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Sediment Quality Index in Mangrove Forest

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Abstract – The objectives of this review are to determine the types of indices to use, to assess the current sediment quality index (SQI) of a mangrove forest and to select the appropriate index to describe the mangrove sediment quality index. Amongst the many indices considered in this review are the enrichment factors (EFs), the geo-accumulation index (Igeo), the pollution load index (PLI), the marine sediment pollution index (MSPI) and sediment quality index (SQI). The different indices give diverse perspectives of the status of mangrove sediment quality. This review also highlights the appropriate parameters that need to be used in assessing sediment quality, such as the physical, chemical and biological properties. As the comparison review, the sediment quality can be utilized for Mangrove quality index (MQI) development like to assess the heavy metal, complete laboratory parameters and a classification following the Interim Sediment Quality Guidelines ISQG, PCA and HACA. For the heavy metal content of sediment, the suggested parameters are Pb, Zn, Cu, Co and Mn. Lastly, for the indices, the enrichment factor (EFs), geo-accumulation index (Igeo), pollution load index (PLI) and marine sediment pollution index (MPSI) are used in develop SQI on mangrove forest.

Keywords: Indices, Mangrove Forest, Parameters, Sediment Quality Index

Introduction

Currently, there are many studies assessing and monitoring sediment quality worldwide. Because of excess toxicity, the persistence and bioaccumulation ability of heavy metals in the natural environment has become one of the most severe environmental problems (Aris *et al.*, 2014), including the decreases of mangrove ecosystems (Praveena *et al.*, 2007). The high metal concentrations are derived from anthropogenic sources around mangrove estuaries, such as disturbance areas, industrial activities, agriculture activities, wastewater disposal and discarded automobiles (Praveena *et al.,* 2007; Aris *et al.,* 2014; Gandaseca *et al.,* 2014).

Studies of sediment quality showed that the metals are deposited on the surface of the sediment once they have been transported by the water body and cannot be degraded, either biologically and chemically (Dwivedi & Padmakumar, 1983; Aris *et al.,* 2014). However, the metals can only be transported along the distance of, or accumulate in the ecosystem (Pakey, 2006; Marchand *et al.,* 2006; Preveena *et al.,* 2007; Aris *et al.,* 2014).

Mangrove forests are amply affected by human activities because they are located close to urban areas. Hence, these forests face a long-lasting impact and receive significant pollution loads from the landward areas (Yunus *et al.,* 2010; Aris *et al.,* 2014; Gandaseca *et al.,* 2014). Mangroves play a significant role as contamination reducer because of their nature capability to act as a sink of industrial and other anthropogenic toxins. The mangrove forest has special characteristics and mechanisms, such as its sediment properties, nutrient cycles, carbon and adaptations to tidal fluxes.

This paper also suggests certain parameters which can be utilized for assessment of sediment qualities index and pollution load index development. To assess the sediment quality index (SQI), several factors need to be taken into account, such as habitat and the assessment methods, because different methods will give different results (Soares *et al.,* 1999). Meanwhile for pollution load index the heavy metal concentrations has gained as one of the important factor in correlation with SQI (Tomlinson *et al.,*1980). For the marine sediment pollution index (MSPI), pollutants weight is important (Shin & Lam, 2001; Caeiro *et al.*, 2005).

Mangrove

Mangrove Forest

Mangrove forests are one of the most dynamic and bio-diverse wetlands on Earth. They grow in unique conditions and frequently are found along sheltered coastlines in subtropical and tropical areas (Gandaseca *et al.,* 2011). They also grow in regions with high salinity, high temperatures, and high sedimentation; in extreme tidal zones; and under aerobic and anaerobic soil conditions (Giri *et al.,* 2011). Mangroves are distributed in the intertidal area of the land and the sea around the world (Rambok *et al.,* 2010). Mangroves are minor to medium evergreen trees or shrubs, usually with complex root systems (Kuanzer *et al.,* 2011).

