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Heavy Metal Content and Spatial Distribution to Determine the Water Pollution Index in Depapre Waters, Papua, Indonesia

Baigo Hamuna[1, 3]* and Rosye Hefmi Rechnelty Tanjung[2, 3]

[1]Department of Marine Science and Fisheries, Cenderawasih University, Jayapura City, Papua Province, Indonesia
[2]Department of Biology, Cenderawasih University, Jayapura City, Papua Province, Indonesia
[3]Center for Environmental Studies, Cenderawasih University, Jayapura City, Papua Province, Indonesia

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Abstract

A determination of water quality should be conducted as a reference to determine the status of pollution in waters. This study aims to determine the content and distribution of several heavy metals and to determine the pollution index of those heavy metals in Depapre waters, Jayapura Regency, Papua. The sampling of seawater was conducted in October 2017 at five observation stations. The results were then compared to the quality standards of seawater for marine biota based on the Decree of the Minister of Environment No. 51 year 2004. Heavy metal concentrations in the seawater samples were analysed using Atomic Absorption Spectrophotometer (AAS). The results showed that concentrations of Cd, Pb, Cu, and Zn ranged between 0.00-0.003 mg/l, 0.001-0.005 mg/l, 0.464-0.600 mg/l, and 0.003-0.008 mg/l, respectively. Mercury was not detected because its concentration was lower than the detection limit of the tool used. The Hg, Pb, and Zn concentrations fell within the concentration limits specified in the quality standards of seawater for marine biota, whereas the Cd concentrations at stations 1, 2, and 4, and Cu concentrations at all observation stations exceeded the limits specified in the quality standards of seawater for marine biota. Based on the water pollution index, all observation stations fell into the moderately polluted category with a pollution index range of 6.94-7.34. The Cu concentration was the biggest contributor to a high pollution index in the Depapre waters, Jayapura Regency.

Keywords: Depapre waters; heavy metals; water pollution index; water quality standard
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*Corresponding author: Tel.: +62 821 9980 1101
E-mail: bhamuna@yahoo.com.sg

1. Introduction

The main problem faced in the marine areas investigated was the condition of the water, which had often been contaminated, and was thus of impaired quality. Ideally, seawater quality for marine biota should meet the standards specified for physical, chemical, and biological parameters [1-4]. A significant decrease in water quality due to high concentrations of poisonous inorganic and or organic materials is not only bad for the marine environment; it can also cause disruption and loss in the economy and society. One of the pollutants that needs to be paid attention to is heavy metals [5]. Although a certain concentration of heavy metals was found in seawaters, the concentration was still under threshold value that could danger marine organisms [6]. However, even in such cases, bad things can happen when the heavy metals that pollute seawaters accumulate in sediments and marine organisms [7].

A range of research work has shown that several bodies of seawater in Indonesia were atrociously contaminated by heavy metals. Heavy metals contamination was found to be a serious problem in Jakarta Bay waters, but the concentrations of heavy metals such as copper (Cu), cadmium (Cd), and lead (Pb) found there were shown to have not been on decreasing or increasing trends [8]. Likewise, pollution that occurred in Central Java waters was caused by the heavy metal concentrations of mercury (Hg), Pb, and Cd that came from domestic wastes, farming activities, and marine transportation that surpassed the quality standards of seawater [9-11]. The Pb and Cd concentrations in Ambon waters also surpassed the standards of quality for marine biota [12]. Moreover, the sediments in the coastal waters of Tangerang were polluted by Hg and surpassed the threshold with higher concentrations [13]. Lead and cadmium were found to have contaminated fishes and marine biota, like *Strombus Canarium* and *Anadara* sp, in the Kalabat Bay waters of Bangka Island [14] and *Euthynnus* sp in North Java coastal waters [15].

Pollutants that enter a body of water can cause the waters to become polluted. To assess the status of pollution in waters, the Government of Indonesia, through Decree of the Minister of Environment No. 115 year 2003, has established several methods to determine the status of pollution in waters, one of which is the water pollution index [16]. The water pollution index is used to determine the level of pollution relative to permitted water quality parameters [17]. The water pollution index has been widely used to determine the status of water pollution in Indonesia in seawaters [3, 11, 18], rivers [19-22], and lakes [23]. The results of water quality assessment based on water pollution index can be used as input to improve water quality if there is a decrease in quality due to the presence of pollutants.

