Spatial Analysis and Risk Assessment of Heavy Metal in Aquaculture Sediment of Porong River Estuary

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Abstract

Study on heavy metal contaminants in sediments provide major role because they have longer residence time. Increased levels of heavy metals in water which originally required for various metabolic processes may turn out to be toxic to aquatic organisms. The metal will be absorbed in the sediment then accumulated into microorganisms through the food chain. The purpose of this study is to analyze the spatial concentration of heavy metals in aquaculture's sediments of in Porong River estuary. Firstly, this research was conducted by examined content of eight heavy metals in the sediment, then tested with ICP-MS instruments. Then, the calculation of some parameters was analyzed spatially with ArcGIS. IgeO Parameter of aquaculture sediment of Porong River Estuary from largest to smallest is are Hg> Pb> Cd> Mn> As> Cu> Zn> Co. EF value of aquaculture sediment of Porong river estuary from largest to smallest values are Hg> Pb> Cd> Mn> Cu> As> Zn> Co. DC Results obtained in all 12 stations of this study has value between is 27.47- 36.35 within the categorization Very High Degree of Contamination. ERI value shows that almost entirely area of Porong river estuary shows High Risk result.

Keywords: Aquaculture, Heavy metal contamination, Porong river estuary, Sediment, Spatial

INTRODUCTION

In the hydrological cycle less than 1% of the dissolved pollutants in water while more than 99% is stored in sediments which are the main carriers of contaminants in aquatic environments [6]. Spatial survey of metal concentrations in sediments were compared with baseline from unpolluted environment. This is a key step in the understanding of transport and deposition of metal contaminants in aquatic systems [11]. Analysis of sediment plays an important role in the assessment of pollution status and determination of sources of contaminants [13]. The river has always been a place that has contaminated sediment disposal. Contamination in the river can be analyzed using either water or sediment suspended, the study of sediments provide a major role because they have a longer residence time [10] [14]. Increased levels of heavy metals in water which originally required for various metabolic processes may turn out to be toxic to aquatic organisms. As a result, the metal will be absorbed and stored in the sediment, then accumulated into microorganisms through the food chain [4] [5] [8].

Heavy metal density at least five times higher than the density of water. Heavy metals are easily adsorbed to sediments, which can act as a sink and secondary source of these contaminants in water and aquatic biota [12] .Porong River estuary has been used as aquaculture ponds with main commodities are shrimp and fish [7]. Increase and development of the industries along the river Porong beside gave positive impacts on development, it can also have negative impacts on the surrounding aquatic ecosystems.

One of GIS products is in the form of a map. A map is basically a set of information obtained from the processing and analysis of data. Spatial distribution of heavy metals in sediments is also very important to explain the history of contamination of aquatic ecosystems, and very useful for distinguish heavy metals in sediments that affected by natural or anthropogenic factors [11].

MATERIAL AND METHOD

Many calculation methods have been proposed to assess the quality of the environment, such as geoaccumulation index (Igeo). Igeo originally defined by Müller in 1969, in order to determine and define the sediment metal contamination in the aquatic environment [4] by comparing the current concentration to pre-industrial levels (before industrialization). It can be calculated by the following equation.

$$Igeo = Log2\left(\frac{Cn}{1.5Bn}\right)$$

Cn is the concentration of heavy metals in sediment,

Bn is the background concentration geochemical or reference value,

Factor of 1.5 is used to minimize variations in the background for geogenic effect.

