Spatial distribution and heavy metal pollution

by Abdul Ghofar

Spatial distribution and heavy metal pollution analysis in the sediments of Garang watershed, Semarang, Central Java, Indonesia

[1]Haeruddin, [1]Supriharyono, [1]Arif Rahman, [1]Abdul Ghofar, [2]Sigit B. Iryanthony

[1] Department of Aquatic Resources, Faculty of Fisheries and Marine Sciences, Universitas Diponegoro, Semarang, Indonesia; [2] Master Study Program of Coastal Resources Management, Department of Aquatic Resources, Faculty of Fisheries and Marine Sciences, Universitas Diponegoro, Semarang, Indonesia. Corresponding author: Haeruddin, haeruddindaengmile@lecturer.undip.ac.id

Abstract. Garang watershed is located in Central Java, Indonesia. Various activities around the Garang watershed cause river pollution, by producing heavy metal waste, which can accumulate in the sediment, being absorbed from the water by organisms. This study was conducted to determine the concentration of heavy metals in the sediments, map the spread in the Garang watershed (Banjir Kanal Barat River, Garang River, Kreo River), and to determine the state of sediment pollution with heavy metals. The sediment samples were collected from 7 stations, with 3 replicates for each station. Samples of sediment were analyzed with Atomic Absorption Spectrophotometry (AAS), then the concentration of metal was mapped according to the sampling location. The sediment pollution index was determined. The results showed that the metal concentrations in sediment varied, from concentrations below the detection limit to tens of thousands of ppb. Lead had the highest concentration, followed by Cr and Cu. Cd and Zn were under the detection limit. The highest lead concentrations were recorded in the Banjir Kanal Barat (BKB) River and the lowest in the Kreo River. The highest Cu concentrations were in the Garang River and the lowest in the Kreo River. The highest concentrations of Cr were in the BKB River and the lowest in the Kreo River. Pb and Cr have similar spatial distribution patterns and differ from the spatial spread of Cu. The sediment pollution index indicated that the sediments of Garang watershed, BKB River, Garang River, and Kreo River had not been contaminated with heavy metals.
Key Words: Banjir Kanal Barat, Kreo, Garang, river, sediment pollution index.

Introduction. Garang watershed stretches from the foot of Ungaran Mountain in Semarang Regency, through 3 sub-districts in Semarang Regency (Bergas, West and East Ungaran), 2 sub-districts in Semarang City (Gunung Pati and West Semarang) to the Java Sea. Garang watershed consists of 4 main rivers, namely the Kreo River, Kripik River, Garang River, and Banjir Kanal Barat (BKB) River.

The rivers of Garang watershed have various functions, such as media transportation, aquaculture, watering farmlands, drinking water resources, and tourism. Various activities around the Garang watershed caused river pollution (Ujianti et al 2018; Haeruddin et al 2019a). Studies conducted by the MMFA (2015) showed that the concentration of metals in the waters from the mouth of Garang watershed has exceeded the water quality standard for marine water and marine biota.

The Government of Semarang and Central Java has been working to control the quality of the water in the Garang watershed through the activities of the Clean Water River Program (PROKASIH), targeting the industries located around the Garang watershed. Marlena (2012) stated that the dominant industries in the target of PROKASIH Garang watershed were the metal industry (50%), food and beverage (20%), pharmaceuticals (20%), and vegetable oils, tiles, and textiles (10%). Various types of metal industry produce heavy metal waste, which can be absorbed from the water by the dissolved particulate materials, and settle in the sediment. Therefore, heavy metals accumulate in the sediment in great concentrations (Bartoli et al 2012; Fu et al 2014). The metals often detected in sediments include iron, manganese, lead, cadmium, zinc, and mercury (US-EPA 2004). The metal concentration in the sediments is usually 3 to 5 times higher than the metal concentration in the water (Bryan & Langston 1992). Therefore, the identification of various metals derived from various sources can be faster by analyzing the sediment than quantifying the metal concentration in the water (Forster & Wittmann 1981).

Sediment can store a wide range of metals in large and consistent quantities. Therefore, the sediment can be used as a reference to determine the status of pollution of dynamic waters, such as rivers and seas (Haeruddin 2006). The spread of metal concentrations in the sediment is influenced by several factors. The highest metal concentrations in the sediment are found in adjacent locations to the source of the contamination, with a high rate of sediment accumulation (ten Brink et al 1997). Some factors that may affect the distribution of pollutants in the sediment are the size of sediment grain, redox state, concentration of organic carbon, and bioturbation (Meador et al 1998). The concentration of heavy metals in the sediments is not only determined by the weathering process of rocks, but also influenced by the concentration of organic matter, the composition of minerals, and the size of mud deposit particles (Togwell 1979). The mobility and bioavailability of metal fractions in the sediment are closely related to the geochemical characteristics of sediment, among others: organic matter, sulfide, Fe-Mn oxide, and redox potential (Zhang et al 2014).

