Molekul, Vol. 16. No. 2, July 2021: 100 – 109

MOLEKUL
www.jmolekul.com

Articles
https://doi.org/10.20884/1.jm.2021.16.2.572

Distribution of Phosphorus Fraction in Surface Sediments of the Jobokuto Bay, Jepara

Lilik Maslukah[1]*, Anindya Wirasatriya[1], Muh Yusuf[1], Resy Sekar Sari[2], Ummu Salma[2],
Muhammad Zainuri[1]

[1]Department of Oceanography, Faculty of Fisheries and Marine Science, Diponegoro University, Indonesia
[2]Bachelor Degree Program of Oceanography, Faculty of Fisheries and Marine Science,
Diponegoro University, Indonesia

*Corresponding author mail: lilik_masluka@yahoo.com

Received September 12, 2019; **Accepted** May 03, 2021; **Available online** July 20, 2021

ABSTRACT. Phosphorus (P) is an essential nutrient that can limit primary productivity in waters. Phosphorus has significant impact on the biogeochemical cycle in marine ecosystems. Surface sediments play an important role in the nutrient dynamics. Riverine input is sources of P to the ocean and sediment plays an important role as a source or sink of P in the coloumn of water. Phosphorous (P) availability is regarded as the most important factor for determining the water quality in coastal waters. However, not all of the P fractions can be released from the sediment. This study was conducted to identify the distribution of phosphorus (P) fractionation in the sediment surface of Jobokuto Bay. Samples were collected from ten locations. Percentage of sedimentary parameters such as sand, silt, clay, and organic carbon were analyzed to find out their relation with various P fractions. The sediment found was mostly sand at the station near to the coast and mud (silt and clay) at offshore stations. The results showed that Ca-P dominant (56.03%) and percentages of Fe-P, OP, and Ads-P were 23.43, 17.41, and 3.2% respectively. Terrestrial inputs and biological deposits cause Ca-P dominant. The bioavailability of P fractions were ranged from 34.45 to 56.1% of the total P (TP) content. The high concentrations of the Ads-P was found in the mud fraction and located at offshore stations. The order of abundance of the major forms of P in the surface sediments of Jobokuto bay is as follows: Ca-P > Fe-P > OP > Ads-P

Keywords: phosphorus fractions, sequential extraction, sediment, Jobokuto Bay

INTRODUCTION

Population growth and rapid economic development in urban areas and the intensive use of agricultural land cause the increasing of pollutants and will affect the aquatic environment, estuary, bay and ocean (Zhang, Wang, Yin, Lü, Yang, & Huang 2014; Zhou et al., 2016; Vicente, de Melo, Neto, & de Oliveira, 2016). Jobokuto Bay located in Jepara City. This bay is a small bay that crossed by two rivers (Wiso River and Sampok River) and one of the development areas in the fisheries sector. Fisheries activities in this area include smallholder and governmental aquaculture (BBPAP), ports, and fish auctions house (TPI). High frequencies of human activity in the upstream areas of the river, such as domestic waste and agriculture, contributed increasing the number of pollutants that reach ocean (Zhou et al., 2016).

Based on the research of Sanusi et al. (2005), the existence of BBPAP ponds (Brackish Water Aquaculture Center) has contributed to ammonia input into the waters of Jobokuto Bay, and the total pollution load of suspended solids (TSS) reaches 157.40 tons.day^{-1}, sourced from two rivers. This affects the turbidity and causes the entry of chemical elements into the waters to increase. River flow is the main source of N and P to coastal waters and has an important role in stimulating biological processes in these waters (Gypens, Borges, & Lancelot, 2009; Yang, Liu, Wu, & Zhang, 2016; Kang et al., 2017).

Phosphorus (P) is a key factor in primary productivity (Zhuang, Gao, Zhang, Xing, Tosi, & Qin, 2014; Kang et al., 2017) and if the concentration excessive, this element is the most common cause of eutrophication in many water systems (Aydin, Aydin, Saydut, & Hamamci, 2009; Gunduz, Aydin, Aydin, & Hamamci, 2011; Soliman, El Zokm, & Okbah, 2017) such as freshwater lakes, reservoirs, rivers, estuary and coastal systems. Labry, Youenou, Delmas, & Michelon (2013) explained that phosphorus carried by river flow reaches 90% of the original concentration and reacts with particulate matter. The high P concentration in this water column will be stored in sediments through the adsorption process of the dissolved phase (Kang et al., 2017). Coastal sediments have an important role in their environment in terms of storage or release of chemical elements from or into the water column (Brigolin et al., 2011; Wallman et al., 2008; Jin et al., 2013, Zhang et al., 2014). The release mechanism is very dependent on the various forms of sediment fraction (Aydin, Temel, Gunduzc, & Aydin, 2018), grain size, organic matter, and pH in the sediment.

To assess the risk of eutrophication in the aquatic system, it is necessary to know the fraction distribution between different P sediments phase (Aydin et al., 2018). Phosphorus form affects the transformation process at the sediment-water interface determined by the nature of the sediment. Previous researchers have characterized the extraction, analysis, and release mechanisms of most P forms (Wang, Jiao, Yang, Jin, & Yi, 2015). The P fraction in marine sediments primarily consists of inorganic forms such as exchangeable P (Ads-P/Ex-P), Aluminium-bounded P (Al-P), iron (Fe)-bounded P (Fe-P), calcium-bounded P (Ca-P), and organic P (OP) (Soliman et al., 2017). The bioavailable fraction including Ads-P, Fe-P and OP are contributory fractions related to the eutrophication process. For better understanding of the phosphorus dynamics in coastal waters, this research investigates the distribution of phosphorus fraction related to the bottom sediments of the Jobokuto Bay waters. Moreover, we also connect each fraction with grain size characteristics, concentration of organic carbon, Fe-metal and sediment pH. Thus, the present study firstly delivers the comprehensive analysis of P fraction and their relation with the sediment characteristics in Jobokuto Bay. Phosphorus fraction distinguished based on the extracting agent and the analysis is carried out sequentially (SEDEX).