Igeo Index are divided into seven classes of the following categories:

≤ 0 Unpolluted

0–1 Unpolluted to moderately polluted

1–2 Moderately polluted

2–3 Moderately polluted to strongly polluted

3–4 Strongly polluted

4–5 Strongly to extremely polluted

>5 Extremely polluted

In addition, there are also Enrichment Factors (EF). They were originally developed to estimate the origin of metals in the atmosphere, precipitation, or seawater. EF index was developed further to study the soil, lake sediment, peat, tailings, and other environmental materials. EF analysis is used to detect the source of pollutants, whether from natural or anthropogenic activities. EF method will normalize the measured data concentration of heavy metals in sediment samples with reference [1] [4]. The formula for calculating EF has been defined by the Buat-Menerd and Chesselt in 1979, while the formula is as follows:

$$EF = \left(\frac{Cn\,(sampel)\Big/Cref\,(sampel)}{Bn\,(Background)\Big/Bref\,(Background)}\right)$$

Cn (sample) is the content of metals in the environment checked,

Cref (sample) is the content of the reference element in the environmental review,

Bn (background) is the content of the metal examined in a reference environment,

Bref (background) is the reference in the metal content of the reference environment.

EF grades are divided into five classes, namely

$EF \leq 2$ Deficiency to minimal enrichment

$2 < EF \leq 5$ Moderate enrichment

$5 < EF \leq 20$ Significant enrichment

$20 < EF \leq 40$ Very high enrichment

$40 < EF$ Extremely high enrichment

Degree of Contamination (DC) is used to assess the level of contamination / pollution by multi-metals in sediments. Hakanson (1980)[9], propose indicators of the overall contamination by integrating data for a series of seven specific heavy metals and organic pollutants PCB [8]. This method was based on calculations for each pollutant of the contamination factor (Cf). However, Cf requires at least five sediment samples to produce an average pollutant concentrations compared to the reference level. The formula for calculating the level of contamination (DC) are:

$$DC = \sum_{i=1}^{8} C_f^i$$

$$C_f^i = \frac{C_{0-1}^i}{C_n^i}$$

C_f^i is metal contamination factor i,

C_{0-1} is the average value of the metal from at least five sampling sites,

C_n^i is the pre-industrial concentration of individual metal (equal to the metal geochemistry background value n).

DC is divided into 4 classes:

$DC \leq 6$ Low degree of contamination

$6 < DC \leq 12$ Moderate degree of contamination

$12 < DC \leq 24$ Considerable degree of contamination

$24 < DC$ Very high degree of contamination

In this study PCB is replaced with other heavy metals so that total of 8 heavy metals that being examined, and in addition to 5 samples then it used only 2 repetitions.

Ecological Risk Index (RI) is based on the characteristics of the metal and environmental behavior. This index is used to evaluate the ecological risks of multi-metal contaminants in sediments [8]. The formula for calculating the ecological risk factor index (RI) are:

$$RI = \sum_{i=1}^{8} E_r^i = \sum_{i=1}^{8} T_r^i C_f^i$$

E_r^i is potential ecological risk factors metals i,

T_r^i is a metal toxic response factor i,

C_f^i is the metallic contamination factor i.

RI is divided into four classes (where each class

RI ≤ 150 Low risk

150 < RI ≤ 300 Moderate risk

300 < RI ≤ 600 Considerable risk

600 < RI High risk

Data Collection

Using the grid method, the location of the samples was determined by specific locations which were chose to represent the characteristics of the local ponds. Sediment sampling sites chose at each grid. Whereas intake of sediment is determined at the location of aquaculture pond around the north and south along Porong river estuary. Reference stations that describe the environment conditions at the time of the pre-industrial has been arboretum in the village Sumber Brantas, Bumiaji, Batu City.
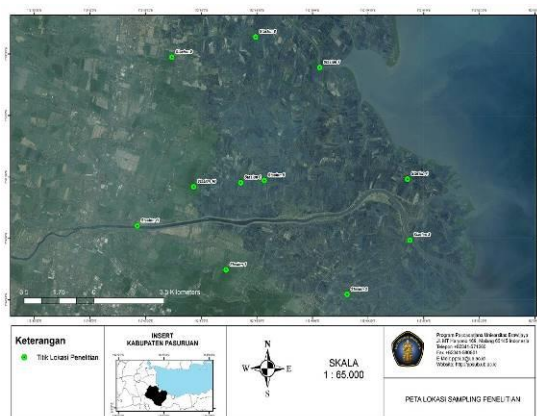
Figure 1. Sediment sampling location