Mangrove species are distinguished into major, minor and associate mangroves. The major species occur only in mangrove habitats and do not spread to landward societies. They play a major role in the arrangement of the societies and have the ability to form clear stands. They develop various morphological specialization to adapt to the environment (aerial root system and viviparous reproduction), such as having special mechanisms for salt exclusion to suit the. The major mangroves include the genera *Avicennia sp*, *Bruguiera sp*, *Lumnitzera sp*, Nypa, *Rhizophora sp* and *Sonneratia sp*. Minor mangroves rarely form pure stands; thus, morphologically, they do not show a dominant role in the community structure. The minor mangroves include *Acrostichum sp, Aegiceras sp, Aegialitis sp, Xylocarpus sp, Heritiera sp, Camptostemon sp, Excoecaria sp, Scyphiphora sp* and *Pelliciera sp*. The associate mangroves are species associating with major and minor elements of mangroves and include the genera *Acanthus sp, Hibiscus sp, Calamus sp, Cerbera sp* and others (Tomlinson, 1994).

Mangroves perform an important ecological and socio-economic function in tropical coastal societies. For example, they provide spawning areas and habitats for many species of fish and crustaceans. They also protect and maintain shoreline marine quality, reduce the severity of rainstorm, flood damage and wave and provide feeding and nursery regions for commercial and artisanal fishery species (Kuanzer & Gebhardt, 2011).

Mangrove Sediment

Mangrove sediment is composed of detritus, organic and inorganic material that are deposited at the bottom of their habitat. The sediment generally is a medium of tools and can be moderately heterogeneous in terms of its physical, chemical and biological appearance. In geological terms, sediments are the final path for natural and anthropogenic tools, which lies at the origin of polluted sediment problems. The sediment can be thought of as having four main components. The major capacity is working by the interstitial water that fills the pore between the sediment particles, which usually accounts for over 50% of the sediment by volume (Förstner, 1987; Power & Chapman, 1992). Inorganic sediment contains rock, mineral particles and shell debris that come from the natural erosion of terrestrial materials. Organic sediment constitutes a minor portion but is significant in terms of regulating sorption and bioavailability of many pollutants. Porosity and permeability of organic sediment is important for the movement of pollutants. Gravel and sand are the most permeable, and mud is the least permeable (Chapman, 1981; Power & Chapman, 1992).

The sediment particles are derived from a combination of component inputs from different sources, including eroded rock, soil, waste particles, atmospheric fall-out and inorganic particles produced naturally. Sediments are of various types; clay, carbonates, feldspar, quartz and organic matter. These particles are frequently coated with iron oxides and hydrous manganese, as well as organic materials. Iron and manganese oxides are formed in lakes, seas and marine waters. Typically, sediments are categorized as mixture coarse and fine particles. The fine particles are represented by sand, silt and clay. The coarse fraction is composed of stable inorganic silicate materials that are non-cohesive and generally not allied with chemical pollutants. However, the fine fraction contains elements with a relatively great surface-range-to-volume ratio, and surface electric charges frequently cause these particles to be more chemically and biologically reactive than the coarser sand, which increases the likelihood of the sorption and desorption of contaminants. The problem of chemical determinations is most often found in the fine sediment, which are characterized as the dispositional area.

Sediment Quality Index (SQI)

To quantify sediment toxicity, sediment contamination and total organic carbon sediment quality index (SQI) is established on the basis of EPA National Coastal Assessment methods. Through industrial, agriculture and urban waste estuaries are polluted by different chemicals, metals and organic matters like pesticides, polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs). These pollutants collect onto suspended particles and eventually mix in the sediments of the seafloor, where they can disturb the benthic community of crustacean's shellfish, and invertebrates. In result it becomes the risk for the living organism in aquatic life. Sediment quality index (SQI) is a standard for assessing and monitoring the sediment quality of mangrove forests. The SQI is helpful for decision making and conservation. SQI will also support for the development and revision of the mangrove quality index (MQI). SQI is based on standard parameters to be used and measured and allows better comparisons of data between monitoring stations at the regional, national, and global levels. These comparisons enhance the option to engage further analyses on mangrove quality at wider geographical scales. In the case of mangroves, the development of a practical SQI is a way forward to provide quick solutions to identify the extents of disturbances, impacts and effective mitigation measure to protect resource sustainability.

