The Bio-effects of Heavy Metal Contaminants in Gajah Mungkur Reservoir Sediments

Peni Pujiastruti*
Department of Environmental Science,
Setia Budi University, Surakarta, Indonesia.
Corresponding Author *E-mail: peni.usb@gmail.com

Sutarno, Muhamad Masykuri
Department of Environmental Science,
Sebelas Maret University, Surakarta, Indonesia.

Totok Gunawan
Department of Geography, Gadjah Mada University,
Yogyakarta, Indonesia.

Abstract

The study aimed at learning the dynamics of the distribution of heavy metals (Al, Fe, Cd, Co, Hg, Ni, Zn, Pb and Cu) in sediments from the contaminated zones of Gajah Mungkur Reservoir (GMR) in Wonogiri. A heavy metal distribution map is employed to evaluate the sediment quality status and its biological effects on the aquatic environment of the reservoir on the SQG-Q value basis. The sediment sampling was conducted based on USEPA (2015) in the waters of GMR at 8 points of the contaminated zones. Samples were collected by using the Eckman Grabe sampler. The determination of heavy metal content consisting of Fe, Cd, Co, Ni, Pb, Zn, and Cu was organized using SW 846-700B: 2007 test method, while Al and Hg was applied (characterized) using SW 846-6010:2007 test method. The test result was determined on the dry-weight basis. The heavy metal content was compared to the quality standard presented by ANZECC and Dutch Quality Standard for Metals in Sediment. In addition, the bio-effects of heavy metal contaminants were calculated on the SQG-Q value basis. It was found that the Fe, Cd, Co, Ni, Pb, Zn, and Cu contents for GMR sediment from 8 sampling point indicated the potential of these metals to have moderate effects on aquatic biota.

Keywords: Heavy metals, Sediment, Reservoir, SQG-Q
Introduction
Human activities in Gajah Mungkur Reservoir (GMR) catchment area in Wonogiri, Central Java, Indonesia, such as agricultural, industrial, and domestic activities produce waste. The waste is disposed to rivers and flows to the reservoir through 7 sub-river basins, involving Keduang, Wiroko, Temon, Bengawan Solo Hulu, Alang, Ngunggahan, and Wuryantoro. It contains organic materials and heavy metals having potential to increase the pollution burden of the reservoir. The increasing content of heavy metals as well as that of human activities may lead to bioaccumulation in the aquatic biota resulting in toxic effects to human (Ceairo at al, 2005). Sediment is the geo-indicator of the environmental pollution due to long-term human activities (Shafie et al, 2014).

Heavy metals Be, Co, Au, Se, Hg, Ni, Cu, Pb, Zn, Ag, Sb, Sn, Cd, Bi and Pt are considered highly toxic and they are relatively abundant. Hg is a heavy metal with the highest toxicity to aquatic animals, while heavy metals with lower toxicity respectively include Cd, Zn, Pb, Cr, Ni and Co. The quality standard of heavy metals in sediments has been decided US-SEPA (2004), ANZECC/ARMCANS 2000 (Simpson et al, 2005), CCME 2001 (Lestari et al, 2008), and Dutch Quality Standard for Metals in Sediment (Simpson et al, 2005). The analysis of sediment’s chemical quality status in waters towards the adverse biological effects on the aquatic environment may are suggested to employ Sediment Quality Guidelines (SQGs) method.

SQGs are quality guidelines developed since 1980 to help create regulation in handling contaminated sediments (Burton, 2002). They function to examine the sediments contaminated by heavy metals by comparing the contaminant concentrations in sediment using the appropriate quality guidelines. The guidelines evaluate the extent of the chemical status of heavy metals in sediment towards the negative biological effects on aquatic organisms. The SQGs method is designed to help interpret sediment quality (Lestari et al., 2013). The SQGs research on the estuary sediments was conducted by Wilson and Jeffret in 1987 (Ceairo et al., 2005). The sediment quality index in waters is calculated on Sediment Quality Guidelines Quotient (SQG-Q) basis. The value of Probable Effect Level (PEL-Qi) should be found to calculate the SQG-Q; it is the calculation result of contaminant concentrations measured using the PEL value. The objectives of the research are to (1) create dynamic map of heavy metal distribution in sediments from the contaminated zone of GMR in Wonogiri, and (2) evaluate the quality standard of sediments and its effects on the aquatic environment based on SQG-Q value.

