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SEDIMENT-FRIENDLY FORMULAS: A REVIEW ON THE SEDIMENT QUALITY GUIDELINES

ŞEYDA FİKİRDEŞİCİ ERGEN

Ankara University, Department of Biology, Faculty of Science, 06100 Ankara, TURKEY

ABSTRACT. Aquatic ecosystems play an important role in maintaining ecological balance such as climate regulation, irrigation, flood control, aquaculture, and especially water supply. Sediments are located at the linkup of the solid-liquid interface, therefore they form an important part of the water body. The purpose of this review article is to reveal the importance of sediment pollution with heavy metals and understand how usage of accordingly sediment quality guidelines and indices.

1. INTRODUCTION

Heavy metal contamination in sediments is a matter of environmental concern, because of their non-degradable, toxic and persistent features [1]. The amount of heavy metals is impacted by two main sources, anthropogenic and natural, which present metals into the aquatic ecosystem by different sources, such as sewage runoff, industrial waste, and agriculture discharges [2]. Thus, these sources cause the entrance of heavy metals into the aquatic system and they are distributed between the liquid phase and sediment during the transportation [3]. A large portion of heavy metal get accumulated in the sediment but only a small quantity of it stays dissolved in water [4]. There is not sufficient information to determine which sources are most influential for metals and locations specifically. Some heavy metal(loid)s such as cadmium, lead, arsenic, and mercury have toxic effects on organisms [5].

Keyword and phrases. Sediment, sediment quality guideline, aquatic, environment

fikirdesici@science.ankara.edu.tr
0000-0002-4623-1256

Heavy metals entering the aquatic environment precipitate to sediment and affect the health of the aquatic ecosystem. Sediments are main reservoir of heavy metals. They are vitally significant components of the aquatic systems because they have a long duration of stay. Also, sediments play an important role in preserve the trophic status of the system. The importance of the sediments not only relevant to the transport of heavy metals but also, they are a secondary heavy metal source [6]. When water parameters change that balance will collapse and heavy metals in the sediment will be released into the water [7,8]. The release processes are carried out by ion exchange, desorption, and dissolution [9] (Figure 1). Therefore, it is possible to have an idea about the pollution level of the wetland by looking at the metal concentrations in the surface sediments.

Sediment pollution is dangerous because of the food web and finally becoming detrimental to organisms. Heavy metals can pass from soil to seed, making plants toxic. When organisms feed on this plant, larger animals feed on these organisms, by the time heavy metals get more effective in the process of biomagnification. It is a significant point to analyze the metal pollution in the sediment during the investigation of the contaminated aquatic environment. Measuring the abundance and structure of organisms in the area may demonstrate the sediment ecosystem health but these measurements are expensive and requires a lot of time. The ecological risk caused by heavy metals is about to be evaluated different “sediment quality standards” have been developed.

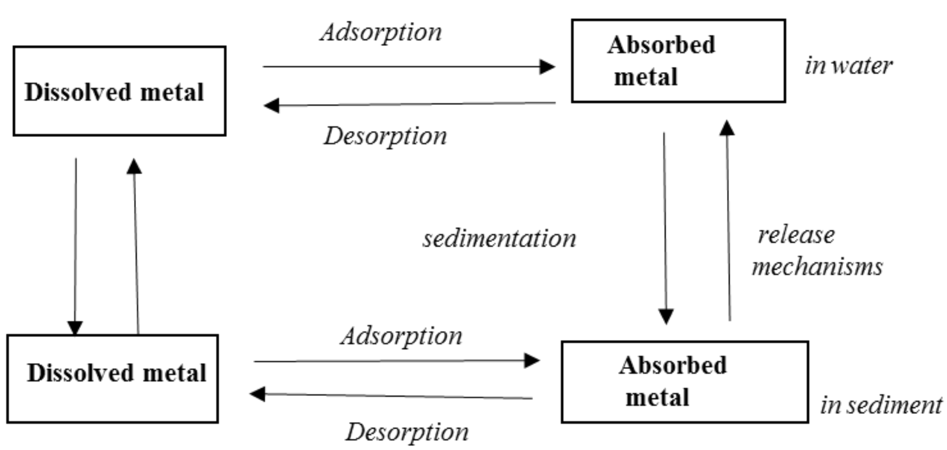

FIGURE 1. Interaction of heavy metals in water and sediment [10].

