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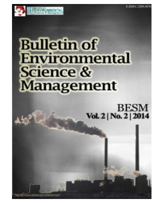

Heavy Metals Distribution in Seabed Sediment at Golok Central and Golok Barat Gas Fields, Sarawak

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ABSTRACT

Drilling activities to extract natural gas from the bottom of the sea can cause the release of several types of heavy metals into the marine water and seabed sediment. Excessive heavy metals concentrations in the marine environment could cause toxicity to the fish and other marine life. Subsequently, the heavy metals will enter into human body when the contaminated fish is consumed by human. Some chemicals present in the marine water will settle down onto the seabed sediment. This study aimed to study the trends of heavy metals distribution in seabed sediment at Golok Central and Golok Barat gas fields, Sarawak from 2010 to 2012. The concentrations of Cd, Cr, Ni, Pb, Co, Ba, Cu, and Zn in seabed sediment were analysed. The result of the analysis showed that the average concentrations of heavy metals in seabed sediment at Golok Central and Golok Barat gas fields from 2010 to 2012 were significantly different ($P < 0.05$). Comparison between means of concentrations of heavy metals in seabed sediment at different locations (Golok Central and Golok Barat gas fields), however, showed no significant difference. Comparing to the EIA baseline data, most of the heavy metals concentrations exceeded the baseline data.

INTRODUCTION

Natural gas is produced from the deposition of plants, animals, and microorganisms that lived millions of years ago, under the Earth at very high pressure and temperature. It emits lower levels of potentially harmful by-products such as nitrogen oxides (NOx), sulfur dioxide (SO_2), carbon dioxide (CO_2), and particulate matter (PM) into the air [1]. Natural gas can be found in reservoirs underneath the Earth, which are often associated with oil deposits and water. Since natural gas is less dense than oil and water, it is located closest to the surface followed by oil beneath it and water. Natural gas is trapped inside the impermeable rock under the Earth, thus drilling process is required to extract it out. Extraction of natural gas can be done onshore or offshore. Offshore gas extraction requires structure installation (production platform, gas pipeline system, and wells) and drilling operations. These installation and operation can cause increased level of metals, hydrocarbons, and other chemical agents in the marine environment [2]. Drilling muds and cuttings from drilling operations will disperse into water column upon discharge and will settle down at the seafloor. Drilling muds and cuttings can give impacts to the benthic communities [3]. The presence of heavy metal can occur naturally in the Earth's crust and can be derived from anthropogenic sources such as domestic, agricultural and industrial activities [4]. The presence of heavy metals in the environment is a concern since they could not be degraded or destroyed. Heavy metals can bioaccumulate and biomagnified in organisms through the food chain [5]. The higher trophic level in marine food chain will result in the increase of heavy metals concentrations [6]. Aquatic organisms have capability to absorb heavy metals from the aquatic environment into their bodies [7]. Humans are at a great risk of heavy metal toxicity when they consume contaminated fish and other seafood. High concentration of heavy metals in living organisms can disturb biochemical and physiological activities in their bodies and can lead to mortality. Thus, environmental monitoring of heavy metals concentration in seabed sediment at gas field is necessary to ensure the amount of heavy metals does not exceed the safety limit. The purpose of this study was to investigate the trends in heavy metals concentrations (Cd, Cr, Ni, Pb, Co, Ba, Cu, and Zn) in seabed sediment at Golok Central and Golok Barat gas fields, Sarawak from 2010 until 2012.

MATERIALS AND METHODS

Site description

The environmental monitoring was conducted for the Gas Development Project at Offshore Bintulu, Sarawak. The project site was located about 60 km from Bintulu at offshore Sarawak. The project involves the construction of gas fields name as Serampang, Merapuh, Golok Central and Golok Barat (Fig. 1). However, this study only focused on Golok Central and Golok Barat gas fields. The monitoring stations were located 1000 m from Golok Central and Golok Barat platforms arranged in a form of concentric circles.