Several studies on the phosphorus fraction in sediments have been carried out in China (Yang et al., 2018; Kang et al., 2017; Zhou et al., 2016) and Brazil (Vicente et al., 2016) and Japan (Yamada & Kayama, 1987). Research on the P fraction in Indonesia has been conducted previously by Maslukah et al. (2019a), in areas far from the mainland. Information about the fraction of P in sediment is important to do in the study area, to see the impact due to anthropogenic effects, because it can affect the productivity of the waters in this area and its surroundings. The results of this study will provide a database related to the P fraction in sediments in Indonesian waters, especially in Jepara coastal waters.

EXPERIMENTAL SECTION

This study was conducted in May 2017. The research locations are shown in **Figure 1**. Surface sediment samples (0-25 cm) collected at ten stations. The method used in this research was purposive sampling method with 10 stations. Stations 1 and 2 represent areas that are close to anthropogenic activities, stations 3, 4 and 5 represent water areas that are still affected by river mouth discharge, stations 6 and 9 represent areas that are close to land but there are no rivers, and stations 7, 8 and 10 represents an area far from the river mouth and close to an island with low anthropogenic activity (**Figure 1**).

Sediment was taken using a stainless-steel grab sampler. The sediment samples were placed in plastic zip lock bags and taken to the laboratory to be dried and homogenized. The sediment samples for analysis of the P fraction were sieved (<150 mesh). Analysis of the P fraction was conducted using chemical extraction and sequencing (Aydin et al., 2009; Maslukah, Sugianto, Salma, & Zainuri, 2019b). Approximately 0.5 g of sediment was extracted using 0.5 M NH_4Cl, 0.1 M NaOH, and 0.25 M H_2SO_4 to obtain Ads-P, Fe-P and Ca-P fractions, respectively. The extracts were centrifuged and the supernatants were filtered through Whatman membrane filter. The soluble phosphorus in each sample was analyzed using the molybdenum blue method by UV/VIS spectrophotometry at ƛ885 nm. The sediment residue was washed twice with milli-Q water prior to the next step. Organic-P (OP) is measured as the difference between 1 M HCl that can be extracted P (24 hours) before and after high temperature combustion (550°C, 2 hours) sediment. The sequential extraction procedure is developed to elucidate the chemical nature of P in sediments (Soliman et al., 2017). Moreover, we use the data on grain size, organic carbon (OC), Fe and sediment pH from the study of Maslukah et al. (2019a).

Data Analysis

The relationship between the P fraction on sediment and their characteristics were analyzed using correlations and principal component analysis (PCA). The principal component analysis (PCA) in this study was used to interpret data from the measurements of marine environmental parameters so that conclusions can be drawn precisely from a data matrix.

RESULTS AND DISCUSSION

Quality Parameter of Sediments

Jobokuto Bay is one of the estuaries in Jepara waters. The Wiso and Sapok rivers flow into the waters of Jobokuto Bay. Mixing of river and sea water will produce the physical and chemical properties such as salinity, pH and dissolved oxygen which is different from the nature of sea water. The estuary zone is often affected by tide as a transitional ecosystem which connects the aquatic system fresh water and sea water. This condition affect the distribution of nutrients in the estuary and its concentration. The estuary is also affected by sedimentation and the transportation of organic material. Sediment in the estuary will experience dynamics by the transportation, resuspension and deposition processes spatially or temporally. The distribution pattern of P nutrients in sediments is closely related to the physical environment such as sediment fraction, pH and organic matter.

