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Review Article

Biomonitoring of Malaysian aquatic environments: A review of status and prospects

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A B S T R A C T

Anthropogenic stressors are reported to be the major drivers of aquatic pollution all over the world. Combating aquatic pollution requires adequate monitoring and inventorying mechanisms, and biomonitoring with the help of bioindicator organisms can be regarded as a sensitive tool for the evaluation of the biological and ecological significance of aquatic pollution. Bioaccumulation, biochemical alterations, morphological and behavioural approaches, population and community level approaches, and in vitro toxicity tests of aquatic organisms are all common techniques employed in biomonitoring of aquatic environments. In this review, the body of literature dealing with the pollution via biomonitoring in Malaysian aquatic ecosystems is discussed. It is evident from the study that, in Malaysia, biomonitoring by bioaccumulation received more attention than other biomonitoring techniques. Aquatic ecotoxicological research studies are very limited in east Malaysia (Sabah and Sarawak), when compared to west (Peninsular) Malaysia. The potential applications of biomonitoring and its relevance for the Malaysian aquatic ecosystems are discussed. Recommendations for future improvements in the Malaysian aquatic pollution biomonitoring are also made.

1. Introduction

Over the past few decades, aquatic ecosystems have been subjected to pollution hazards at an alarming rate due to various anthropogenic stressors such as industrialization, domestic and urban effluents and diffuse sources linked to agriculture which have a direct impact on a fragile ecology. The organic and inorganic pollutants continuously finding their way into aquatic ecosystems also pose a direct threat to human health, which calls for the development of proper management strategies in order to protect these ecosystems from severe and irreversible damages. Hence, it is imperative to develop methods for the identification, estimation, comparative assessment and management of the risks posed by pollutants to the environment and natural resources (Cajaraville et al., 2000).

The aquatic ecosystems of Malaysia on which this review focuses includes lakes, freshwater swamps, rice-fields, mangroves, freshwater peat swamps, mudflats and coastal waters occupying an area of about 39,000 km^2, which is more than 10% of the total land area of 330,000 km^2 (Chew, 1996; Yusoff et al., 2006). The country's total coastline extends to about 4800 km, with 2100 km lining Peninsular Malaysia and 2700 km lining east Malaysia on the Borneo Island (Mazlan et al., 2005). It is estimated that these aquatic ecosystems contribute to

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1.6% of the nation's GDP while providing employment to about 100,000 people (Tan and Yap, 2006).

The rapid economic growth of Malaysia following the industrialization policies of the 1980s, was accompanied by urbanization, deforestation, irrigation and dam construction, drainage of freshwater wetlands and peat swamps which in turn led to the ever increasing land, air and water pollution (Tan and Yap, 2006; Morse et al., 2007). In the three decades that preceded 2006, the quantity and diversity of toxic and hazardous pollutants in Malaysia were found to have increased due to the proximity of industrial activities to the water resources (Hassan et al., 2006). In 2006, the Ministry of Natural Resources and Environment of Malaysia monitored 146 river basins and reported 80 rivers as 'clean', 59 'slightly polluted' and seven as 'polluted'. All seven rivers categorized as 'polluted' flow in the industrial areas of Penang, Selongor and Johor (Bin Khalit, 2005).

Of the 473 rivers monitored by the Department of Environment Malaysia ("the DOE") in 2012, 278 rivers (59%) were reported as clean, 161 (34%) as slightly polluted and 34 (7%) as polluted. However in 2013, 315 (72%) of 473 rivers monitored were regarded to be polluted, with 25 rivers (~12%) classified as highly polluted. In 2014, a total of 473 rivers were monitored, out of which 244 (52%) were found to be clean, 186 (39%) slightly polluted and 43 (9%) polluted. A total of 477 rivers were monitored in 2015 and it was found that 276 (58%) rivers were clean, 168 (35%) slightly polluted and 33 (7%) polluted. The river water quality was found to have improved in 2015, as the percentage of clean rivers had increased to 58% in 2015, compared to the 52% in 2014 (DOE, 2015). The report also shows that in addition to the organic pollutants, inorganic pollutants especially heavy metals have also contributed crucially to the environmental degradation. The DOE also identified about 1,662,329 point sources of river pollution comprising of 4595 manufacturing industries, 9883 sewage treatment plants (excluding individual and communal septic tanks), 754 animal farm (pig farming), 508 agro-based industries, 865 wet markets and 192,710 food services establishments.