The area of Depapre waters is one of the coastal areas in Papua that underwent significant development in the areas of port construction, marine tourism, settlement housing, marine transportation, and aquaculture and fisheries. All of these activities were suspected of contributing to water pollution. Hamuna *et al.* [24] showed that the Depapre waters were lightly to moderately polluted, with several physical and chemical parameters exceeding the specified quality standards. However, the water chemical parameters studied in the study did not include heavy metals, and there has been little or no information regarding the concentration of heavy metals in Depapre waters to date.

The purpose of this study was to determine the concentration and spatial distribution of various heavy metals in Depapre waters, Jayapura Regency, Papua Province. The analyzed heavy metals in this study were Mercury (Hg), Cadmium (Cd), Lead (Pb), Copper (Cu), and Zinc (Zn). These heavy metals are very dangerous if their concentrations exceed the threshold determined by the Government of Indonesia in the Minister of Environment Decree No. 51 year 2004, which deals with Seawater Quality Standards [25]. The obtained heavy metal concentrations were analyzed further to determine the pollution index of heavy metals in Depapre waters.

2. Materials and Methods

2.1 Study area

The area of this study was the Depapre waters, Papua Province, Indonesia. It was conducted in October 2017. The locations for measurement and sampling of seawater included 5 stations, namely (1) Harlem tourism beach waters, (2) coastal waters of Tablasupa Village (settlement houses in around the waters), (3) Dua Island waters, (4) waters in the construction area of Depapre harbor, and (5) Depapre Village waters (settlement houses in surrounding land). The sampling location in this study is presented in Figure 1.

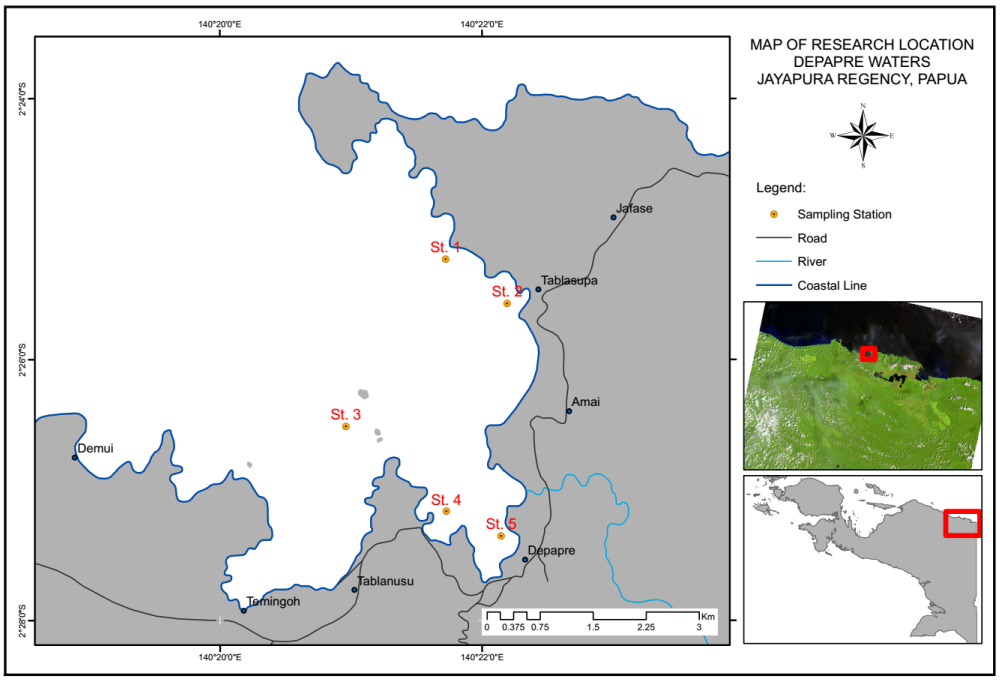

Figure 1. Locations of the sampling stations in Depapre waters, Papua Province, Indonesia

2.2 Seawater sampling and analysis

The seawater sampling was done based on the Indonesian National Standard (Standar Nasional Indonesia - SNI) method No. 6964.8.2015. In this study, seawater samples were taken once from each research station. Each sample was taken at a depth of 50 cm from the sea surface using a water sampler (Vandorn bottle). The sample was then filtered with cellulose nitrate filter paper (0.45 µm). A total of 250 ml of the sample was put into a Niskin bottle that had been filled with concentrated nitric acid (HNO_3) for the sample preservation process. Furthermore, each sample was stored in a cool box until being analyzed in the laboratory.