The sediment samples which taken in this study is the surface sediment, sediment were taken with a grab sampler that has been modified. Firstly, laboratory testing was conducted by destructing samples, the destruction were performed using a Microwave Digester Mars 6. Then, samples that have been extracted using microwave digester was read with the ICAP RQ ICP-MS (Thermo Scientific Fisher SN-3439 ,UK) that provided by UPT. PM2KP, banyuwangi, East Java [2]. Lastly, data results of the instrument processed and calculated with MS-Excel for data computation to get a spatial map used ArcGIS 9.3.

RESULT AND DISCUSSION

Heavy Metal concentrations that examined in this study are Aluminum (Al), calcium (Ca), Manganese (Mn), Cobalt (Co), copper (Cu), zinc (Zn), arsenic (As), cadmium (Cd),

lead (Pb) and mercury (Hg). The area of this research is about 21.334 hectares (ha) and parameters of heavy metals such as Mn, Co, Cu, As and Cd showed category Igeo ≤1 almost in the entire area of research defining that aquaculture area is not contaminated by the heavy metal. Other patterns of Zn metal shown that the vast majority (20.192 ha) is in the range 1 <Igeo≤ 2 which shows the level of pollution being moderate. Hg showed a very different pattern in 17.373 ha in the range of 3 <IgeO ≤4 and the balance of 3961 hectares in the range 4 <Igeo≤5 showing the heavily polluted up to extreme polluted. Pb shows that most of the study area (21.184 ha) is in the range of 2 <IgeO≤3. This indicates the region in the level of polluted moderate to heavily polluted.

Igeo distribution pattern for heavy metals in aquaculture sediments of Porong river estuaries obtained results that indicate the distribution of heavy metals contained in the sediments Hg higher on the south side Porong estuaries, and almost similar pattern is also seen in metal Cu. Igeo of sediment Cultivation Around Porong River Estuary from largest to smallest is Hg> Pb> Cd> Mn> As> Cu> Zn> Co.