2. Sediment Quality Guideline (SQG)

Sediment quality guideline has been developed in order to understand the effects of heavy metal pollution accumulating on sediment on the organisms since the reference values or "background" used before 1980 were insufficient to understand the effect of organism [10]. In the last 20 years, many studies have been conducted that demonstrate the importance of determining and maintaining sediment pollution in order to maintain aquatic ecosystem quality using this method [11-16]. Emprical-SQG is based on both land and laboratory data, which shows the response of benthic organisms exposed to metal concentration in sediment. It focused primarily on two approaches to assessing pollution in sediment, these are the relationship between the response of the toxicity and contamination of the sediment [17-19].

Sediment quality criteria established by the National Oceanic and Atmospheric Administration (NOAA) are used to understand about contaminated sediment in the aquatic environment, specially TEL and PEL and the ERL and ERM [20]. TEL is the level of sediment contamination where toxic response begins in benthic organisms. PEL is the level of sediment contamination in which a large percentage of benthic populations show a toxic response. In summary, sediment contamination below the TEL value is acceptable, while the concentration above the PEL value is unacceptable. Further work and evaluation are required for the value between TEL and PEL. The 10th (ERL: Effects range-low) and the 50th (ERM: Effects range-median) percentile of the effects outputs were determined for each metal. The value below the ERL means that effects would rarely occur, above the ERM means that effects would frequently occur [18]. There have been references to such effects levels by different sources for heavy metals and a table has been created (Table 1).

Table 1. Some SQG values

	As	**Cd**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Zn**	**Reference**
TEL*	5.90	0.60	37.30	35.70	0.17	18.00	35.00	123.00	[19,20]
PEL*	17.00	3.53	90.00	197.00	0.486	36.00	91.30	315.00	[19,20]
ERL**	33.00	5.00	80.00	70.00	0.15	30.00	35.00	120.00	[18,20]
ERM**	85.00	9.00	145.00	390.00	1.30	50.00	110.00	270.00	[18,20]

Some of the Methods Used in the Assessment of the Sediment Pollution

Different indices have been developed to determine metal concentrations and anthropogenic effect levels in the sediment such as enrichment factor (EF), metal enrichment index (MEI), geo-accumulation index (Igeo), contamination factor (CF), pollution load index (PLI), and (Table 2). Reference values are generally source data of Turekian and Wedepohl [17].

Enrichment Factor (EF): It is used to determine whether the metals contained in the sediment are naturally (from rocks) or anthropogenic sources and also calculate the rate of pollutants in sediments [21]. Thus, it is possible to understand the status and degree of environmental pollution with this index.
In the literature, it is the most used index in the evaluation of metal pollution in sediment [11-16]. Classification values are given in the Table 2. It is formulated as follow [22]:

$$EF = \frac{C_n/C_{ref}}{B_n/B_{ref}} \quad (1)$$

Cn= It means that concentration of heavy metals in sample, Cref= It means that concentration of the heavy metals in the reference value, Bn= It means that reference element amount in the samples, Bref= It means that the value of the reference element in the reference environment, Fe is accepted as the reference element [23].

Metal Enrichment Index (MEI): This index is applied in an industrial area when investigating anthropogenic relationship with heavy metal accumulation [24, 25]. Classification values are given in the Table 2. This index has been reported to be more suitable for use in metal deposits in surface sediment and is also called surface sediment index and it is formulated as follow [24]:

$$MEI = \frac{C_A - C_B}{C_A} \quad (2)$$

Where C_A and C_B stands for total concentration of individual heavy metals, and stands for background level, respectively.

Geo-accumulation Index (Igeo): It is a frequently used index to evaluate the degree of anthropogenic and geogenic accumulated pollution loads and also this index has been reported to be successful in detecting heavy metal accumulation especially in the sediment due to industrial activity [13, 26]. In addition, it was used by most researchers to detect the severity of the pollution and quality of sediment [13, 14, 27, 28]. Classification values are given in the Table 2. It is formulated as follow [29]:

$$I_{geo} = log_2 \frac{C_n}{1.5 \times B_n} \quad (3)$$

Cn= Concentration of heavy metals in sample, Bn= amount of the reference element in the reference environment, 1.5= natural oscillation coefficient

Contamination Factor (CF): This method evaluates the enrichment of metals based on the background concentrations of each metal in sediments. It is found by dividing each metal concentration in sediment by the background value. Classification values are given in the Table 2. It is formulated as follow [30,31]:

$$CF = C_s / C_{ref} \quad (4)$$

Where Cs: concentrations of the element in the sediment sample, Cref are and the background value of the element.

Pollution Load Index (PLI): This index shows the magnitude of heavy metal pollution in sediment and also Igeo also use for this reason. Classification values are given in the Table 2. It is formulated as follow [32]:

$$PLI = (C_{f1} \times C_{f2} \times C_{f3} \ldots . \times C_{fn})^{1/n} \quad (5)$$

n = number of metals and CF = contamination factor.