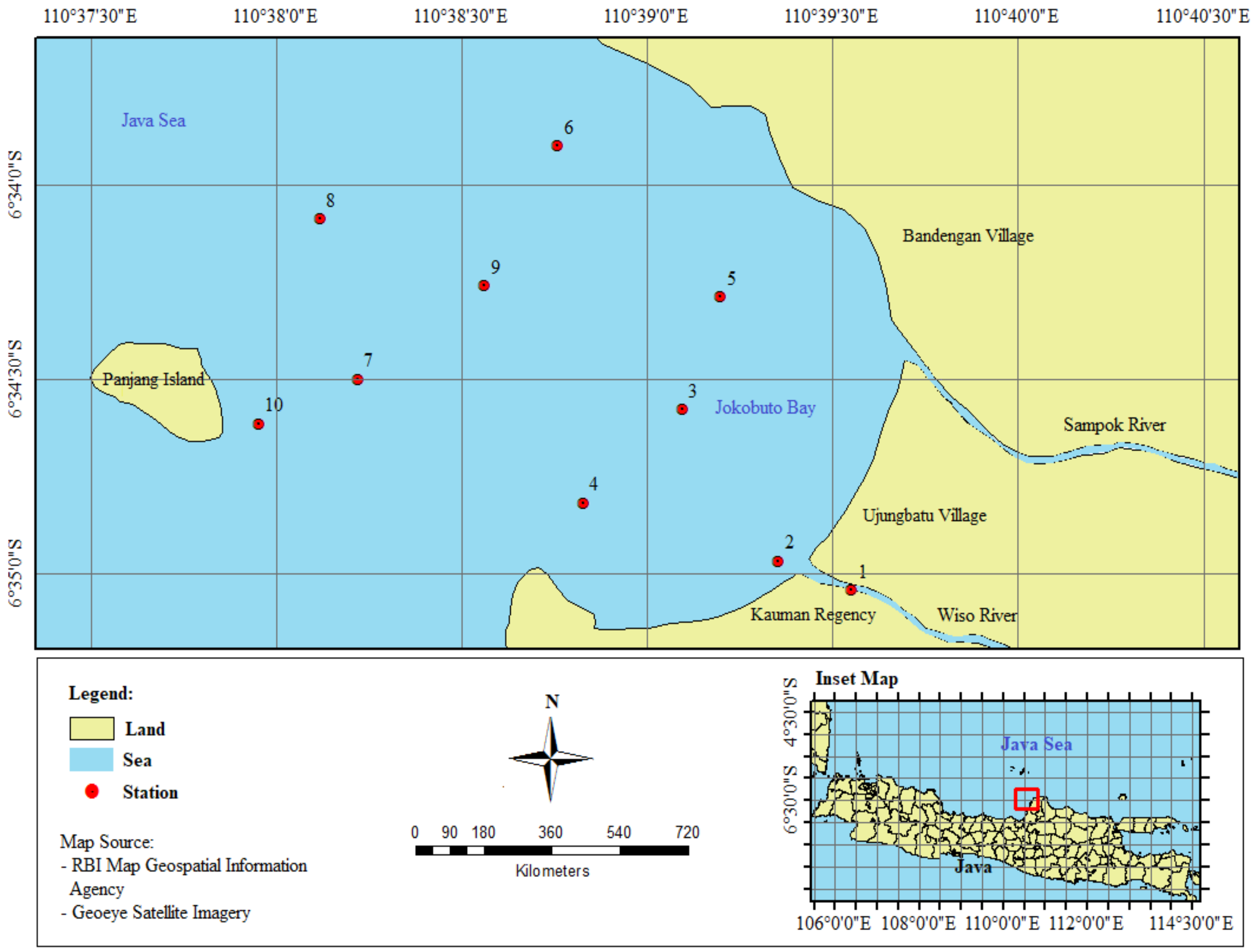

Figure 1. Research Location

The results of previous research by Maslukah et al. (2019a) at this location explained that the sand sediment fraction was found at stations 1, 2, 3, 4, 5 and 10, while stations 6, 7, 8 and 9 were dominated by silt. The distribution of the sediment fraction then affects organic carbon and Fe concentration in the sediment. The concentration of Fe in these sediments was found in the range 0.279-90.10 mg.kg^{-1}. At stations 6, 7 and 8 have higher organic carbon than other stations (4.56-8.14%). Meng et al. (2014) stated that high carbon organic matter is found in areas that have a fine fraction. Spatial variability of sediment particle size is a complex interaction of hydrodynamic processes and geomorphology. The presence of sand reflects stronger hydrodynamic energy (Vicente et al., 2016). The location of this station located at a relatively shallow depth (≤10m). The study of Sanusi et al. (2005) shows the Jobokuto Bay also dominated by sand fractions and a sufficient buffering capacity. Therefore, it is necessary to see the effect on a nutrient fraction in sediments, especially the fraction of P. The quantity of total phosphorus concentration is considered as the key factor for determining the eutrophication levels in water ecosystems (Aydin et al., 2018). The understanding of total phosphorus is not sufficient to determine the risk associated with its presence in this mass naturally (Vicente et al., 2016). The study of fractions is important for better monitoring of the availability of different forms of P fraction in water.

The Fraction of P in Sediments

Phosphorus sediment fraction in this study includes NH$_4$Cl-P (Ads-P) fraction which has loosely properties, fraction with NaOH extract (NaOH-P/Fe-P) which is an organic fraction that is easily separated and its presence is bound by iron oxide and aluminum and finally the results of sequencing of extraction using sulfuric acid (H$_2$SO$_4$-P/Ca-P). Inorganic phosphate (IP) calculated from the number of Ads-P, Fe-P, and Ca-P fractions. Furthermore, total phosphorus (TP) is the amount of organic-P (OP) and IP. The P released into the coastal surface sediments originated from the inorganic P fraction (Aydin et al., 2018). The Ca-P as the major P fraction in surface sediments in Mediterranean sea related mainly to the over saturation of calcite and co-precipitation of Phosphorus (Aydin et al., 2018). The results presented Ca-P as the major P fraction and relative abundances of the remaining P fractions follow the order : Fe–P > OP>Ads-P (**Table 1**).

Table 1. Concentrations of P fractions from Jobokuto Bay (μmol.g^{-1})

Station	Ads-P	Fe-P	Ca-P	IP	Org-P	TP
1	0.124	4.818	6.461	11.403	1.419	12.822
2	0.286	2.878	6.209	9.373	1.078	10.451
3	0.113	2.928	4.730	7.771	0.437	8.208
4	0.130	1.334	4.509	5.973	1.995	7.968
5	0.102	3.290	5.365	8.758	0.612	9.370
6	0.038	3.176	5.822	9.036	1.883	10.918
7	0.517	1.688	6.126	8.331	1.358	9.688
8	0.613	1.080	5.234	6.928	1.058	7.985
9	0.713	1.318	4.359	6.390	1.837	8.227
10	0.180	0.409	3.670	4.259	4.101	8.360

Spatial variations of inorganic phosphorus (IP) and total phosphorus (TP) of Jobokuto Bay sediments are shown in **Table 1**. Total range of P was 7.968-12.822 μmol.g^{-1} (average, 9.400±1.603 μmol.g^{-1}). The highest value found at the river mouth at station 1 and minimum at station 4. The IP content in sediments were ranged from 7.259-11.403 μmol.g^{-1} (average, 7.822±2.022 μmol.g^{-1}), reaching 82.6% of TP.