Enrichment Factor (EF), is a good tool to determine the source of the metal sediment as derived from anthropogenic sources or natural events. In this index, aluminum is widely used, showing aluminum silicate in the coastal area where the element is dominant. Generally, the value of EF approximately 1 illustrates that the metal enrichment entirely derived from the crust material or natural weathering processes and EF values greater than 2 showed significantly heavy metals derived from the non-crust material or non-natural weathering process [14]. Metal Co, Cu, and Zn. Having an average value EF <2 indicates that these metals are not affected by anthropogenic impact and almost entirely come from natural weathering processes or materials crust. Although some sites EF values> 2, but not far from EF <5 indicates that anthropogenic input may have an influence on the higher enrichment as shown in metals Mn, As, Cd and Pb. Things are very different in get to Hg where EF value obtained an average of 13.81 which indicates anthropogenic influence on heavy metal concentrations in sediments of aquaculture around Porong river estuary. EF value of aquaculture sediment around Porong river estuary, from largest to smallest values, which as Hg> Pb> Cd> Mn> Cu> As> Zn> Co.
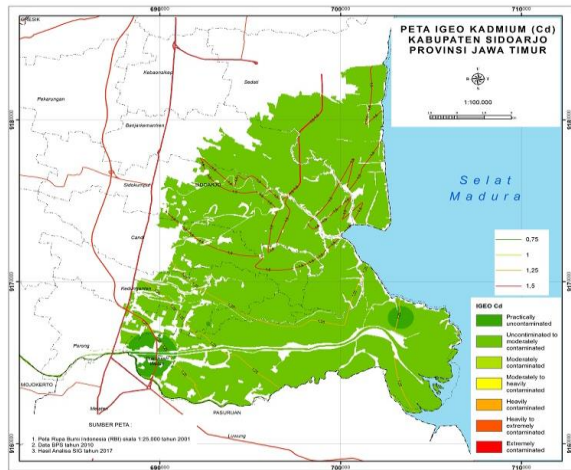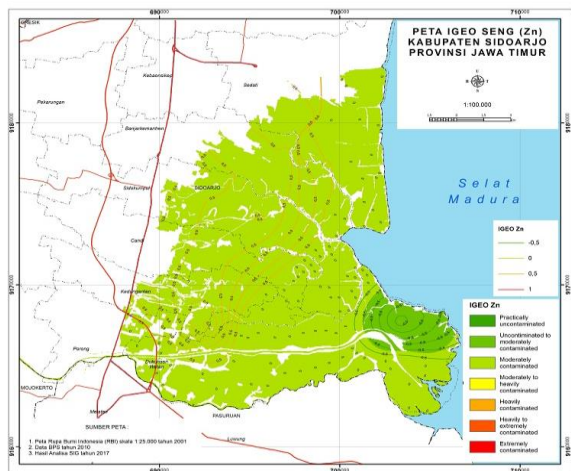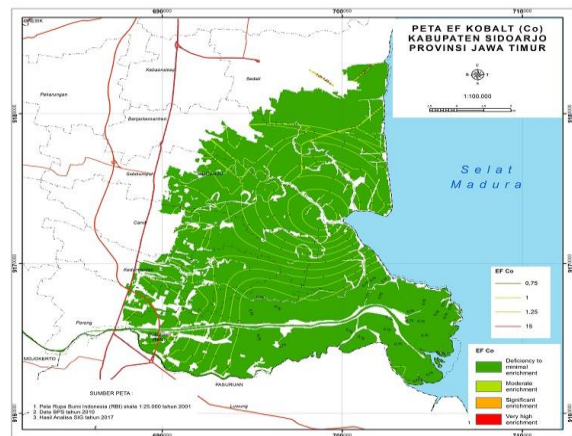
(a)