Literature Review
The heavy metals entering the reservoir will be transferred from the body of water through deposition, adsorption, and absorption done by the aquatic organisms. Heavy metals are more likely to bind to organic materials and to deposit in bottom water, and then are aligned with sediments; therefore, heavy metal concentrations in sediments are possibly higher than those in waters. Next, the metals experience physical and chemical processes, including absorption and deposition, and therefore they are
accumulated in the sediments. Heavy metal content in sediments is influenced by certain seasons; in dry season the heavy metal content is less than that in rainy season. The accumulation of heavy metals in lentic waters is more than that in lotic waters (Cahaya, 2012). Connell & Miller (1995 in Priyanto et al, 2008) claimed that the high heavy metals in sediment, is closely linked with its easily bound to the sediment organic materials. The quality standard of heavy metals in sediments has been decided by some countries. The United States has determined the quality standard of heavy metals in sediment in the form of US-SEPA (2004). Australia and New Zealand adopted the quality standard named ANZEC/ARMCANS (2000) (Simpson et al, 2005) completed with the approach to assessment of sediment quality. In Canada, Canadian Council of Ministers of the Environment (CCME, 1994) issued the quality standard of CCME (2001) (Lestari et al, 2008), and Dutch Quality Standard for Metals in Sediment (Simpson et al, 2005). The analysis of sediments chemical quality status in waters towards the adverse biological effects on the aquatic environment may are suggested to employ Sediment Quality Guideline (SQGs) method. Alian et al (2014) propose that Pb and Zn are the most bio-available metals in sediments of rivers in Malaysia.

Previous Research
Studies that have been conducted, among others: 1) Loska et al (2003), have examined Rybnik Reservoir (southern Poland). The concentrations of metals were determined in the bottom sediments, Cd 25.8 µg/g, Cu 451.7 µg/g, Zn 1583.4 µg/g, Ni 71.1 µg/g, Pb 118.6 µg/g, Cr 129.8 µg/g, Fe 38 782 µg/g and Mn 2018.7 µg/g. 2) Priyanto et al (2008), has evaluated the heavy metals Hg, Pb, Cd dan Cu in the sediment inlets, outlet and cage net Cirata reservoir Indonesia. Pb content of 107-348 ppb, Cd 22-491 ppb dan Cu 550-4.645 ppb, below the permitted threshold. 3) Aderinola et al (2009), Cd, Cr, Cu, Fe, Mn, Ni levels in sediments Lagos Lagoon Nigeria, were higher than those of all the metal examined, Iron was found to be the in the lagoon surface water and organisms. 4) Sudaryo et al (2010), heavy metals Fe, Al, Si and Cr found in the sediment inlets, outlet and net cage WGR. The site has undergone heavy metal pollution Cr, Fe, Al, and Cr are detected in sediments from floating fish net, Fe and Al are found in outlet locations of GMR. 5) Lestari et al. (2013), have found metals (Cd, Cu, Pb, Zn, Hg) with high concentrations were detected in some places Gresik waters and based SQG-Q, surface sediment showed a moderate impact level of biological adverse effects in aquatic sediments. The research determines the distribution pattern of heavy metal quality in water and sediments from 8 points of contaminated zones of GMR on the SQG-Q value basis. This research strengthens the previous researches with the existence of distribution map of heavy metal in water and sediments, involving the estuaries of sub-river basins, reservoir body, floating net, and the reservoir outlet, on the SQG-Q value basis.
Research Methods
Sampling Design and Analytical Procedures:
Surface Sediment Sampling was applied based on Simpson et al., 2005 and USEPA (2005) comprising several points: (1) it was conducted in the waters of GMR, particularly in the points of contaminated zones, and (2) the samples of sediments were collected using Eckman Grabe Sampler. The sediment sample taking was organized by lowering the Eckman Grabe Sampler in open and straight position slowly until it reached the reservoir bottom. The device was a bit shaken so its flaps could close themselves, and was pulled immediately back upward. Afterwards, samples of sediments were poured in a container (Nisa, et al, 2013). (3) The samples of sediments were put in a contaminant-free plastic bag and labeled based on the location code (the plastic bag should be closed without leaving any air spaces). (4) The temperature, pH, sediment color, and salinity were then noted. (5) The samples were brought using ice box with temperature of 4°C into laboratory for analysis on heavy metals.
Sampling design should be considered in the context of an overall monitoring program and its overall objectives. As an initial step, as recommended in the Australian and New Zealand Guidelines for Water Quality Monitoring and Reporting (ANZECC/ARMCANZ, 2000), the objectives of the monitoring program need to be set. (Simpson et al, 2005) Collection of surface sediments is conducted in the sediment thickness of 2-10 cm. The surface provides information on the most recently deposited sediment materials and should be used to determine the horizontal variation in sediment properties and the distribution of contaminants.