In the laboratory, the seawater samples were analyzed using Atomic Absorption Spectrophotometer (AAS) in the Jayapura Health Laboratory of Papua Province. The types of heavy metals and standard analysis are presented in Table 1. The data analysis was done by comparing the results of laboratory analysis with the seawater quality standards based on Minister of Environment

Decree No. 51 year 2004, which is concerned with Seawater Quality Standards that relate to lives of marine biota [25].

Table 1. Standard and analytical methods of heavy metals for seawater quality

Heavy metals	Quality standards (mg/l) *	Analytical methods
Hg	0.001	SNI 19-6964.2-2003
Cd	0.001	Standard Method 2005, Section 3111-Cd.B
Pb	0.008	Standard Method 2005, Section 3111-Pb.C
Cu	0.008	IKM/5.4.38/BLK-Papua (Spectrophotometer)
Zn	0.05	Standard Method 2005, Section 3500-Zn.C

* Minister of Environment Decree No. 51 year 2004 about Seawater Quality Standards for Marine Biota

2.3 Spatial distribution of heavy metals

The heavy metals data and coordinates were then analyzed using the Geographic Information System approach. The analysis of the spatial distribution of heavy metals involved interpolation. Interpolation is a method used to predict values on grids that are not represented by sample points [26]. The interpolation method applied in this study was the Inverse Distance Weight (IDW). IDW is a method that shows interpolation results that are similar to the maximum and minimum values of the sample data and will change linearly according to the distance from the sample data [26, 27]. The IDW method can be used on a small number of data samples whose distribution is representative [28].

2.4 Analysis of water pollution index

One of the most important indices in water quality assessment is the water pollution index [29]. The water pollution index is a useful tool to provide information about water quality. It was determined based on the Decree of the Minister of Environment No. 115 year 2003, using the following formula [17]:

$$PI_j = \sqrt{\frac{(C_i/L_{ij})_M^2 + (C_i/L_{ij})_R^2}{2}} \quad (1)$$

where:

L_{ij} : standard water quality parameter for each parameter at specified water quality purpose (j)
C_i : measured water quality parameters i
PI_j : the pollution index for a specified j water quality purpose (j)
$(C_i/L_{ij})_M$: maximum value of C_i/L_{ij}
$(C_i/L_{ij})_R$: average value of C_i/L_{ij}

The relation between the level of water pollution and the pollution index criteria based on the Decree of the Minister of Environment No. 115 year 2003 about Determination of Water Quality Status is as follows [16]:

$0 \leq PI_j \leq 1$: good quality
$1 < PI_j \leq 5$: lightly polluted
$5 < PI_j \leq 10$: moderately polluted
$PI_j > 10$: heavily polluted

3. Results and Discussion

3.1 Concentration and spatial distribution of heavy metals

This study was concerned with analysis of the quality of seawater in the Depapre waters and in particular examined whether those waters were safe or harmful to marine biota. Ideally, marine waters should meet the specified physical, chemical, and biological quality standards and waters that fail to do so are considered to be contaminated. The laboratory analysis showed that the concentrations of Cd, Pb, Cu, and Zn ranged between 0.001-0.003 mg/l, 0.001-0.005 mg/l, 0.464-0.600 mg/l, and 0.003-0.008 mg/l, respectively. Meanwhile, the concentration of Hg could not be detected because the value was smaller than the limit of detection of the tool used. The results of the analysis of heavy metals concentration in Depapre waters are presented in Table 2.