Comparison SQI Worldwide

Table 1 shows the comparison of SQI worldwide. It shows the places where many research studies have been performed on sediment quality around the world, such as Tampa Bay Florida (Wenning *et al.*, 2005), Mengkabong Sabah (Praveena *et al.*, 2007), Sepang Besar (Ramsie *et al.*, 2014), Tanjung lumpur (Yunus *et al.*, 2011), Tanzania (Mremi & Machiwa, 2002), and Kota Merudu Sabah (Aris *et al.*, 2011). All of these research studies have been conducted in mangrove areas. Many factors are taken as variables for the purpose of comparison, such as the location, the sampling design, the parameters and the sample analysis. As a result, there are significant differences amongst the studies in terms of the locations, variables, sampling methods, parameters and indices used. To assess the sediment quality in a mangrove forest, many variables need to be taken into account, such as the season. It is so because the dry and wet periods in tropical and subtropical areas will influence the parameters under consideration.

The tidal level also needs to be considered as a variable because low and high tides are characteristic of mangroves and their estuary areas. Different tides create different conditions for mangrove habitats and rivers. In the previous research, only the study of Mengkabong Sabah considered this variable; it shows a significant difference between low and high tides. Sediment depth is another variable worth considering since sediments formed a long time ago are typically belowground, either in a river bed and or at a substantial depth on land. Thus, many metals will be stored at a lower depth.

Suggested Parameters on SQI

Parameters such as pH, EC, salinity, OM, texture, base cations and heavy metals are considered for this study. To ensure maximum usefulness of the data, all parameters are analysed using standard laboratory methods and are measured using standard equipment.

Assessment of Sediment Quality Index (SQI)

To assess the sediment quality index, several factors need to be accounted for, as each method will yield a different outcome. Mangrove forests are involved in estuary habitats that require site-precise SQI and additional bioassays because they are dynamic areas that are conquered by grain size, salinity, electrical conductivity, pH and other gradients. Pollutants, sediments move bi-directionally from upstream and move to downstream. The suggested method is to define grain size and salinity zones both temporally and spatially using appropriate salinity bioassays, site-specific SQI and regulated background comparisons and by designing sampling based on grain size and salinity zones (Soares *et al.*, 1999).

For sediment sample collection, random sampling is easy and useful because geographically mangrove forest is not uniform and many limitations can be experienced in the field. For depth sampling, numerous depths sampled, such as 0-5 cm (Ramsie *et al.*, 2014) and 0-10 cm. Since many previous studies do not mention the sampling depth the appropriate depth was determined by the sediment profiling. The suggested depths are 0-15 cm, 15-30 cm, 30-50 cm, 50-100 cm and >100 cm. Using this scheme, the samples will be accurate when they are submitted for analysis. As a result, the physical, chemical and biological characteristics can be fairly determined.

The sediment samples were kept in zip lock plastic bags during transport to the laboratory. The samples were constantly air-dried and ground using a mortar. Ground samples were sieved passed through a 2 mm sieve, stored in zip lock plastic and labeled. Physical parameters such as pH, salinity and electrical conductivity (EC) were measured in 1:2 soil-to-water ratios. For determination of chemical and heavy metals elements, the samples were digested using aqua-regia method. Approximately 2 g of each sample was digested with 15 mL of aqua-regia (1:3 HCl: HNO3) for 2 hours at 120°C. After cooling, the digested samples were filtered and kept in plastic vials prior to analysis. Base cations were determined by the measurement of exchangeable cations using ammonium acetate. All parameters were analyzed using Atomic Absorption Spectrometer (AAS).