The procedure of analysis on heavy metals in sediments from the contaminated zones:
Test method of metals Fe, Cd, Co, Ni, Pb, Zn, and Cu employed USEPA SW84-700B:2007, while USEPA SW846-6010:2007 test method was applied for metals Al and Hg. The sediments from each sampling point were placed into porcelain cups and dried in an oven with the temperature of ±60°C for 2 days. The dry sediments were then sorted and crushed using a mortar and were homogenized. About 2 grams of the samples was destructed with 20 ml of aqua regia (HNO₃-HCl, 1:3) in beaker glasses covered with watch glasses. After that, they were destructed on a hotplate with the temperature of 110-149°C for 3 hours (Chen and Ma, 2001 and Birch et al, 2001 in Utomo et al, 2011). The destruction results were filtered and diluted with aquades until the volume reached 100mL. Their absorbency of filtrates was then measured using AAS.

Data analysis and calculation:
The quantitative values of samples of sediments are reported in milligrams per kilogram (mg/kg) for appropriate calculation result for solids on dry-weight basis.

\[
\text{Concentration (dry weight) (mg/kg)} = \frac{C \times V}{W - S}.
\]

Where, C is Digest Concentration (mg/L); V is final volume in liters posterior to sample preparation; W is Weight in kg wet sample; and S is % solid/100.
The test result is calculated on dry-weight basis. The heavy metal content is then compared to the quality standard of ANZECC and Dutch Quality Standard for Metals in Sediment as exhibited in table 1 and table 2. The bio-effects of the heavy metal contaminants are calculated on SQG-Q value basis.

**Table 1**: The Quality Standard of Heavy Metals in Sediments Based on ANZECC/ARMCANZ (2000) and CCME (2001).

<table>
<thead>
<tr>
<th></th>
<th>mg/Kg dry wt</th>
<th>Hg</th>
<th>Cd</th>
<th>Cu</th>
<th>Pb</th>
<th>Zn</th>
<th>Ni</th>
<th>Cr</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANZECC/ARMCANZ Guidelines</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>0.15</td>
<td>1.5</td>
<td>65</td>
<td>50</td>
<td>200</td>
<td>21</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>1</td>
<td>10</td>
<td>270</td>
<td>220</td>
<td>410</td>
<td>52</td>
<td>370</td>
<td></td>
</tr>
<tr>
<td>CCME</td>
<td>ISQG*</td>
<td>0.13</td>
<td>0.7</td>
<td>18.7</td>
<td>30.2</td>
<td>124</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PEL**</td>
<td>0.7</td>
<td>4.2</td>
<td>108</td>
<td>112</td>
<td>271</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(*) **ISQG**, Interim Sediment Quality Guidelines  
(**) **PEL**, Probable Effect Levels  
*Source: Lestari et al., 2013; Simpson et al., 2005*

**Table 2**: The Value of Metal Quality Standard Based on Dutch Quality Standard for Metals in Sediment

<table>
<thead>
<tr>
<th>Metal</th>
<th>Target Level</th>
<th>Limit Level</th>
<th>Test Level</th>
<th>Intervention Level</th>
<th>Danger Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ni</td>
<td>3.5</td>
<td>35</td>
<td>45</td>
<td>210</td>
<td>200</td>
</tr>
<tr>
<td>Cd</td>
<td>0.8</td>
<td>2</td>
<td>7.5</td>
<td>12</td>
<td>30</td>
</tr>
<tr>
<td>Cu</td>
<td>35</td>
<td>35</td>
<td>90</td>
<td>190</td>
<td>400</td>
</tr>
<tr>
<td>Cr</td>
<td>100</td>
<td>380</td>
<td>380</td>
<td>380</td>
<td>1000</td>
</tr>
<tr>
<td>Arsen</td>
<td>29</td>
<td>55</td>
<td>55</td>
<td>55</td>
<td>150</td>
</tr>
</tbody>
</table>