The DOE has also been involved in monitoring of marine water quality in Peninsular Malaysia, and in Sabah and Sarawak during 1978 and 1985 respectively using 168 coastal, 78 estuary, and 93 Island monitoring stations. In 2012, the water quality of 155 stations were analyzed, of which three stations (1.9%) were categorized as excellent, 32 stations (20.6%) as good, 111 (71.6%) stations as moderate and nine (5.8%) stations as poor. In the recent years, the number of stations with excellent and good water quality has decreased, while the number of stations with moderate water quality has increased, indicating a further deterioration in marine water quality. Analysis of 69 out of 78 monitoring stations from estuaries shows a slender improvement in the number of good category stations from 8.7% in 2011 to 11.6% in 2012. However, the number of moderate category stations decreased from 50% to 48% during the same period, while excellent and poor category stations remain unchanged. Likewise, the number of island stations with good water quality was found to be decreased from 17 stations in 2011 to 13 stations in 2012. The stations recording good and moderate water quality was similar to that recorded in 2011 with 18 stations (20.9%) categorized as good and 52 stations (60.5%) as moderate. The Islands off the Malaysian coast recorded relatively less pollution with only two stations in 2011 and three stations in 2012 recording 'poor' water quality (DOE, 2014; Huang et al., 2015). In 2014, a total of about 150 coastal, 76 estuary and 89 island stations were monitored. Out of 150 coastal stations, 30 stations (20%) were found to be of excellent quality, 45 stations (30%) of good and 75 stations (50%) of moderate water quality. In the case of 76 estuaries monitoring stations, seven stations (9.2%) were reported to be of excellent water quality, eight stations (10.5%) of good and 61 stations (80.3%) of moderate water quality. The waters around 74 islands were monitored and found that 10 stations (11.2%) were of excellent, 34 stations (38.2%) of good and 45 stations (50.6%) of moderate water quality.

In 2015, about 151 coastal, 76 estuaries, and 90 island stations were monitored. Of the 151 coastal stations, the monitoring results indicated that 9 stations (6%) were of excellent water quality, 54 stations (36%) of good, 86 stations (57%) of moderate, and 2 stations (1%) of poor water quality. In the case of estuaries, about 76 estuary stations were monitored, out of which 6 stations (8%) were recorded to have excellent quality, 12 stations (16%) of good, 54 stations (71%) of moderate and 4 stations (5%) of poor water quality. The estuarine water quality shows a decreasing trend when compared to 2014, as the stations with excellent category were found to be reduced from 7 stations to 6 stations, while 4 stations fell under poor category. Of the 90 island stations, 3 stations (3%) were found to be of excellent, 24 stations (27%) good, 62 stations (69%) moderate and 1 station (1%) of poor water quality. Despite the adoption of some effective treatment systems, industry in Malaysia continually contributes immensely to the pollution load of waterways. This can only be attributed to the lack of adequate maintenance of effluent treatment systems (Abdullah, 1995). This also underscores the need for enforcing strict laws and implementing adequate management strategies that draw inputs from continuous monitoring of the health status of the aquatic ecosystems.

Chemical analysis of water and sediments is the commonly employed 'direct approach' to assess the pollution status of an aquatic environment. However, it is also known that the actual toxicity levels of pollutants and their combined effects in an ecosystem cannot be completely revealed by such approaches (Lambou and Williams, 1980; Kozuharov, 1985; Zhou et al., 2008; Schöne and Krause, 2016). This is because, certain toxicants can easily be dispersed into aquatic environments in concentrations below detectable limits where they are readily available for uptake and accumulation by living organisms despite the low levels (Thomas and Shearer, 1986; Schöne and Krause, 2016). Moreover, it may be difficult to evaluate the behaviour of these pollutants in complex natural ecosystems (Yasuno and Whitton, 1986). Thus, it is important to study the deleterious effects of pollution in relation to a biological system (Oertel and Salánki, 2003), by employing methods such as biomonitoring (Cerveny et al.,

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