Table 2. The heavy metals concentration in Depapre waters, Jayapura Regency, Papua, Indonesia

Stations	Heavy metals concentration (mg/l)				
	Hg*	**Cd**	**Pb**	**Cu**	**Zn**
1	<0.0008	0.003	0.001	0.600	0.004
2	<0.0008	0.002	0.005	0.554	0.003
3	<0.0008	0.001	0.002	0.464	0.005
4	<0.0008	0.002	0.003	0.502	0.003
5	<0.0008	0.001	0.005	0.592	0.008

* <0.0008 mg/l are below the detection limit.

According to the quality standards for heavy metals concentration for marine biota, the concentrations of Hg, Pb, and Zn met the quality standards of seawater. On the contrary, the concentration of Cd at stations 1, 2, and 4, and also the Cu concentration at all observation stations was higher than the quality standards for marine biota. Even low concentrations of heavy metals in seawater do not mean that these pollutants will not have a negative impact, and this is especially the case with non-essential heavy metals. Heavy metals can be dangerous for marine biota, especially if the concentration inside the seawater is higher than the quality standard [30, 31]. Heavy metals that accumulate in sediments and marine organisms may be of increased concentration depending on the condition of the waters [32]. Hg, Pb, Cd, and Cu can be very dangerous because of biomagnification, which means that they accumulate in an organism's body over time and reach toxic levels [33].

The spatial distribution of heavy metals (except Hg) in Depapre waters are presented in Figure 2. Generally, heavy metals concentrations (except Zn) in research locations tended to be higher nearer to the beach and lower towards the open water. Heavy metals distributions in seawaters can be influenced by several inputs and water dynamics [13], topography, patterns of wind movement, and circulation of surface currents [34, 35]. The availability of heavy metals in the waters is influenced by dynamic system influences (tidal flow), hydraulic systems, organic materials, and salinity [36].

The sources of heavy metals varied in each body of seawater. Heavy metals in Depapre waters were thought to be the results of human activities and natural sources. Because there is no waste in the area due to industrial activity, which is one of the biggest sources of heavy metal pollution in waters, the heavy metals in Depapre waters are suspected to have come from activities such as household waste disposal, small-scale agricultural, fisheries, and marine transportation. Research has shown that in general, the higher the level of human activities in coastal and seawaters

areas, the bigger the possibility of an increase of heavy metals concentrations in seawaters. Naturally, heavy metals concentrations in seawater are very low (around 10^{-5}-10^{-2} ppm); however, they can accumulate in seawaters by various means [6]. Mercury can get into waters from volcanic activities and groundwater seepages that have passed through areas of mercury deposits. Lead enters the sea through crystallization in the air and then with the assistance of rain, as well as from mineral stones that erode due to waves and wind. Copper also finds its way into bodies of water due to erosion of minerals. Furthermore, Cu compounds present on the atmosphere can be brought down by the rain. Cadmium naturally enters waters in smaller amounts [37].