(d)
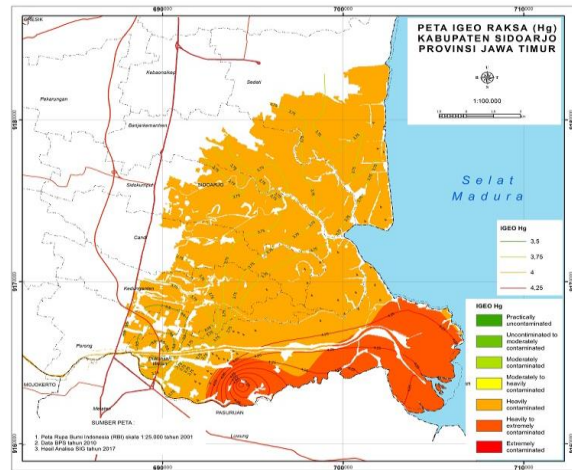
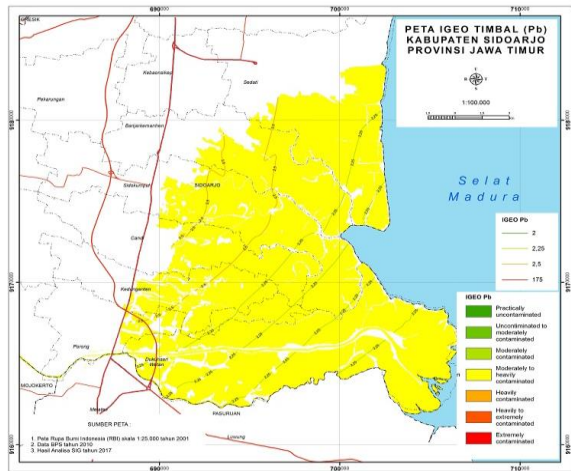**Figure 2**: Distribution of geoaccumulation index of (a) Cd, Igeo ≤ 1; (b) Zn, 1 <Igeo≤ 2); (c) Pb (2 <Igeo≤ 3); (d) Igeo Hg (3 <Igeo≤ 4 dan 3 <Igeo≤ 4)
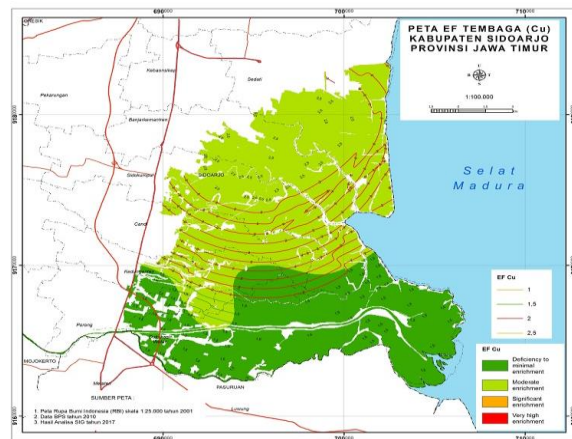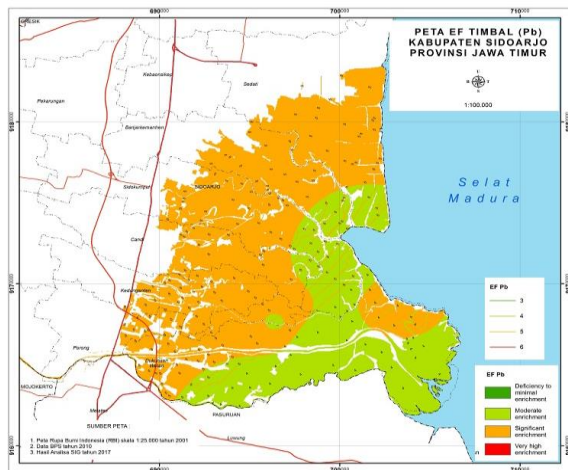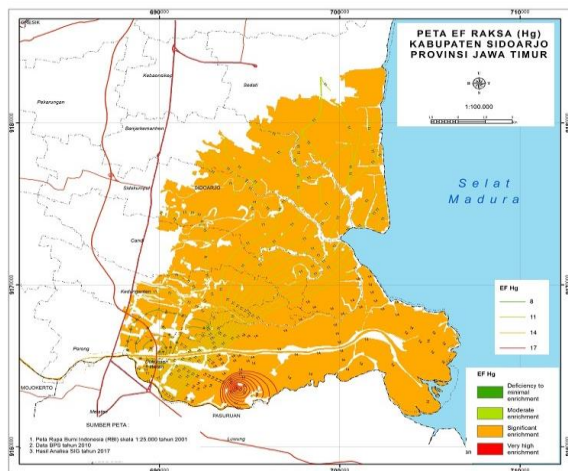

(b)

(a)

(c)

(b)

(c)

(d)

Figure 2: Distribution of Enrichment Factor index of (a) Co (EF≤2, Natural Source Enrichment); (b) Cu (EF≤2, Natural source enrichment)); (c) Pb (2<EF≤5, Partly Anthropogenic enrichment); (d) EF Hg (Anthropogenic enrichment)

The Degree of contamination (DC) is an index to assess the extent of multi-metal contamination in the sediments, which is different from a single metal factor. The level of contamination is the sum value of each individual metal which is shared with the pre-industrial concentration (background), in this study was obtained from the sum of 8 individual metals (Mn, Co, Cu, and Zn, As, Cd, Hg and Pb).