TABLE 2. Some sediment quality classification.

Indices	Sediment quality classification for multiple indices to assess heavy metals	Reference
EF	EF<1 = no enrichment	[22]
	1<EF< 3 = minor enrichment	
	3<EF< 5 = moderate enrichment	
	5<EF<10 = moderately severe enrichment	
	10>EF>25 = severe enrichment	
	25>EF>50 = very severe enrichment	
	EF>50 extremely severe enrichment	
MEI	1= no enrichment	[24]
	2=low enrichment	
	3=moderate enrichment	
	4=strong enrichment	
	5=extremely enrichment	
Igeo	Igeo≤0 = practically uncontaminated	[29]
	0<Igeo<1 = uncontaminated to moderately contaminated	
	1<Igeo<2 = moderately contaminated	
	2<Igeo<3 = moderately to strongly contaminated	
	3<Igeo<4 = strongly contaminated	
	4<Igeo<5 = strongly to extremely contaminated	
	Igeo≥5 = extremely contaminated	
CF	CF<1 = low contamination	[30]
	1≤CF<3 = moderate contamination	
	3≤CF<6 = considerable contamination	
	CF≥6 = high contamination	
PLI	PLI <1 no pollution	[32]
	PLI is >1 deterioration	

Many indexes have been used in the literature to evaluate the current state of heavy metal in sediment. Some studies using these indices are summarized in Table 3.

TABLE 3. Summary of some studies using indices

Indices	Researched metals	Situation	Region	Reference
Igeo	As, **Cd**, Cr, Cu, Hg, Ni, Pb, Zn	moderately to strongly contaminated	Lake Taihu, China	[27]
EF, Igeo, CF	Cu, Cr, Ni, Zn, Pb, Mn	low ecological risk	Weihe River, China	[33]
CF,EF	Al, **As**, Cr, Cu, **Fe**, **Mn**, Ni, Pb, **Zn**	natural and anthropogenic sources	Lake Naivasha, Kenya	[11]
CF, PLI	Cr, Mn, Co, Ni, Cu, Zn, **Pb**	considerable contamination	Lishui River, China	[34]
EF, Igeo, PLI, CF	Pb, **Cd**, Cu, Cr, Ni, Hg, Zn, Mn, Fe	strongly/extremely polluted	Mashavera River, Georgia	[35]
EF, Igeo, CF	Pb, Cu, **Cd**, Ni, Cr, Zn	moderate-considerable pollution	Baltic Sea, Lithuanian zone	[36]
EF, Igeo, PLI, CF	Cu, Cr, **Pb**, Zn	very severe enrichment	Kuala Perlis, Malaysia	[37]
EF, Igeo	As, Cd, Pb, Cr, Co, Ni, Zn, Cu, Fe, Al	highly polluted	Gökçekaya Dam Lake,Turkey	[38]
EF, MEI, Igeo	Fe, Cr, Zn, Cu, Co, Ni, Mn , **Pb**, Cd	moderate contamination	Niger Delta Region, Nigeria	[39]
CF, PLI	Pb, **Cd**, As, **Hg**	moderate contamination	Danube Delta, Romania	[40]
EF, Igeo	Pb, Cu, Cr, **Ni**, **As**, Mn, Al, Fe, Zn	high contamination	Lake Beyşehir, Turkey	[41]
EF, Igeo	**Cd**, Cr, Cu, Ni, Pb, Zn	moderately severe enrichment	Laizhou Bay, China	[42]
PLI, Igeo	Fe, Cu,Pb, Mn, Ni, Cr	unpolluted by heavy metals	Benin River, Nigeria	[43]
PLI, Igeo	Mn, Ni, **Pb**, Cu, **Cd**	slightly polluted	Tigris River, Baghdad, Iraq	[44]
EF, Igeo, CF, PLI	As, Cd, **Co**, Cr, **Cu**, Mn, Ni, **Zn**, **Pb**	moderately polluted	Tigris River, Turkey	[45]

3. CONCLUSION

Numerous indices have been developed to understand the current health status of a wetland sediment. Thanks to these indices, it is possible to understand whether the presence of a metal in the sediment is natural or anthropogenic and also its level. But do these indices only have advantages? There are many advantages such as predicts toxic response, field tests and large database of lab, and easy to use. However, they also have some disadvantages such as difficult to separate effects from a mixture of contaminants, the area between thresholds, poor documentation for formulations, test errors and most data for metals. In this study, some indices frequently used in the literature are included. Studies in the literature have also shown that despite their disadvantages, they have very useful uses in terms of saving and protecting a wetland.

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