The inorganic form of P (IP) reached the highest concentration of total phosphorus (TP) compared to organic phosphorus (OP) fraction. The highest OP found at stations close to the river. This reflects sources of input from the mainland (Zhou et al., 2016; Yang et al., 2016). Inorganic fraction (IP) is the sum of the fraction of Ads-P, Fe-P and Ca-P. IP fraction is more dominant than organic phosphorus (OP). This is related to the research located near to the coast where the dynamics of the bottom waters, such as currents and waves, are quite high. Previous studies showed that the physicochemical properties of sediments, oxygen conditions, and depth of water column have a significant impacts on spatial variability TP and its fractionation. The high total P (TP) in the sediments of Laizhou Bay is the result of a combination of a complex geological structure due to river input, waste disposal and agricultural activities in the coastal area (Zhuang et al., 2014).

Ads-P is the lowest fraction compared to other fractions. The fraction was in the range of 0.038-0.713 μmol.g^{-1} (average, 0.282±0.243 μmol.g^{-1}) and reaches 3.2% of TP. Ads-P presents P absorption which is easily released and easily exchanged in sediments (Yang et al., 2016) and concentration of P in porewater. Ads-P in sediments are reactive P. Ads-P can be used directly by phytoplankton formed by direct adsorption of phosphorus onto mineral surface sediments (Kang et al., 2017). The factors that influence the existence of this P are oxides and hydroxide particles in clay minerals in sediments. The existence of physical, chemical factors such as temperature, pH, dynamic conditions of water, and redox properties can cause the release of Ads-P into the water column (Chen et al., 2012). High values of Ads-P are recorded on station of 7, 8 and 9. These may correspond to the high organic matter and silty fraction of sediment. Yang et al. (2016) showed that the size of sediment particles and organic matter are important factors controlling the concentration and distribution of Ads-P in sediments. Futrhermore, Meng et al. (2015) has shown that samples with a fine sediment fraction have wide surface area, which provides more sites for absorption and binding to the phosphorus (especially as HPO_4^{-2}). On the other hand, Ads-P is formed by binding of phosphorus to the surfaces of mineral and released during degradation of the organic matter. This may help to explain why Ads-P was found to be high in fine-grained sediments and rich in organic matter. Yang et al. (2016) obtained a significant linear relationship between fine-grained sediments with Ads-P.

The concentration of Fe-P fraction ranges from 0.409-4.818 g.mol^{-1} (average 2.292±1.340) reaching 23.4% of TP. The Fe-P is found to be the highest at station 1, which is located in front of the mouth of the Wiso river. This is related to the metal concentration of Fe in these sediments which reaches 90.10 mg.kg^{-1}. The concentration of Fe-P gradually decreases towards the sea. Yang et al. (2016) explained that the concentration of Fe-P in coastal waters is higher and decreases towards the sea due to the shift of phosphorus species from $H_2PO_4^-$ to HPO_4^{2-}, and changes in surface charge on Fe oxide/hydroxide which inhibits the adsorption of phosphorus to oxide/hydroxide from Fe (Hou et al., 2009). Andrieux-Loyer and Aminot (2001) explain that Fe-P concentrations are relatively higher in brackish waters compared to salty waters in coastal areas, due to the large amount of phosphorus being trapped by Fe hydroxide/oxides in sediments.

The Ca-P fraction is the most dominant and is in the range of 3.670–6.461 μmol.g^{-1}, representing 56% of TP. The highest Ca-P was found at station 1, and its location is in the mouth of the Wiso river. The distribution of Ca-P is the opposite of OP which is found highest at station 10, with the location farthest from the estuary. The most abundant Ca-P is found at station 1, probably from terrigenous input, while the OP generated by biological sources is supported by the seagrass ecosystem in this region (station 10). The Ca-P comes from terrigenous, which is distributed by rivers and sea current (März et al., 2014). Organic P (OP) in this study ranges from 0.437 to 4.101 μmol.g^{-1} (average 1.578±1.029). Based on the average value of each station, the difference in the sequential fraction from the largest is Ca-P>Fe-P>OP>Ads-P. The high percentage of Ca-P indicates that the sediment in the study area does not significantly contribute to the addition of dissolved P concentration in the water column and does not directly affect the eutrophication. This is different if the highest fraction is found in Fe-P, which is often used as an indicator of polluted waters (Vicente et al., 2016; Yang et al., 2018). The percentage of each fraction of P to the P total (TP) is presented in **Figure 2**.

The relationship of P fraction on sediment quality

The relationship between the P fraction on sediment characteristics was analyzed using correlations (**Table 2**) and principal component analysis (PCA) (**Figure 3**). Statistical analysis (**Table 2**) shows that Ads-P positively correlated with clay and silt (r=0.46 to silt and r=0.67 to clay and negatively correlated with sand (r=-0.66). This indicates that particle size is a significant factor that controls the concentration and distribution of Ads-P in sediments (Yang et al., 2016). Fine particles have a wider surface and provide strong bonds to phosphate adsorption (especially HPO_4^{2-}) (Meng et al., 2015; Soliman et al., 2017). The concentration of Ads-P in this study reached 3.2% of TP and was the lowest P fraction. These results are the same with the study of Yang et al. (2016) in Hainan Beach, hina and Vicente et al. (2016) in Guapirimim, Brazil. The results of Vicente et al. (2016) shows that the Ads-P fraction ranges from 0.03 to 0.93 μmol.g^{-1} and the value reaches 3.4% of the total inorganic phosphorus (TIP). This fraction behaves similarly to organic matter and is a fine grain size. Furthermore, Meng et al. (2014) describes the contribution of organic matter to the retention of phosphorus by sediment. Vicente et al. (2016) obtained a significant positive correlation of this fraction with sedimentary organic matter (r=0.83).