The objective of this research was to determine the concentration of heavy metals, map their distribution in the sediment of the Garang watershed, and to determine the status of sediment pollution based on the Sediment Pollution Index (SPI), according to the Haeruddin method (Haeruddin 2006).

Material and Method. The research was conducted from July to November 2019. Sediment samples were obtained from 7 stations (Figure 1), located on 3 rivers, Banjir Kanal Barat River, Garang River, and Kreo River (Figure 1). At each station, the sediment sample was collected 3 times. Sediment samples were collected using a teflon-plated grab to prevent metal contamination of the grab compound material. Each sediment sample had 1.5 kg. After the sediment sample was removed from the grab, it was placed in a plastic container and labeled.

Moreover, the plastic containers were placed into a cool box filled with ice cubes and blue ice and transported to the Laboratory of Fish Resources and Environment Management. In the laboratory, the sediment samples were placed in a freezer at −10°C. The heavy metals analyzed in this study were: Cd, Cr, Cu, Pb, and Zn. The metal concentrations in the samples were analyzed by using atomic absorption spectrophotometry (AAS) according to APHA (1989) part 3111 C: Extraction/Air-Acetylene Flame Method. The calculated concentration of each metal was expressed in $\mu g\ L^{-1}$ and refers to the appropriate calibration curve.

Metal concentration mapping in the sediment of Garang watersheds was carried out by plotting the coordinates of the sampling location of sediment into the map of the research locations and the concentration of metals in each sample. Mapping was carried out using ArcGIS software.

The SPI is set based on the modification of the arithmetic weighted formula developed by SDD (1976). The highest value of the index is 5 and the lowest value is 0. The meaning of the value is as follows (Haeruddin 2006): 4.01 to 5 - heavily contaminated (highly polluted); 3.01 to 4 - moderately polluted; 2.01 to 3 - lightly polluted; 1.01 to 2 - contaminated; 0 to 1 - not contaminated.

The index value range is obtained from simulated computer results using Microsoft Excel software. The lowest index weight value used in the simulation was 0. Each weighted index is multiplied by the quality rating of sediment from 1 to 5. The obtained index value range is then checked for its spread. If the value of the obtained index is spread normally, the index value is divided into the top percentile of 5 classes, according to the highest number of indexes. The results of the dividing index value of 0-1 are in the

1st to the 20th percentiles range, the 1.01-2 values are in the 21st to the 40th percentiles range, and so on, until the 4.01-5 index value is at the 81st to 100th percentile range.

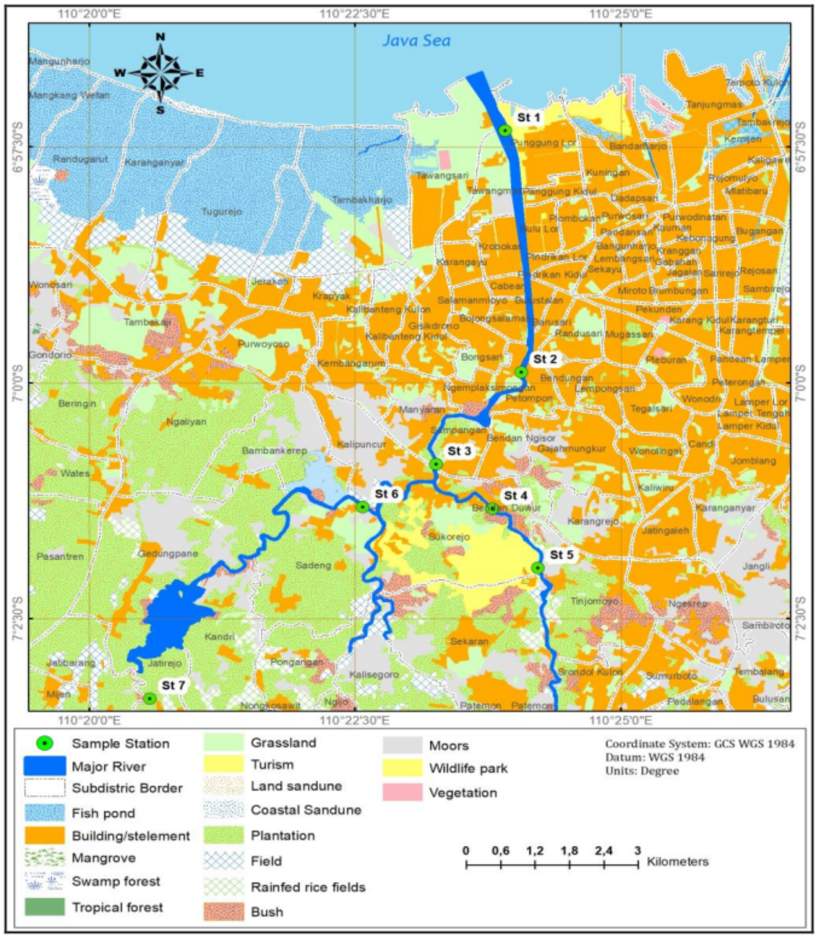

Figure 1. The location of the sediment sampling station.