*Source: IADC/CEDA, 1997; Dani, 2012*

**Indices Calculation:**
The SGQ-Q value is calculated on the basis of Probable Effect Level (PEL-Qi) value, using the following formula 2 or 3:

\[
P_{EL} - Q_i = \frac{contaminant_{PEL}}{PEL} \quad (2)\]

\[
SGQ-Q = \frac{\sum_{i=1}^{n} P_{EL} - Q_i}{n} \quad (3)\]

The analysis of sediment status in waters contributing to adverse biological effects on the aquatic biota surrounding the waters may employ the following table 3 figuring out the category of SQG-Q:
### Table 3: The Category of SQG-Q

<table>
<thead>
<tr>
<th>Class</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>SQG-Q≤0.1</td>
<td>un-impacted, lowest potential for observing adverse biological effects</td>
</tr>
<tr>
<td>0.1&lt; SQG-Q&lt;1</td>
<td>moderate impact potential for observing adverse biological effects</td>
</tr>
<tr>
<td>SQG-Q≥1</td>
<td>highly impacted potential for observing adverse biological effects</td>
</tr>
</tbody>
</table>

*Source: MacDonald et al., 2000*

### Results

**Water Quality of Gajah Mungkur Reservoir:**

GMR is located in the province of Central Java in Indonesia. There exist pollutants coming from both outside and inside reservoir. The pollutants coming from outside reservoir are sourced from activities of people in the water catchment areas, such as agricultural, domestic and industrial areas. Meanwhile, the source of pollutants which comes from inside reservoir includes activities of fish farming using floating fish net. Several activities such as making use of inorganic fertilizers in agricultural, domestic and industrial areas and of non-environmentally friendly fish food lead to moderately to highly contaminated water of GMR. The research samples of sediments were taken from 8 points in moderately to highly contaminated zone, comprising station 1,2,3,4,5,6,7 and 8 which are located on Wiroko estuary, Wuryantoro estuary, Alang estuary, traditional floating fish net, modern floating fish net, tourism area, free zones and middle area of the reservoir respectively. The distribution map of water quality of GMR is figured out in Figure 1.

![Spatial Distribution of Water Quality](image)

**Figure 1:** Distribution Map of Water Quality of GMR

**Content of Heavy Metal in Sediments Contaminated Zones GMR:**

Soluble heavy metals will transfer to sediments and bind to free organic materials or organic materials overlaying surfaces of sediments in such a way that direct absorption done by the surfaces occurs. The organic materials in sediments and the
capacity of metal absorption are related to the size of particles and the absorption width and therefore heavy metal concentrations in the sediments are influenced by the size of particles in the sediments (Widowati et al., 2008). The results of the laboratory analysis on heavy metal content in sediments found in 8 station of contaminated zones of GMR are shown in Table 4 below.

Table 4: Content of Heavy Metal in Sediments Contaminated Zones GMR

<table>
<thead>
<tr>
<th>Heavy Metals</th>
<th>Units</th>
<th>Heavy Metal Content in Sediments Found in Contaminated Zones of Gajah Mungkur Reservoir</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>St 1</td>
</tr>
<tr>
<td>Al</td>
<td>%</td>
<td>4.55</td>
</tr>
<tr>
<td>Fe</td>
<td>g/Kg</td>
<td>4.34</td>
</tr>
<tr>
<td>Cd</td>
<td>mg/Kg</td>
<td>0.58</td>
</tr>
<tr>
<td>Co</td>
<td>mg/Kg</td>
<td>14.54</td>
</tr>
<tr>
<td>Hg</td>
<td>mg/Kg</td>
<td>undetected</td>
</tr>
<tr>
<td>Ni</td>
<td>mg/Kg</td>
<td>&lt;0.22</td>
</tr>
<tr>
<td>Zn</td>
<td>mg/Kg</td>
<td>79.46</td>
</tr>
<tr>
<td>Si</td>
<td>%</td>
<td>23.36</td>
</tr>
<tr>
<td>Pb</td>
<td>mg/Kg</td>
<td>21.10</td>
</tr>
<tr>
<td>Cu</td>
<td>mg/Kg</td>
<td>108.82</td>
</tr>
<tr>
<td>Salinity</td>
<td>mg/Kg</td>
<td>0.80</td>
</tr>
<tr>
<td>Water Content</td>
<td>%</td>
<td>77.03</td>
</tr>
<tr>
<td>pH</td>
<td></td>
<td>4.34</td>
</tr>
</tbody>
</table>