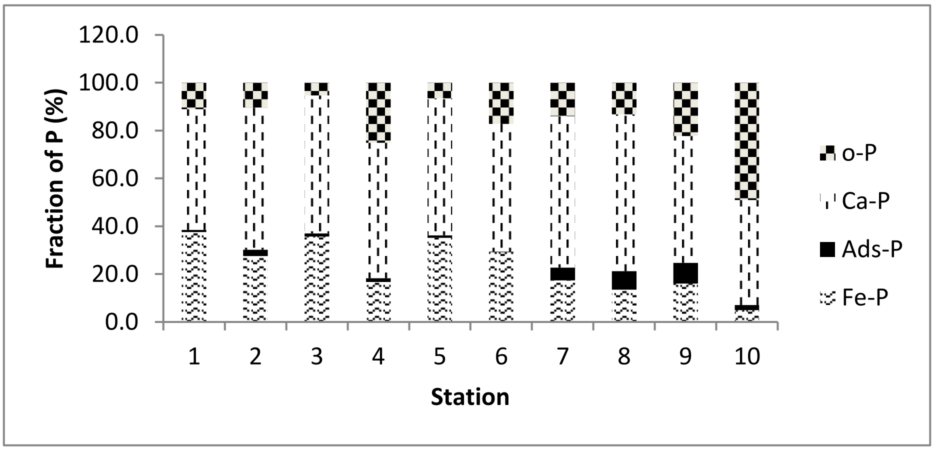

Figure 2. Percentage of each fraction from Total P (TP)

Table 2. Correlation coefficients P-fraction and characteristic geochemical of sediments

Var	Ads-P	Fe-P	Ca-P	IP	OP	TP	pH	OC	depth	Fe	sand	silt	clay
Ads-P	**1.00**	-0.49	-0.08	-0.23	-0.15	-0.38	0.37	0.36	0.53	0.36	-0.66	0.67	0.46
Fe-P	-0.49	**1.00**	**0.73**	**0.93**	-0.50	**0.85**	-0.06	-0.01	-0.60	-0.02	0.24	-0.24	-0.18
Ca-P	-0.08	**0.73**	**1.00**	**0.93**	-0.57	**0.80**	0.55	0.25	-0.33	0.25	-0.17	0.15	0.44
IP	-0.23	**0.93**	**0.93**	**1.00**	-0.61	**0.88**	0.25	0.15	-0.48	0.15	0.00	-0.01	0.14
OP	-0.15	-0.50	-0.57	-0.61	**1.00**	-0.15	0.01	-0.42	0.27	-0.42	0.19	-0.18	-0.25
TP	-0.38	**0.85**	**0.80**	**0.88**	-0.15	**1.00**	0.32	-0.07	-0.43	-0.07	0.11	-0.12	0.02
pH	0.37	-0.06	0.55	0.25	0.01	0.32	**1.00**	0.41	0.37	0.41	-0.50	0.48	**0.81**
OC	0.36	-0.01	0.25	0.15	-0.42	-0.07	0.41	**1.00**	0.61	**1.00**	**-0.82**	**0.82**	**0.76**
depth	0.53	-0.60	-0.33	-0.48	0.27	-0.43	0.37	0.61	**1.00**	0.61	**-0.77**	**0.77**	0.61
Fe	0.36	-0.02	0.25	0.15	-0.42	-0.07	0.41	**1.00**	0.61	**1.00**	**-0.82**	**0.82**	**0.76**
sand	-0.66	0.24	-0.17	0.00	0.19	0.11	-0.50	**-0.82**	**-0.77**	**-0.82**	**1.00**	**-1.00**	**-0.80**
silt	0.67	-0.24	0.15	-0.01	-0.18	-0.12	0.48	**0.82**	**0.77**	**0.82**	**-1.00**	**1.00**	**0.78**
clay	0.46	-0.18	0.44	0.14	-0.25	0.02	**0.81**	**0.76**	0.61	**0.76**	**-0.80**	**0.78**	**1.00**

In the pesent study, we also found that there is a positive correlation between organic matter and Fe-P fraction. Particle size is also an important factor in the control of Ads-P in sediments. Sediment with fine particle sizes have a stronger adsorption capacity due to their wider specific surface area (Zhuang et al., 2014). In their research, Vicente et al. (2016) obtained a positive correlation between Ads-P and silt (r=0.80) and clay (r=0.72). Li et al. (2013) also find the largest storage capacity phosphate occurs in fine particles in the Yangtze estuary and Hangzhou bay. The mobility of phosphorus in sediments depends on the original existing chemical forms (Wang et al., 2015) and changes in physical and chemical factors, such as pH sediment, dynamic conditions of water, bioturbation and redox characteristics, could caused release Ads-P into the water column (Chen et al., 2011).

Fe-P is an important indicator in the mobility of P and Fe (Vicente et al., 2016). This fraction is often used as an indicator of sediment quality and the level of environmental pollution (Xiang and Zhou, 2011; Yuan et al., 2015; Vicente et al., 2016). Fe-P is formed through co-precipitation of phosphate with Fe oxide and hydroxides (Meng et al., 2014). Its presence is closely related to anthropogenic activity and mainly comes from domestic and industrial wastes (Vicente et al., 2016). This fraction is most likely to change due to changes in environmental redox (Zhuang et al., 2014; Vicente et al., 2016). When Eh is low, P will be released, and the concentration of dissolved P waters increases, and vice versa, on the other hand when Eh is high P will be adsorbed by particles (Vicente et al., 2016). Aydin et al. (2018) explain that under reduced conditions, the oxidized form of iron, Fe (III), is converted into the reduced form, Fe (II). Fe (III) fraction is more difficult to release than Fe (II). Fe-P in this study reaches 23.4% of TP, the second most abundant after Ca-P (**Table 1**).