Sample collection and analysis

Seabed sediment samples were collected at Golok Central and Golok Barat platform areas. The samples were collected from four stations at each platform. For Golok Central platform, the stations were represented as GOC-1, GOC-2, GOC-3, and GOC-4. For Golok Barat platform, the stations were represented as GOB-1, GOB-2, GOB-3, and GOB-4. Seabed sediment samples were collected using a 0.1 m^2 KC Day grab sampler [8]. The samples were placed in polyethylene bag and preserved at temperature below 4 °C before being transferred to the laboratory for analysis of heavy metals content. The analysis was conducted by Golden Ecosystem Sdn. Bhd. (for samples from 2010) and by Chemsain Consultant Sdn. Bhd. (for samples from 2011 and 2012). Golden Ecosystem Sdn. Bhd. implemented the method introduced by American Public Health Association (APHA) 3120B [9], 1995 while Chemsain Consultant Sdn. Bhd. implemented the USEPA 3050B method (10) and AAS for the analysis of cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), zinc (Zn), cobalt (Co), and barium (Ba). Results of the heavy metals concentrations in seabed sediment were compared with the EIA baseline data (data collected in 2006 before the gas development project started).

Statistical analysis

Data were analysed using two-way Analysis of Variance (ANOVA) for repeated measures to compare the differences between the concentrations of heavy metals at Golok Central and Golok Barat. ANOVA was also used to compare differences among the concentrations of heavy metals in 2010, 2011, and 2012.

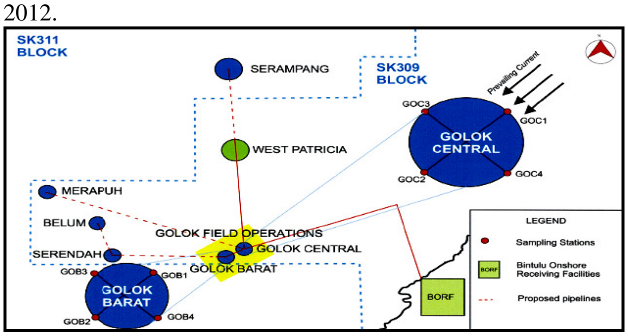

Fig. 1 Location of Golok Central and Golok Barat gas fields at Bintulu Offshore, Sarawak. Source: Golden Ecosystem Sdn. Bhd. [11].

RESULTS AND DISCUSSIONS

The concentrations of heavy metals at Golok Central and Golok Barat gas field were compared. Two-way ANOVA results showed that the means of concentrations of heavy metals in seabed sediment at Golok Central and Golok Barat gas fields were not significantly different ($P > 0.05$). This might be because the difference in the concentrations of heavy metals at Golok Central and Golok Barat gas fields was not very huge. As shown in the graph in Fig. 2, the concentrations of Cd, Cr, Ni, Pb, Co, Ba, Cu, and Zn at Golok Central gas field were higher than Golok Barat gas field in 2010. This might be because Golok Central gas field started their operation first in 2009 [12]. The amount of heavy metals was more prominent at this area (Golok Central gas field) compared to the other area, Golok Barat gas field, that started their operation later. The concentrations of Cr, Ni, Pb, Co, and Cu at Golok Barat gas field were higher than at Golok Central gas field in 2011-2012. These heavy metals might come from the drilling mud used during the gas extraction process. According to Phillips et al. [13], elements such as Cd, Cr, Cu, Zn, Ni, Pb, Ag, As, V, and Hg can be found in drilling mud. The heavy metals might also come from chemicals used at the gas field for turbine washes, to lubricate drill pipe joints, to control wellheads, to maintain pipeline from erosion, and to prevent attachment of marine life at the platform [14].