DC Results obtained in all 12 stations in this study gave value 27.47 – 36.35 and the overall area of 21.334 hectares of the research area shows the results of Very High Degree of Contamination. ~~At~~ The starting point of the Porong River flow at Station 12 (Mlirip Zone) has obtained results that indicate the condition of the level of contamination is very high.
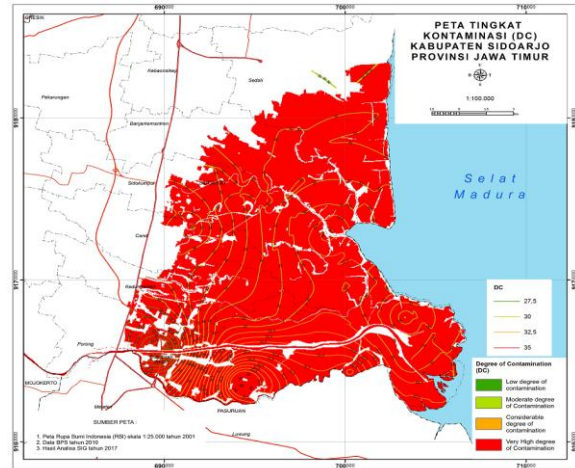

Figure 4. *Degree of Contamination* (DC) Aquaculture sediment of Porong River estuary.

Ecological Risk Index (ERI) is based on the characteristics and behavior of metal in environment. This index is used to evaluate the ecological risks of multi-metal contaminants in sediments. Value ERI showed almost total (20.767 of 21 344 Ha) of overall land in area aquaculture of Porong river estuary shows the results of High Risk, both in the area adjacent to the sea (Stations 3,4 and 7), adjacent to the river (Stations 3 and 11) and adjacent to the area of rice cultivation (station 1, 10 and 11). If the terms of the original flow in Porong river contamination (especially Hg) is located in an area between the water source Sumber Brantas until before the location of the station 12.
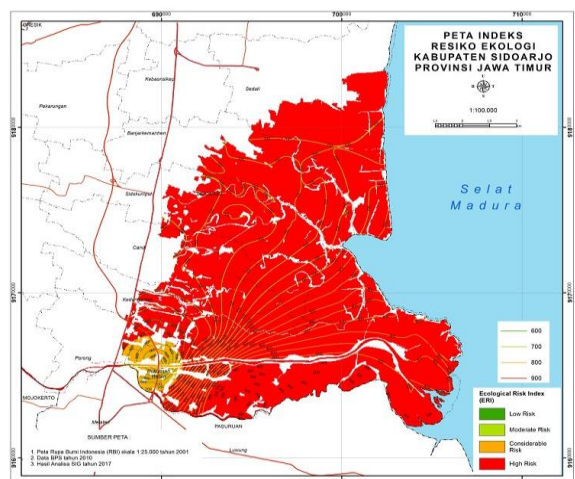

Figure 5. *Ecological Risk Index* (ERI) Aquaculture sediment of Porong River estuary.

CONCLUSION

In general, the condition of aquaculture sediment in Porong River estuaries meet the threshold. Igeo distribution pattern indicated that the distribution of heavy metals contained in the sediments Hg higher on the south side of estuaries. EF value of aquaculture sediment around Porong river estuary, from largest to smallest values, are Hg> Pb> Cd> Mn> As> Cu> Zn> Co. DC results obtained in all 12 units of this study gave value 27.47 − 36.35 is within categorization of Very High Degree of Contamination. ERI value shows that almost the entirely of the area shows the results of High Risk. Spatial analysis concluded sediment conditions in the area of aquaculture in Porong River estuaries in conditions that are contaminated by heavy metals, and heavy metals Hg (mercury / mercury) provided the largest contribution.

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ABBREVIATION :

DC	: Degree of Contamination
EF	: Enrichment Factor
ERI	: Ecological Risk Index
GIS	: Geographical Information System
ICP-MS	: Inductively Coupled Plasma- Mass Spectrometry
Igeo	: Geoaccumulation Index
PCB	: Polychlorinated biphenyl