Based on **Table 1**, Ca-P reaches 67.1% of IP in sediments and has the highest percentage compared to other fractions. The highest Ca-P found at station 1 located in the river. Ca-P primarily of terrestrial origin is derived from the weathering of rocks (Ruttenberg, 1992; Labry et al., 2013). Source of Ca-P is from biological deposits and terrestrial inputs.

The sum of concentrations Ads-P, Fe-P, and OP are bioavailable from P in sediments (Meng et al., 2014; Kang et al., 2017). This bioavailability is a P element which can be immediately available either in porewater or directly released into the water column and ready for use by phytoplankton through physical, chemical, and biological processes. Organic phosphorus (OP) reached 17.4% of TP. The location is found farthest from the mainland and close to the location of Panjang Island (station 10). OP mainly comes from terrestrial and biological input processes (Liu et al., 2004, Zhuang et al., 2014; Yang et al., 2016). In addition to anthropogenic inputs, OP also derived from in situ marine primary productivity (Thouvenot-Korppoo1 et al., 2012), and Panjang Island characterized by high productivity. The existence of seagrass in Panjang Island is the cause of the highest OP concentration at station 10.

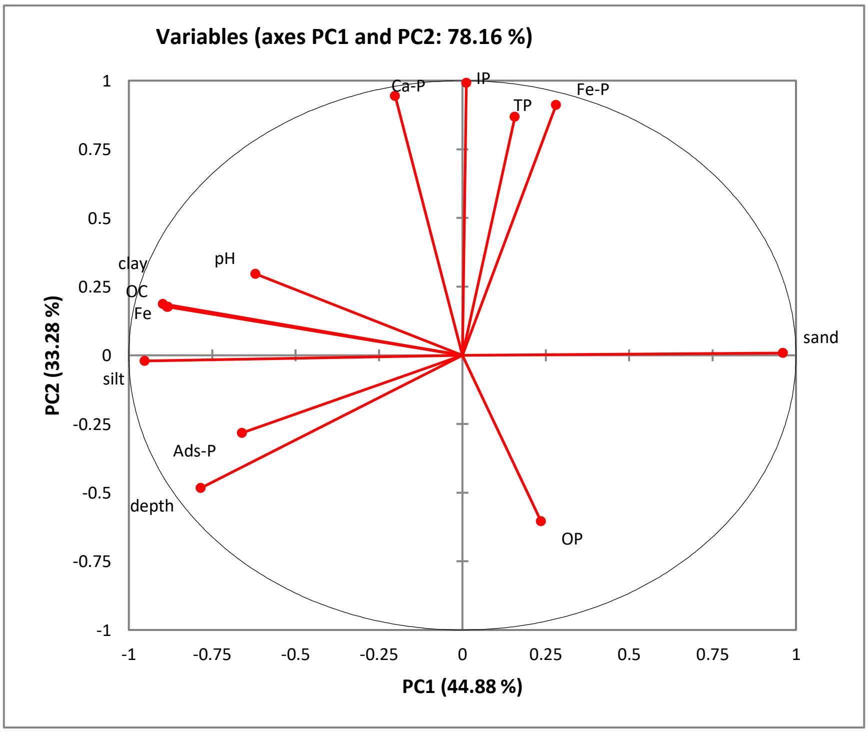

Figure 3. The Principal Component Analysis (PCA) of all parameters

Table 3. Summary phosphorus fractions in different coastal environment (P fractions are extracted with the SEDEX method or modified (μg.g^{-1}).

Location	Sampling time	TP	IP	Ads-P	Fe-P	Au-P	OP	Bio-P	Reference
East China Sea shelf	May-Jun., 2014	324.0-499.6	222.8-423.2	2 0.8-21.9	7.7-36.5	28.0-250.7	39.6-131.4	72.4–187.1	Zhoau et al., 2016
	Oct.-Nov., 2014	345.1-810.4	293.9-732.1	5.4-20.4	7.6-42.2	60.0-332.1	39.6-144.5	57.6–203.2	Zhoau et al., 2016
Rushan Bay	2014-2015	10.9-29.5 μmol.g^{-1}	Na	0.10-0.34 μmol.g^{-1}	0.61-5.48 μmol.g^{-1}	0.66-4.72 μmol.g^{-1}	1.39-5.29 μmol.g^{-1}	na	Liu et al., 2016
Zhangzi Island	November 2011	81.3-401.3		2.3-9.5	9.1-27.9	3.1-24.1	22.8-85.8	na	Zhuang et al., 2014
Eastern coastal of Hainand Island, South China Sea	August 2008,	7.96-22.34 μmol.g^{-1}	6.39-14.24 μmol.g^{-1}	0.63-1.29 μmol.g^{-1}	0.67-1.85 μmol.g^{-1}	2.27-5.96 μmol.g^{-1}	1.14-9.39 mmol.g^{-1}	na	Yang et al., 2016
Guapimirim estuary	July 2010	na	3.18-7.13 μmol.g^{-1}	0.03-0.93 μmol.g^{-1}	0.79 – 1.71 μmol.g^{-1}	0.85-1.91 μmol.g^{-1}	na	na	Vicente et al., 2016
Jobokuto Bay	Mei 2017	7.968-12.822 μmol.g^{-1} (~ 247-397 μg.g^{-})	7.259-11.403 μmol.g^{-1}	0.038-0.713 μmol.g^{-1}	0.409-4.818 μmol.g^{-1}	3.670-6.461 μmol.g^{-1}	0.437-4.101 μmol.g^{-1} (~ 13.5-127 μg.g^{-1})	na	This study

Analysis of P fraction and sediment quality parameters using the Principle of Component Analysis (PCA). PCA is a multivariate analysis tool that can reduce data. Based on the component eigenvalues, both axes are extruded and distinguished by high loading. The loading for two variance PCA shown in **Figure 3**. The number of variances that can be explained reaches 78.16%. PC1 reaches 44.88% of the variance data and is distinguished by high positive charges on Ads-P, silt, clay, TOC, pH, and depth of the water. This indicates that the high Ads-P associated with fine fractions (clay and silt) has high organic carbon. The high Ads-P are associated with high sediment pH, and this location is found in deeper waters. PC2 explains 33.28% of the total variance and distinguished by high Fe-P, Ca-P, IP dan TP. Some studies from other countries about the fraction of P can be observed in **Table 3**.