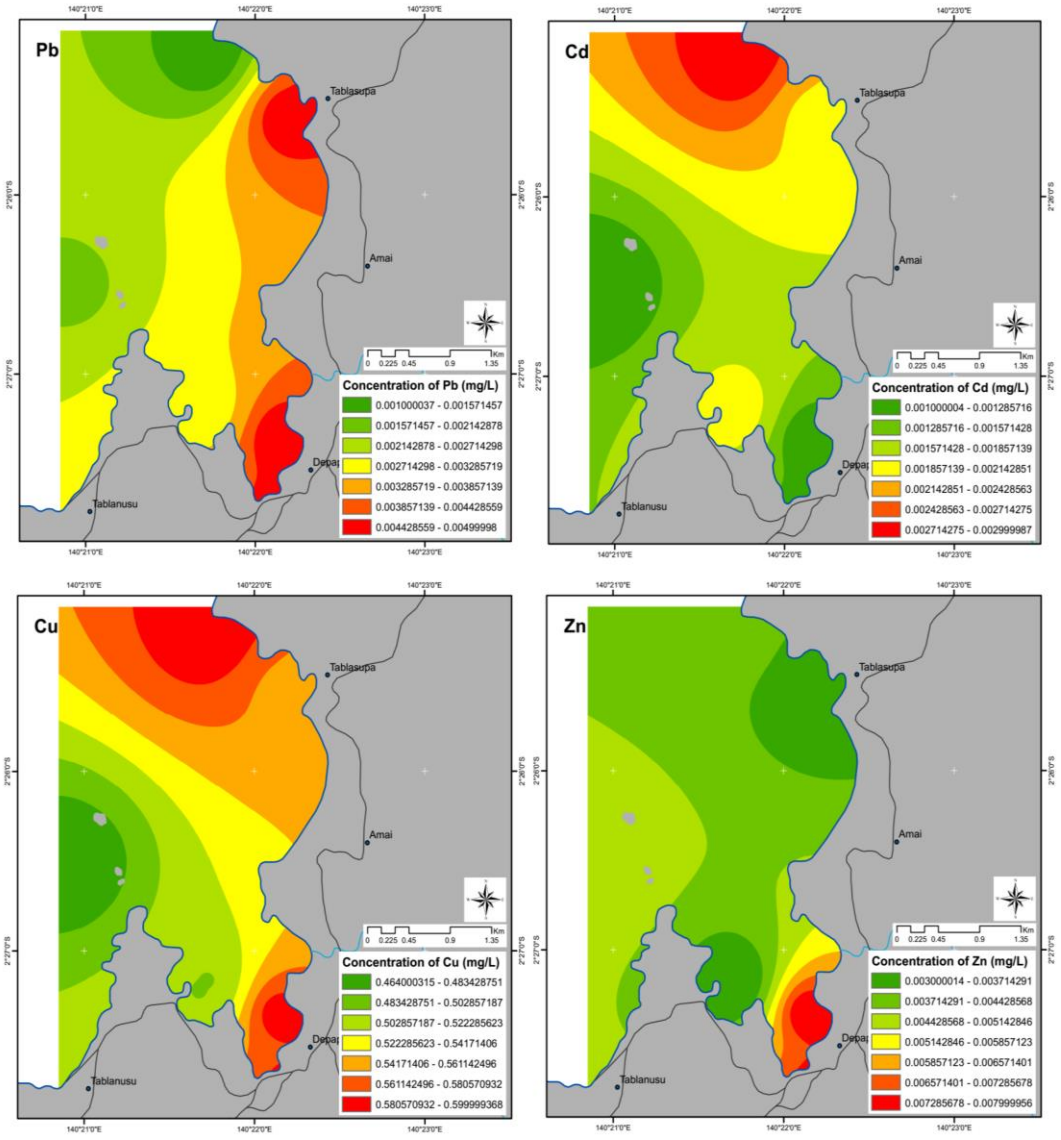

Figure 2. The spatial distribution of heavy metals concentrations (Pb, Cd Cu, and Zn) in Depapre waters, Papua Province, Indonesia

Spatially, the interpolation results of the distribution of Cu and Cd in Depapre waters exceed the quality standards. Although Cu is classified as an essential heavy metal that is needed by aquatic organisms, it can be highly toxic to aquatic organisms at higher concentrations. This is in contrast to Cd, which is classified as a non-essential heavy metal that is very dangerous for aquatic organisms. It needs special attention because Cd is toxic even though its concentration in seawaters is low and because it is persistent. In aquatic ecosystems, Cd contamination has great effects on ecosystem function, structure, and biogeochemical nutrition of water [38, 39]. Heavy metal pollution in seawaters can act as an important intermediary for subsequent pollution in aquatic ecosystems or public health [40]. Various human activities are suspected to be sources of Cd in Depapre waters, and included are household waste disposal, agricultural waste disposal, and marine transportation activities.

3.2 Water pollution index based on heavy metal concentrations

The water pollution index functions as a tool to discover and express pollution levels in waters. The water pollution index provides a single assessment score of various environmental parameters, and it is analyzed to interpret the water quality [41]. The results from the analysis of the pollution index values at each station are fully presented in Figure 3. According to the results of the pollution index evaluation of heavy metals, all the research stations can be classified in the moderately polluted category with water pollution index values in the range of 6.94-7.34.