Golok Barat gas field consists of a production platform and 9 wells with 3 sidetracks while Golok Central gas field consists of a production platform and only 7 wells with 2 sidetracks [12]. The extra two wells at Golok Barat gas field thus require more installation activities and more chemicals usage. This subsequently causes the increase of heavy metals concentrations at the area. According to Gates and Jones [15], the increasing number of wells at gas field could result in larger areas being affected by drilling mud and cuttings. The locations of Golok Barat and Golok Central gas fields are directly proportional to the movement of ocean current (Fig. 1). Since the location of Golok Barat gas field is next to Golok Central gas field, it is possible that ocean current transports heavy metals from Golok Central gas field to Golok Barat gas field, thus causes the increase of heavy metals concentration in seabed sediment at the area. Veltman et al. [16] mention that particle deposition on seafloor is influenced by local environmental conditions such as ocean currents, turbulence, and particle size. The trends of concentrations of heavy metal at Golok Central and Golok Barat gas fields from 2010 until 2012 were studied. Two-way ANOVA results showed that the means of concentrations of heavy metals in seabed sediment at Golok Central and Golok Barat gas fields from 2010 until 2012 were significantly different ($P < 0.05$). As shown in the graph in Fig. 3, the concentrations of Ni, Pb and Ba increased at Golok Central and Golok Barat gas fields from 2010 to 2011 and decreased in 2012. These heavy metals might be released from drilling activities, which involved the use of drilling muds to cool down and clean the drill bit, to control subsurface pressures, and to bring out the drill cuttings to the surface [17]. Drilling muds used at study site were water-based drilling muds, low-toxicity oil-based muds (LTOBM), and synthetic-based drilling muds. According to Scholten *et al.* [18], drilling muds contain a mixture of water, oil or synthetic organic fluid, barite, and chemical additives (e.g. emulsifiers, biocides, lubricants, wetting agents, corrosion inhibitors, surfactants, detergents, caustic soda, salts, and organic polymers) to give the mud the desired properties. Barite ($BaSO_4$) is a major component added in drilling muds as weight material to provide sufficient density to the drilling muds [19].

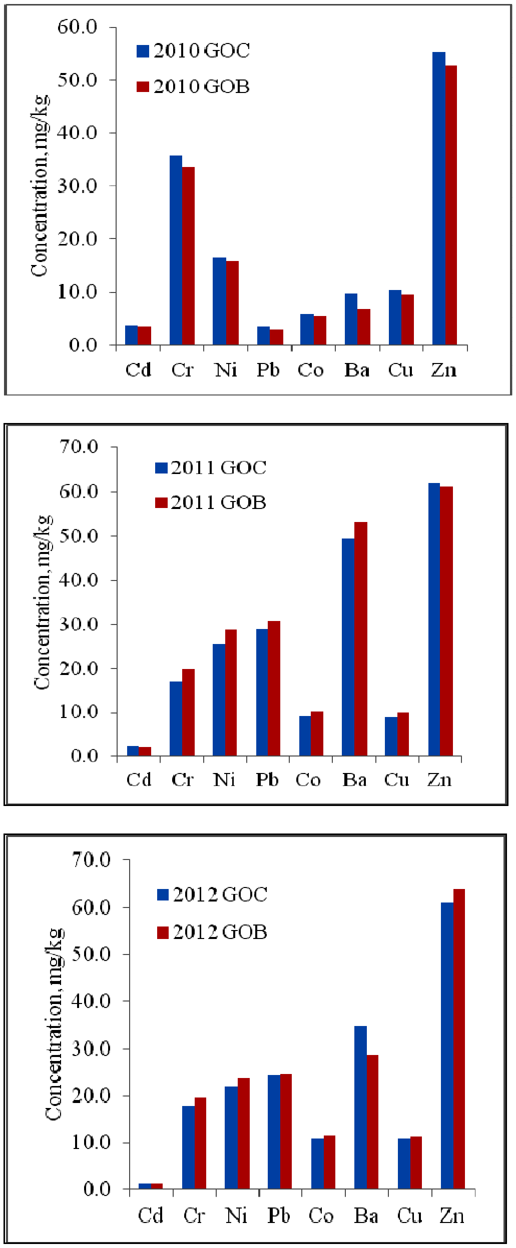

Fig. 2. Graphs showing comparison in terms of concentrations of heavy metals in seabed sediment at Golok Central and Golok Barat gas fields at Bintulu, Sarawak in 2010, 2011, and 2012.