CONCLUSION

This study revealed various forms of P in Jobokuto Bay and their distribution of total P (TP). Total P (TP) ranges from 7.968-12.822 μmol.g^{-1} (average, 9.4±1.6 μmol.g^{-1}). The inorganic form of P (IP) reaches the highest concentration of total phosphate (TP) compared to organic phosphorus (OP) fraction. The Ca-P predominates in P pool and its concentration in the study area accounts for 56%. The Ca-P primarily of terrestrial origin is derived from the weathering of rocks. The distribution of Ca-P is the opposite of OP and Ads-P. The high concentrations of the Ads-P are found in the mud fraction and located at offshore stations. Their distributions are controlled by texture of sediment and organic carbon. The Ads-P fraction is positively correlated to fine sediment (silt and clay), sediment pH and depth, while the Fe-P fraction is influenced by the concentration of Fe metal and Ca-P by organic carbon. The bioavailable P (BAP) fraction ranges from 34.45 to 56.1% of the total P (TP) content. This BAP value is still low compared to areas that have undergone the process of eutrophication. Nevertheless, it still needs to consider external and internal P source to reduce the risk of eutrophication in Jobokuto Bay and coastal ecosystems.

ACKNOWLEDGMENTS

We would like to thank to the Faculty of Fisheries and Marine Science, Diponegoro University for the research funding with the contract 013/UN7.5.10.2/PP/2020.

REFERENCES

Andrieux-Loyer, F. & Aminot, A. (2001). Phosphorus forms related to sediment grain size and geochemical characteristics in French coastal areas. Estuar. Coast. Shelf Sci. 52, 617–629.

Aydin, I., Aydin, F., Saydut, A., & Hamamci, C. (2009). A sequential extraction to determine the distribution of phosphorus in the seawater and marine surface sediment. *Journal of Hazardous Materials*, 168(2–3), 664–69.

Aydin, I., Temel, Z., Gunduzc, B. & Aydin, F. (2018). Comparative determination of phosphorus fractionsin coastal surface sediment (NE Mediterranean Sea) by ICP-OES and UV/VIS Spectrometry. *Atomic Spectroscopy*, 39(5), 193-197. DOI: 10.46770/AS.2018.05.003.

Brigolin, D., Lovato, T., Rubino, A., & Pastres, R. (2011). Coupling early-diagenesis and pelagic biogeochemical models for estimating the seasonal variability of N and P fluxes at the sediment-water interface: Application to the Northwestern Adriatic Coastal Zone. *Journal of Marine Systems*, 87(3–4), 239–255.

Chen, T. & Yu, K. (2011). P/Ca in coral skeleton as a geochemical proxy for seawater phosphorus variation in Daya Bay, northern South China Sea. *Mar Pollut Bull,* 62(0) :2114–2121. doi:10.1016/j.marpolbul.2011.07.014.

Chen, Y., Liu, R., Sun, C., Zhang, P., Feng C., & Shen, Z. (2012). Spatial and temporal variations in nitrogen and phosphorous nutrients in the Yangtze River Estuary. *Marine Pollution Bulletin*. 64, 2083–2089.

Gypens, N., Borges, A.V., & Lancelot, C. (2009). Effect of eutrophication on air-sea CO2 fluxes in the coastal Southern North Sea: a model study of the past 50 years. *Global Change Biology*, 15, 1040–1056.

Gunduz, B., Aydin, F., Aydin, I., & Hamamci, C. (2011). Study of phosphorus distribution in coastal surface sediments by sequential extraction procedure (NE Mediterranean Sea, Antalya Turkey). *Microchemical Journal*, 98 (1), 72–76.

Hou,L.J., Liu, M., Yang,Y., Ou, D.N., Lin,X., Chen, H., & Xu, S.Y. (2009). Phosphorus speciation and availability in intertidal sediments of the Yangtze Estuary, China. *Appl. Geochem*, 24,120–128.

Jin, X.D., He, Y., Kirumba, G., Hassan, Y., & Li, J.B. (2013). Phosphorus fractions and phosphate sorption-release characteristics of the sediment in the Yangtze River estuary reservoir. *Ecol. Eng,* 55, 62–66.

Kang, X., Song, J., Yuan, H., Shi, X., Yang, W., Li, X., Li, N., & Duan, L. (2017). Phosphorus speciation and its bioavailability in sediments of the Jiaozhou Bay. *Estuarine, Coastal, and Shelf Science,* 188, 127–36.

Labry, C., Youenou, A., Delmas, D. & Michelon, P. (2013). Addressing the measurement of particulate organic and inorganic phosphorus in estuarine and coastal waters. *Continental Shelf Research*, 60, 28–37.

Li, M, Whelan, M.J., Wang, G.Q. & White, S.M. (2013). Phosphorus sorption and buffering mechanisms in suspended sediments from the Yangtze Estuary and Hangzhou Bay, China. Biogeoscience, 10(5):3341–3348. doi:10.5194/bg-10-3341-2013.

