability of River Tana Basin in terms of the physical, chemical and biological conditions. Yet, being the longest river in Kenya, it forms an important riverine basin ecosystem for various uses by human and for biodiversity management. Within Tana River Basin, various human activities (e.g., hydroelectric supply and flood control dams, agriculture, forestry, urbanization, industrialization) threaten the water and biological quality. Tana River Basin as a multifunctional ecosystem in Kenya, has several dams (Masinga, Kiambere, Kamburu, Gitaru, and Kindaruma) in the upper section that account for 60% of hydroelectric power supply in the country (Government of Kenya Report, 2007). There is more emphasis to reclaim the projects in Tana River Basin under the National Economic Food Security Project (NEFSP) to improve livelihoods through fish production, horticulture, livestock development among other enterprises. Notably, Tana River Basin is generally dry and prone to drought especially in June–August. Rainfall is erratic, with rainy seasons in March–May and October–December. Conflicts have occurred between farmers and nomadic peoples over access to water. Flooding is also a regular problem, caused by heavy rainfall in upstream areas of the Tana River (Government of Kenya Report, 2007). The Basin supports a fishery whose species diversity and abundance is influenced by the prevailing climatic conditions and long term impacts of human activities (Government of Kenya Report, 2012). Such unique features of Tana River Basin provide the necessity to assess the spatio-temporal status of the resource, especially in the lower sections of the river in order to ascertain the anthropogenic impact on the ecosystem.

Thus, based on the Tana River riparian influences due to the aforementioned anthropogenic activities, hydrological character and water retention of the basin is seasonally altered resulting in destructive flooding with increased precipitation (Government of Kenya Report, 2007). The human activities pose a challenge to the holistic physical, chemical and biological attributes of the basin as the water quality is degraded and quantity reduced during the dry seasons. Amid the inevitable climate change and increasing population, such problems will only exacerbate. In order to protect resources like those in Tana River Basin, there is need to regulate human influences using low-cost and integrated decision-support tools that monitor such changes. One major contribution is the development of new methodologies and tools such as IBI to assess and monitor the ecological integrity of such riverine ecosystems using species-environmental relationships (Karr and Chu, 1997, 2000) such as use of Macroinvertebrate Multi-index of Biotic Integrity (hereafter, MMiBI). This is because bioindicators such as benthic macroinvertebrates are superior to chemical analyses since they are widely employed in monitoring and assessing water quality of most freshwater bodies (e.g., Ndaruga et al., 2004; Mereta et al., 2012; Pace et al., 2012). They are increasingly studied and commonly used as indicators of ecological disturbance since they are long-lived and integrate varied levels and kinds of pollutants accumulated over a long period of time (Raburu et al., 2009), because of their sensitivity to environmental changes and ease of sampling (Morse et al., 2007).

Globally, IBIs that have been developed have little information on the temporal aspect of assessing their holistic performance on water resources and their sustainability. Due to limited resources for research, the lower sections of the basin (i.e. urbanization and forestry) were studied to assess the resultant longitudinal influence of anthropogenic activities on the holistic ecosystem status of the basin using temporal scales. We hypothesized that the MMiBI developed will account for various attributes and microhabitats that are evaluated based on their predictive accuracy and their ability to perform in a temporal scale in the lower Tana River Basin ecosystem scenarios. Therefore, in this study, we developed a spatio-temporal MMiBI for Tana River Basin, Kenya, as a decision-making support tool for river basin management for water resources sustainability.

2. Materials and methods

2.1. Study area

This study was conducted on Tana River Basin (Fig. 1). The 1014 km Tana River is the longest and major river in Kenya, and gives its name to the Tana River County. Its tributaries include the Thika, Sagana and Thuci. The river rises in the Aberdare Mountains and passes through the towns of Garissa, Hola and Garsen before entering the