Polluted Load Index (PLI)

Enrichment factor is the comparative abundance of a chemical compound in a mangrove soil and sediment compared to its abundance in bedrock (Hernandez *et al.*, 2003; Praveena *et al.*, 2007); it is also a suitable measure of geochemical movement and it is used for comparison between areas. Enrichment factor has been applied in mangrove geochemical studies around the world. (Abraham, 1998; Ramanathan *et al.*, 1999; Kamau, 2002; Praveena *et al.*, 2007) The formula below, which was used by Hernandez *et al.*, (2003), has been applied in this study to assess the extent of anthropogenic and lithogenic contribution to the heavy metals that were evaluated. Anthropogenic heavy metals were predicted using the following formula. Where, $[M]_{Anthropogenic} = [M]Total - [M]_{Lithogenic}$. For lithogenic heavy metals $[M]_{Lithogenic} = [Al]_{Sample}$ X $([M]/[Al])_{Lithogenic}$. Where, $([M]/[Al])_{Lithogenic}$ corresponds to the average ratio of the earth crust.

The geo-accumulation index (I_{geo}) introduced by Muller (1979) was also used to measured metal pollution in the sediments, in addition to the enrichment factor. The geo-accumulation index is stated as in ($I_{geo} = Log_2 (C_n/1.5B_n)$). The C_n = Measured concentration of heavy metal in the mangrove sediment, B_n = Geochemical background value of the element in average shale (Turekian & Wedepohl, 1961; Praveena *et al.*, 2007) of elements. However, n 1.5 is the background matrix correction factor due to lithogenic effects. The geo-accumulation index table includes seven grades (0, 0-1, 1-2, 2-3, 3-4, 4-5 and >5 grades). It also contains various degrees of enrichment above the background value, ranging from background concentration unpolluted, moderately to unpolluted, moderately polluted, moderately to highly polluted, highly polluted and very highly polluted in sediment quality index. The class six is highest grade reflects 100-fold enrichment above the background values (Singh *et al.*, 2003).

Pollution load index (PLI) proposed by Tomlinson *et al.*, (1980) refers to the heavy metal concentrations and gained as concentration factors (CFs). The CFs is the quotient obtained by dividing the concentration of each metal by its background value and the formula is CF= Cmetal /C Background value. The pollution load index formula is PLI = n√ (CF1 x CF2 x CF3 x CF4…..x CFsn). Where, these formula show an area is calculated by obtaining the n-root from the n-CFs that were obtained for all the metals. With the PLI obtained for each location, it is quickly understood by unskilled personnel in order to compare the pollution status of different locations (Ray *et al.*, 1998; Soares *et al.*, 1999). As a result, the recommended varies from 0 (unpolluted) to 10 (highly polluted).

Marine Sediment Pollution Index (MPSI)

The marine sediment pollution index (MSPI) has a value of the earlier indices in that it provides different weights to each pollutant. MSPI formula is as follows (MSPI = ($\Sigma_{ni}=1_{qiwi}$) 2/100). Where, qi is the sediment quality rating of the *i* contaminant and *wi* is the weight attributed to the *i* variable (the proportion of eigenvalues obtained from the results of a principal component analysis, (PCA)). Application of PCA to identify important variables from a monitoring programme can reduce sampling resources. The parameters that do not show significant spatial variations can be analyzed with lesser frequency than those that have been identified as more important from the results of the PCA. Additionally, the use of the PCA allows the successful assessment of the source of pollution because this multivariate analysis tool does not require any linear assumptions and establishes the correlations amongst the original variables in the dataset when the objective is to reduce the number of variables (Shin & Lam, 2001; Caeiro *et al.*, 2005).