With AAS (Atomic Absorption Spectroscopy), heavy metals in samples of sediments found in contaminated zones of GMR include: Al ranging from 3.43 – 6. 21%, Fe ranging from 2.96 – 4.34 %, Cd ranging from 0.44 – 0.67 mg/Kg, Hg which is undetected, Ni ranging from < 0.22 – 1.83 mg/Kg, Zn ranging from 44.26 – 117.12 mg/Kg, Si ranging from 16.73 – 23.69 mg/Kg, Pb ranging from 12.36 – 35.96 mg/Kg and Cu ranging from 77.16 – 140.92 mg/Kg. Salinity of the sediments is between 0.76 and 1.48 mg/Kg and sediment pH ranges from 4.34 – 7.22. Complete description of heavy metal content in every sampling point can be seen in Table 4 and 2. Loska et al’s research findings (2003) indicate that 25.8µg/g Cd, 451.7 µg/g Cu, 1583.4 µg/g Zn, 71.1 µg/g Ni, 118.6 µg/g Pb, 129.8 µg/g Cr, 38 782 µg/g Fe and 2018.7 µg/g Mn found in sediments lying on the bottom of Rybnic Reservoir in Northern Poland come from waste water irrigation and nutrients of N and P.

Heavy metal distribution of Al, Cd, Co, Cu, Fe, Ni, Pb, and Si found in sediments from contaminated zones of GMR is revealed in Figure 2 below.
Discussion

Comparing heavy metal content in the sediments with quality standard:

Heavy metal content in the surface sediments from GMR consisting of 1.5 mg/Kg Cd, 200 mg/Kg Zn, 50 mg/Kg Pb if compared to ANZECC’s quality standard on low level (Table 1) are included below the quality standard. Meanwhile, content of Cu in all sampling points is 65 mg/Kg indicating that it is above ANZECC’s quality standard on low level.
Figure 3: Comparison between Sediments from Metals Pb, Cu, Cd, and Zn and ANZECC/ARMCANZ’s Quality Standard, 2000-Low

Based on Dutch Quality Standard for Metals in Sediment as shown in Table 2, heavy metal availability in sediments from contaminated zones of GMR is as well determined by quality status. Dutch Quality Standard for Metals in Sediment divides quality into 5 levels (Dani, 2012), including: 1) Target level (if contaminant concentration of the sediments is below target level value, substances in the sediments are harmless for the environment), 2) Limit level (if contaminant concentration of the sediments has maximum value which can be tolerated by both human health and ecosystem), 3) Test Level (if contaminant concentration of the sediments is between value of limit and test level, the sediments are categorized lightly contaminated), 4) Intervention level (if contaminant concentration of the sediments ranges from test level to intervention level, the sediments are considered moderately contaminated), 5) Danger level (if contaminant concentration of the sediments has bigger value than that of danger level, the sediments are classified highly contaminated). The laboratory analysis results in several indications. First, metal Ni in sediments from all sampling points of contaminated zones of GMR ranges from $< 0.22 - 1.83$ mg/Kg which is still below target level of 3.5 mg/Kg revealing that Ni contained in the sediments is not too harmful for the environment. Second, metal Cd ranges from 0.44-0.67 mg/Kg, which is below target level of 0.8 mg/Kg, indicating that Cd contained in the sediments from all contaminated zones of GMR is harmless for the environment. Metal Cu in the sediments from contaminated zones of GMR ranges from 77.16 – 140.92 mg/Kg, which is above the target level of 35 mg/Kg. Sediments in Wiroko estuary contain 108.82 mg/Kg Cu which is between test level of 90 mg/Kg and intervention level of 190 mg/Kg and therefore they are classified moderately contaminated. Moreover, sediments from floating fish net in Aquafarm Nusantara point, of free zones and of middle area of the reservoir contain Cu consecutively as much as 114.26 mg/Kg,
140.92 mg/Kg, and 104.25 mg/Kg. This implies that Cu in the sediments from the three aforementioned sampling points on one hand is classified moderately contaminated. On the other hand, Cu contained in the sediments from Wuryantororo estuary, Alang estuary, traditional floating fish net and tourism area is 78.70 mg/Kg, 86.74 mg/Kg, 85.25 mg/Kg and 77.16 mg/Kg respectively. Cu content is included in test level since the contaminant concentration of the sediments has value ranging between limit level of 35 mg/Kg and test level of 90 mg/Kg and therefore the sediments are classified lightly contaminated.