Liu, S.M., Zhang, J., & Li, D.J. (2004). Phosphorus cycling in sediments of the Bohai and Yellow Seas. *Estuarine, Coastal, and Shelf Science,* 59(2), 209–218.

März, C., Poulton, S.W., Wagner, T., Schnetger, B. & Brumsack, H.-J. (2014). Phosphorus burial and diagenesis in the central Bering Sea : perspectives on the marine P cycle. *Chem.Geol*, 363,270–282.

Maslukah, L., Wulandari, S.Y., Herlintang, A.S. & Muslim. (2019a). Concentration of heavy metal lead (Pb) and iron (Fe) in sediments and its relationship with organic carbons & grain size in Wiso Estuary, Jepara. *Maspari Journal*, 12(2),149-158.

Maslukah, L., Sugianto, D.N., Salma, U. & Zainuri, M. (2019b). Phosphorus fractionation and its bioavailability in Panjang Island Jepara. *IOP Conference Series: Earth and Environmental Science,* 246 (0), 012051

Meng, J., Yao, P., Yu, Z., Bianchi, T.S., Zhao, B., Pan, H. & Li, D. (2014). Speciation, bioavailability, and preservation of phosphorus in surface sediments of the Changjiang estuary and adjacent East China Sea inner shelf, *Estuarine, Coastal, and Shelf Science* 144(0), 27–38.

Meng, J., Yu, Z., Yao, Q., Bianchi, T.S., Paytan, A., Zhao, B., Pan, H., & Yao, P. (2015). Distribution, mixing behavior, and transformation of dissolved inorganic phosphorus and suspended particulate phosphorus along a salinity gradient in the Changjiang Estuary. *Marine Chemistry*, 168 : 124–134. doi : http://dx.doi.org/10.1016/j.marchem.2014.09.016

Ruttenberg, K.C. (1992). Development of a sequential extraction method for different forms of phosphorus in marine sediments. *Limnol. Oceanogr.*, 37 (7), 1460-1482.

Sanusi, H.S., Kaswadji, R.F., Nurjaya, I.W. & Rafni, R. (2005). Assimilative capacity study of organic and inorganic pollution load at Jobokuto Bay, Jepara District, Central Java. *Jurnal Ilmu-ilmu Perairan dan Perikanan Indonesia*, 12(1), 9-16.

Soliman, N.F., El Zokm, G.M. & Okbah, M.A. (2017). Evaluation of phosphorus bioavailability in El Mex Bay and Lake Mariut sediments. *International Journal of Sediment Research*, 32, 432–441

Thouvenot-Korppoo, M., Lukkari, K. Järvelä, J., Leivuori, M, Karvonen, T. & Stipa, T. 2012. Phosphorus release and sediment geochemistry in a low-salinity water bay of the Gulf of Finland. *Boreal Env. Res,* 17, 237-251

Vicente, M.A.F, de Melo, G.V., Neto, J.A.B. & de Oliveira, A.S. (2016). Phosphorus fractionation distribution in Guapimirim estuary: SE Brazil, *SpringerPlus,* 5(1).

Wallmann, K., Aloisi, G., Haeckel, M., Tishchenko, P., Pavlova, G., Greinert, J., Kutterolf, S., & Eisenhauer, A. (2008). Silicate weathering in anoxic marine sediments. *Geochimica et Cosmochimica Acta*, 72(12), 2895−2918

Wang, L. & Liang, T. (2015). Distribution characteristics of phosphorus in the sediments and overlying water of Poyang Lake. *PLoS One*. 10(5): e0125859

Xiang, S-L. & Zhou, W-B. (2011). Phosphorus forms and distribution in the sediments of Poyang Lake, China. *Int J Sedim Res*, 26, 230–238. doi: 10.1016/S1001-6279(11)60089-9

Yamada, H., & Kayama, M. 1987. Distribution and dissolution of several forms of phosphorus in coastal marine sediments. *Oceanologica Acta,* 10:311– 21.

Yang, B., Kang, Z., Lu, D., Dan, S.D., Ning, Z., Lan, W. & Zhong, Q. (2018). Spatial variations in the abundance and chemical speciation of phosphorus across the river-sea interface in the Northern Beibu Gulf. *Water,* 10(0), 1103

Yang, B., Liu, S.M. Wu, Y., & Zhang, J. (2016). Phosphorus speciation and availability in sediments off the Eastern Coast of Hainan Island, South China Sea. *Continental Shelf Research,* 118(0), 111–27.

Yuan, H., An, S., Liu, E., Pan, W. & Zhu, Z. (2015). Fractionation and bioavailability of phosphorus in sediments of Huaihe River, China. *Journal of Soil and Water Conservation,* 70(5), 313–321.

Zhang, L., Wang, L., Yin, K., Lü, Y., Yang, Y. & Huang, X. (2014). Spatial and seasonal variations of nutrients in sediment profiles and their sediment-water fluxes in the Pearl River Estuary, Southern China. *Journal of Earth Science*, 25(1), 197–206

Zhou, F., Gao, X., Yuan, H., Song, J., Chen, C.T.A, Lui, H.K. & Zhang, Y. (2016). Geochemical forms and seasonal variations of phosphorus in surface sediments of the East China Sea Shelf. *Journal of Marine Systems,* 159, 41–54.

Zhuang, W., Gao, X., Zhang, Y., Xing, Q., Tosi, L. & Qin, S. (2014). Geochemical characteristics of phosphorus in surface sediments of two major chinese mariculture areas: The Laizhou bay and the coastal waters of the Zhuangzi island. *Marine Pollution Bulletin,* 83(1), 343–51.