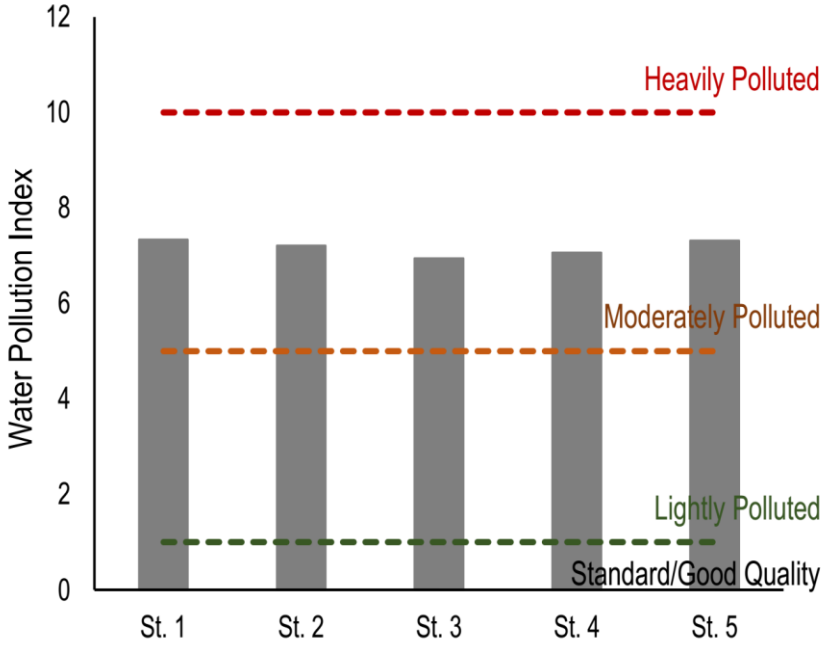

Figure 3. Water pollution index based on heavy metals concentration in Depapre waters, Papua Province, Indonesia

Based on the analysis of heavy metal concentrations, the high concentration of Cu was the largest input contributing to the high index of heavy metal pollution in Depapre waters. This high Cu concentration needs to be monitored because if the Cu concentration keeps increasing, it will surely have a negative impact on marine biota and the local society. The Cd concentration also influenced the determination of the water pollution index, although it was not as significant as the Cu concentration. The evaluation of the results of water pollution index-based study of heavy metals concentrations may provide solutions for decision-makers who must value the quality of waters for allocations, and fix up the quality of waters if there is quality decrease caused by the presence of contaminated materials.

Although the water pollution index only shows the level of relative pollution, it can be used as a reference for the regional government to mitigate pollution in local seawaters. Therefore, the regional government must define strategies and actions for the prevention and control of seawater pollution and the recovery of seawater quality. The purpose of monitoring is not to detect minor fluctuations that are quickly disappearing but to detect significant changes in sea waters and aquatic ecosystems, so spatial and temporal monitoring of seawater quality is needed.

4. Conclusions

The heavy metals found in Depapre Waters came from household waste disposal, farming activities, minor-scaled fisheries, marine transportation, and also from natural processes. The copper concentration in all locations, and cadmium in three research stations, were higher than the limits indicated in the water quality standards, whereas the concentrations of mercury, lead and zinc in all locations were within standard range for water quality for marine biota. Heavy metals distributions (except Zn) tended to be higher near to the beach and lower towards open water. According to the results of the pollution index of heavy metals, the Depapre waters have been classified into the moderately polluted category, and show water pollution indexes in the range of 6.94-7.34. The concentrations of Cu and Cd as inputs caused the high value of the heavy metal pollution index in Depapre waters. There is a need for policies and regulations from the regional government to regulate the disposal of waste in an effort to control pollution in the area's seawaters, and the disposal of both anthropogenic and industrial waste need to be monitored. The research also suggests that authorities need to keep a close eye on the disposal of fuel and ballast water of ships. If the concentration of heavy metals in seawaters can be controlled, the quality of sea waters will also be good. This assessment of the concentration and distribution of pollutants provides more than just a way of determining the water pollution index; it also provides information on water quality that gives a picture of the overall level of water pollution. The concentrations of heavy metals in seawaters that come out of this study can be used as baseline data for future activities.

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