**Ecological Risk Index:**
The quality of water sediments contaminated by the heavy metals and their effects on aquatic biota can be examined using Sediment Quality Guidelines (SDGs) by comparing the contaminant concentrations on a sampling location with appropriate quality guidelines. SQGs apply an empirical frequency based approach in order to construct a relationship between sediment contamination and toxic response, and theoretical approach to explain the distinction of bioavailability through partition balance (Burton, 2002). In order to retain value of sediment quality on a sampling point (SQG-Q), it is necessary to calculate the value of PEL-Qi of each heavy metal as contaminant first. The value of PEL-Qi is obtained by dividing laboratory analysis result of a heavy metal and PEL of the heavy metal and then values of PEL-Qi are summed. The results of the division of total values of PEL-Qi and a number of observed heavy metals indicate value of SQG-Q of each sampling point location. The effects of heavy metal contaminants of sediments on aquatic biota can be determined after comparing value of SQG-Q with appropriate quality standard, as shown by Table 3. If the value of SQG-Q is less than or equals to 0.1, heavy metals in the sediments do not bring an effect but have lower potential of biological effects on aquatic biota surrounding the waters. However, if the value of SQG-Q is less than or greater than 0.1, the heavy metals bring about moderate biological effects on aquatic biota surrounding the waters. In addition, when value of SQG-Q is greater than or equals to 1, they have high potential of giving biological effects on aquatic biota surrounding the environment (MacDonald et al, 2000). Caeiro et al. (2005) postulate that the SQGs application model has been developed by Wilson and Jeffrey (1987) specifically for the estuaries. Several similar researches have been enhanced by Long et al (1995) for sea waters (Lestari et al, 2012) as well as for estuaries (Chapman and Wang, 2001).

SQG-Q categories as seen in Table 3 can be used to analyze sediment status in waters contributing to adverse biological effects on aquatic biota surrounding them. The value of SGQ-Q is calculated based on Probable Effect Level (PEL-Qi) using formula 2 and 3.
The PEL value for Cd in sediments at the quality standard proposed by CCME is 4.2. The result of laboratory analysis for Cd in the sediments at all sampling points ranges from 0.49 to 0.67 mg/Kg. By using formula 1 equation, from those two data, PEL-Qi value is measured, with the value ranging from 0.10 to 0.16 and the total value of PEL-Qi of 1.05. On the basis of the total PEL-Qi value assessed with formula 2 equation, the SQG-Q value for Cd is obtained (0.13). As presented in Table 3, Cd content in the sediments at all sampling points of contaminated zones of GMR is considered to be potential to have moderate biological effects on aquatic biota. The PEL standard value of Cu is 108, while the PEL-Qi total value is 7.37, and its SQG-Q value is 0.92; and therefore, Cu at every sampling point in contaminated zones of GMR is categorized potential for producing moderate biological effects on aquatic biota. Zn appears to have PEL value of 271, with the PEL-Qi total value of 2.14 and the SQG-Q value of 0.27; and therefore Zn at all sampling points in contaminated zones of GMR is considered to be potential to have moderate biological effects on aquatic biota. The PEL value of Pb determined at the quality standard is 112, its PEL-Qi total value is 1.29; and therefore, its SQG-Q value is 0.16. This means Pb in sediments in contaminated zones of GMR is categorized moderate, in other words, it brings about medium biological effects on aquatic biota surrounding the environment.

According to the PEL-Qi calculation for each heavy metal contaminant at every sampling point, the result of SQG-Q analysis is derived, as presented in Graph 4. The SQG-Q values in contaminated zones of GMR range from 0.28 to 0.45. In station 1 along Wiroko estuary point, sediments contain 0.58 mg/Kg Cd, with PEL value of 4.2, and PEL-Qi value of 0.14. Wiroko estuary sediments also contain 108.82 mg/Kg Cu, with the PEL standard value of 108; and therefore, its PEL-Qi value is 1.01. Besides Cd and Cu, Wiroko estuary sediments contain 79.46 mg/Kg Zn, with PEL standard value of 271; thus, the PEL-Qi value is 0.29. Moreover, Wiroko estuary sediments contain 21.1 mg/Kg Pb, with the PEL standard value of 112; and hence, its PEL-Qi value is 0.29. Based on the results of PEL-Qi value assessment of Cd, Cu, Zn,
and Pb (1.63), the SQG-Q value of Wiroko estuary is obtained, that is 0.41. Compared to the proposed quality standard, the SQG-Q value is still above 0.1 and below 1; and therefore, the heavy metal contaminants (Cd, Cu, Zn and Pb) in Wiroko estuary sediments are proven to have moderate biological effects on aquatic biota surrounding the environment.