Conclusion

As a conclusion, this paper reviews sediment qualities and the methods. Indices will be used in developing SQI that could be used as a guideline to assess the sediment quality in mangrove forests for decision making and conservation purposes. To assess sediment quality index at mangrove forest, one approach is suggested to improve the index because of the factors from mangrove ecosystem encourage the changes of sediment quality. This review also highlights the appropriate parameters that need to be used in assessing sediment quality, such as the physical, chemical and biological properties. As the comparison review, the sediment quality by Wenning *et al.,* 2005 can be utilised for MQI development, by Praveena *et al.*, 2007 is more to assess the heavy metal), by Yunus *et al.,* 2011 is the less on number of parameters. Ramsie *et al.*, 2014 has a complete both insitu and laboratory parameters, by Aris *et al.,* 2011 has a classification following the Interim Sediment Quality Guidelines ISQG, PCA and HACA. For heavy metal content on sediment, the suggested parameters are Pb, Zn, Cu, Co and Mn. Lastly, for the indices, the enrichment factors (EFs), geo-accumulation index (Igeo), pollution load index (PLI) and marines sediment pollution index (MPSI) were used to develop SQI on mangrove forest.

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Table 1: Comparison Sediment Quality Index (SQI) worldwide.

Places / Variables	Tampa Bay Florida	Mengkabong Sabah, Malaysia	Sepang Besar River, Malaysia	Tanzania	Tanjung Lumpur, Kuantan Pahang	Kota Merudu, Sabah
Author	Wenning *et al.*, 2005	Praveena *et al.*, 2007	Ramsie *et al.*, 2014	Mremi & Machiwa, 2002	Yunus *et al.*, 2011	Aris *et al.*, 2011
Year	2005	2007	2014	2002	2011	2014
Research Area	Bay	Mangrove Forest / Lagoon	Mangrove Forest / River	Mangrove Area	Mangrove Forest	Mangrove
Objective	MQI development	Assessment of Heavy Metal	Determined the anthropogenic and lithogenous sources of heavy metal in surface sediment	Assessment of Heavy metal at Sediment and Biota	Study Concentration of heavy metals in sediment.	Evaluate the degree of heavy metal contamination in lakes and the extent to which the sediment quality
Transect	-	-	-	3	2	-
Total Sample	-	33	-	-	40	17
Storage ºC	-	-	-	-	-	4ºC
Tide	-	Low and High Tide	-	Low Tide	-	-
Season	-	-	-	-	Rain Season	-
Depth	-	-	0–5 cm	0-5 cm	-	0-20 cm
Mangrove Sp	-	-	-	*A. marina*	-	-
Plant	-	-	-	Root / Leave	-	-

Aquatic	-	-	-	Crab	-	-
Zonation	-	-	-	-	-	-
Sieve	-	2 mm	63 um	2 mm	63 um	2 mm for physical 62 um for heavy metals
In-Situ Parameter	-	-	pH	-	-	-
	-	-	Salinity	-	-	-
	-	-	EC	-	-	-
Heavy Metals Analysis	ASS	AAS	AAS	AAS	ICP	ICP
Laboratory Parameters	Pb	Sand	Zn	Pb	Pb	pH
	Al	Silt	Pb	Zn	Cu	EC
	Arsenic	Clay	Cu	Co	Co	Salinity
	Cd	pH	Ni	Ni	Mn	Pb
	Co	EC	Cd	Cu	-	Cd
	Cu	Na	-	-	-	Cu
	Ni	K	-	-	-	Cr
	Zn	Ca	-	-	-	Zn
	-	Mg	-	-	-	Al

	-	Cu	-	-	-	Ni
	-	Fe	-	-	-	Fe
	-	Pb	-	-	-	OM
	-	Zn	-	-	-	-
	-	Al	-	-	-	-
SQI Classification	SQGS	(I_{geo}) PCA MPSI	(I_{geo})	Statistical non-parametric test.	EFs	Interim Sediment Quality Guidelines ISQG, PCA and HACA

*SQI- Sediment Quality Index

*MQI- Mangrove Quality Index