Other sources of heavy metals at offshore gas field are drill cuttings and produced water. Drill cuttings are pieces of rock from the bottom sedimentary layer that are brought to the surface during drilling [17]. If the drill cuttings are contaminated with oil-based drilling muds, the cuttings will be shipped ashore for disposal or treated to remove the oil before being discharged into the ocean [20]. Water-based drilling muds and drill cuttings will disperse into the seawater upon discharge and the solid components will settle onto the seabed sediment. According to Neff [17], accumulated drilling muds and cuttings on the seafloor surrounding oil installations will contribute high concentrations of heavy metals and hydrocarbons.

Produced water refers to groundwater that has been extracted together with oil and gas, recovered, and released back to the ocean [20]. Produced water may contain residual hydrocarbons, naturally occurring radioactive material, heavy metals, and residual production chemicals [21]. However, produced water discharged from this gas development project is very limited [22,23].

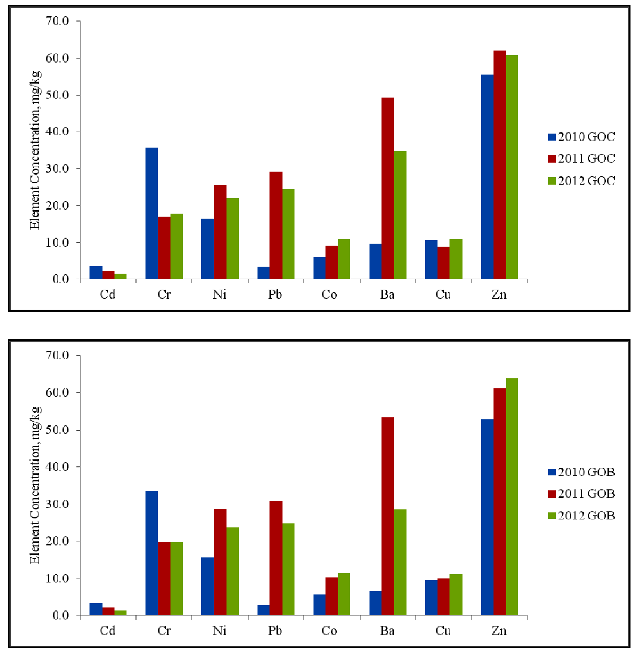

Fig. 3. Graph trends of concentrations of heavy metal in seabed sediment at Golok Central and Golok Barat gas fields, Bintulu, Sarawak from 2010 until 2012.

In order to assess whether the heavy metals in seabed sediments comes from natural or anthropogenic sources, the data were compared with EIA baseline data (Table 1). When the concentrations of heavy metals at Golok Central gas field were compared with EIA baseline data, concentrations of Cd, Cr, Ni, Cu, and Zn from 2010 to 2012 exceeded the baseline data while concentrations of Pb, Co, and Ba only exceeded the baseline data from 2011 to 2012. For Golok Barat gas field, concentration of Cd, Cr, Ni, Co, Cu, and Zn from 2010 to 2012 exceeded the baseline data while concentrations of Pb and Ba only exceeded baseline data from 2011 to 2012.

Previous study conducted by Rezende *et al*. [24] shows the average concentrations of Al, Cu, and Ni significantly increase after 7 months of drilling operation particularly at station closest (250 m) to the drilling site. This indicates that the heavy metals in seabed sediment come from anthropogenic source specifically drilling activities.