In the sampling point of station 2, Wuryantoro estuary, the sediments contain 0.45 mg/Kg Cd, with the PEL standard value of 4.2; and hence, its PEL-Qi value is 0.11. Cu is also contained in the sediments in station 2, that is 78.7 mg/Kg; and therefore, its PEL-Qi value is 0.73. Besides Cd and Cu, the sediments in Wuryantoro estuary contain 44.26 mg/Kg Zn, with the PEL value of 271; thus, the PEL-Qi value is 0.16. The sediments also contain 15.04 mg/Kg Pb, with the PEL value of 112, and the result of measurement shows PEL-Qi value of 0.13 and total PEL-Qi value of all measured heavy metals of 1.13; and hence, the SQG-Q value reaches 0.28. Compared to the proposed quality standard, the heavy metals in the sediments of Wuryantoro estuary have moderate biological effects on aquatic biota surrounding the environment.

The sampling point 3 is the sediment along Alang estuary, containing 0.57 mg/Kg Cd, with the PEL standard value of 4.2 and the PEL-Qi value of 0.14. The sediments also contain 86.74 mg/Kg Cu, with the PEL standard value of 108 and the PEL-Qi value of 0.80. The content of Zn in Alang estuary sediments is 59.35 mg/Kg, with the PEL value of 271; and therefore its PEL-Qi value is 0.22. Besides Cd, Cu, and Zn, Pb is also found, i.e. 14.64 mg/Kg, with the PEL value of 112; and hence, the SQG-Q value is 0.13. Based on the PEL-Qi total values of the four heavy metals, that is 1.29, the SQG-Q value is 0.32. Compared to the quality standard, the SQG-Q value of sediments along Alang estuary remains above 0.1 and below 1. Therefore, the heavy metal contaminants (Cd, Cu, Zn and Pb) in Alang estuary sediments have moderate biological effects on aquatic biota surrounding the environment.

The sampling point 4 is sediment along the area of floating fish net (keramba jaring apung) which is modernly cultured by PT Aquafarm Nusanatara. The sediments contain Cd, Cu, Zn, and Pb of 0.67 mg/Kg, 85.25 mg/Kg, 117.12 mg/Kg, and 14.39 mg/Kg, respectively. The contents of heavy metals are divided with the PEL value of each metal, and then the PEL-Qi values are obtained, 0.16, 0.79, 0.43, and 0.13 respectively, and the SQG-Q value is 0.38. Compared to the quality standard, the SQG-Q value of sediments along floating fish net is still above 0.1 and below 1. Therefore, the heavy metal contaminants (Cd, Cu, Zn and Pb) in the sediments along floating fish net have moderate biological effects on aquatic biota surrounding the environment.

As a whole, the SQG-Q value of heavy metals in the sediments along contaminated zones of GMR is more than 0.1 and less than 1. This means the metals have low potential on the sustainability of aquatic biota surrounding the environment. According to a research conducted by Caeiro et. al. (2005), in general, the heavy metals (Cd, Cu, Cr, Zn and Pb) in Sado estuary sediments appear to be potential to
produce low and moderate contamination effects on aquatic biota; with only 30% heavy metals potential for having moderate biological effects. Aderinola et al (2009) adds that the heavy metal contents (Cr, Cd, Pb and Ni) in sediments are more than those in water and organisms.

Conclusion
The SQG-Q values for heavy metals (Cd, Cu, Zn and Pb) in the sediments along contaminated zones of GMR at sampling points of Alang estuary, Wuryantoro estuary, Wiroko estuary, modern floating fish net, traditional floating fish net and floating fish net at the middle area of reservoir, range from 0.28 to 0.45, at the standard point of 0.1<SQG-Q<1, indicating the potential of these metals to have moderate effects on aquatic biota; and therefore, can be potentially harmful for aquatic biota such as fish and shrimp.

Acknowledgment
The researchers would like to express their deep gratitude to the Ministry of Research, Technology, and Higher Education for the financial support of doctoral research grant; Setia Budi Education Foundation for the doctoral program scholarship; The Department of Environmental Science, Sebelas Maret University; Promoter and co-promoter; Sampling Teams; and CGS for the help to finish the spatial distribution mapping.

References
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