Table 1. Heavy metal concentrations in seabed sediment at Golok Central and Golok Barat gas fields at Bintulu Offshore, Sarawak. Each value is expressed as mean ± standard deviation of heavy metal concentrations for all stations (n=4). All elements are in mg/kg.

Location	Year	Cd	Cr	Ni	Pb	Co	Ba	Cu	Zn
Golok Central	2010	3.68 ± 1.04	35.75 ± 2.99	16.50 ± 4.36	3.50 ± 1.00	5.98 ± 1.50	9.75 ± 0.96	10.55 ± 1.22	55.50 ± 10.38
	2011	2.28 ± 0.26	16.98 ± 2.57	25.50 ± 2.52	29.05 ± 2.82	9.13 ± 1.42	49.45 ± 33.47	8.85 ± 0.89	61.88 ± 2.23
	2012	1.45 ± 0.06	17.83 ± 2.64	22.00 ± 1.78	24.43 ± 1.72	10.93 ± 0.63	34.68 ± 9.39	10.90 ± 0.96	60.85 ± 7.63
	EIA	<1.00	7.00 - 16.00	7.00 - 13.00	6.00 - 11.00	7.00 - 10.00	<10.00 - 15.00	3.00 - 5.00	25.00 - 42.00
Golok Barat	2010	3.45 ± 0.72	33.50 ± 2.38	15.75 ± 0.96	3.00 ± 0.82	5.60 ± 0.88	6.75 ± 0.50	9.55 ± 0.38	52.75 ± 2.75
	2011	2.13 ± 0.13	19.83 ± 1.35	28.70 ± 0.73	30.80 ± 4.22	10.25 ± 0.51	53.28 ± 41.57	9.90 ± 0.45	61.05 ± 2.54
	2012	1.40 ± 0.08	19.73 ± 2.12	23.80 ± 0.59	24.68 ± 1.37	11.53 ± 0.42	28.55 ± 20.61	11.23 ± 0.57	63.80 ± 3.77
	EIA	<1.00	12.00 - 16.00	10.00 - 14.00	9.00 - 12.00	4.00 - 9.00	<10.00	4.00 - 6.00	32.00 - 45.00

The concentrations of heavy metals were also compared with the National Oceanic and Atmospheric Administration (NOAA) marine sediment guidelines for the biological effect of metal concentrations [25]. Only concentrations of Cd and Ni exceeded the effects range low (ERL). ERL indicates the concentration at which a small percentage of biota is affected (Table 2). Comparison to the Malaysian standard limit for heavy metals in marine sediment could not be made as no standard limit has been set.

Table 2. Summary of marine sediment guidelines used by NOAA.

Type of metal	Effects Range Low (ERL)
Cd	1.2
Cr	81
Cu	34
Pb	46.7
Ni	20.9
Zn	150

CONCLUSION

Drilling activities are the major source of heavy metals pollution at the gas field since drilling involves the use of drilling muds that contain various chemical compounds to give the mud desired properties. Other materials such as drill cuttings and produced water might be contaminated with drilling muds since they move together to the surface [26]. The drill cuttings can cause accumulation of heavy metals in seabed sediment because these cuttings will settle down onto the seabed sediment upon discharge. The heavy metals might also come from chemical usage for the maintenance of the platform.

The trends of concentrations of heavy metals in seabed sediment at Golok Central and Golok Barat gas fields from 2010 until 2012 showed many variations, which can be attributed to changes in circulation patterns that can cause erosion and redeposition of bottom material or desorption of the contaminants [19, 27].

When compared to EIA baseline data, all concentrations of heavy metals in seabed sediment at Golok Central and Golok Barat gas fields in 2011 and 2012 exceeded the baseline data. Higher concentration of heavy metals when compared to baseline data could support the suggestion that accumulation of drill cuttings at the seabed sediment is the source of heavy metals at Golok Central and Golok Barat gas fields.

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