The value of SPI is calculated using the following formula (Haeruddin 2006):

$$SPI = \frac{(\Sigma Q_i \times W_i)^2}{5}$$

Where: SPI - Sediment Pollution Index; Q_i – the rating of sediment quality variable i; W_i – the weight of sediment quality variable i; the variables i were: Cd, Pb, Zn, Cu, and Cr.

The SPI is the square of the summation of multiplication between the weights of all sediment quality variables with the rating of all sediment quality variables divided by 5. The weight of the sediment quality variable i is obtained through multiplication between the relative Eigen vector and the relative eigenvalue of the same main component. The relative Eigen vector feature is the result of the relative Eigen vector of the sediment feature on the main component with the sum of all the relative Eigen vector of the selected feature (i. e. the relative Eigen vector of various sediment quality changes that have a load value higher or equal to 0.7). Similarly, the relative Eigenvalue is the result of the selected value of the sediment Eigenvalue with the amount of sediment quality Eigenvalue in one particular key component. The sediment quality variable selected for index counting is sediment quality assessment with an absolute Eigenvalue greater than 0.7, as recommended by Comrey & Lee (1992).

The rating of sediment quality variable is one of the components that need to be known in the determination of the SPI, besides the weight of quality sediment. The quality rating of the sediment is carried out based on the sediment toxicity using the range from the Threshold Effect Level (TEL) to the concentration level that causes the effect - probable effect (PEL). The concentration of sediment variables below the TEL value is rated 1, between TEL and PEL, concentrations are rated 2 to 4, and concentrations above PEL value are rated 5.

The TEL and PEL values are obtained from the sediment quality guidelines from NOAA (1999) through the National Status and Trends (NS&T) Program. TEL and PEL are used to identify 3 ranges of chemical concentrations related to biological effects that are caused by water biota. The TEL can be used as interim sediment quality guidelines (ISQGs) (CCME 2001). The concentration ranges are: lower than TEL - the concentration range rarely poses a detrimental effect to freshwater biota; between TEL and PEL - the concentration range may cause adverse effects on freshwater biota; PEL - the concentration range causes adverse effects on water biota.

Based on the TEL and PEL values for the metal and organic elements of the NOAA (1999) criteria for the rating of metals were compiled (Table 1).

Table 1

Metal rating criteria

SQR	*Pb (ppb)*	*Cd (ppb)*	*Zn (ppb)*	*Ni (ppb)*	*Cr (ppb)*	*Cu (ppb)*
1	<35000	<596	<123100	<18000	<37300	<35700
2	35000<x≤ 56433	596<x≤ 1574	123100<x≤ 187067	18<x≤23967	37300<x≤ 54867	35700<x≤ 89467
3	56433<x≤ 77867	1574<x≤ 2552	187067<x≤ 251033	23967<x≤ 29933	54567<x≤ 72433	89467<x≤ 143233
4	77867<x≤ 99300	2552<x≤ 3530	251033<x≤ 315000	29333<x≤ 35900	72.433<x≤ 90000	143233<x≤ 197000
5	>99300	>3530	>315000	>35900	>90000	>197000

Note: source - NOAA (1999); SQR - sediment quality rating.

Results and Discussion. The metal concentration in sediment samples at each station is presented in Table 2. Pb had the highest concentration in the area of the Garang watersheds, followed by Cu and Cr, while Cd and Zn were not detected (Pb>Cu>Cr>Cd/Zn).

Table 2

Concentrations of different types of metals in the sediment (ppb) of 3 rivers of the Garang watershed

Location	*Limit*	*Cd (ppb)*	*Cr (ppb)*	*Cu (ppb)*	*Pb (ppb)*	*Zn (ppb)*
Banjir Kanal Barat River	Upper	0.005	11400	42700	100600	0.005
	Lower	0.005	0.005	22600	0.005	0.005
	Mean±SD	-	5333.34± 4277.56	32288,89± 7612.56	36866.67± 35400.74	-
Garang River	Upper	0.005	9500	54900	78700	0.005
	Lower	0.005	0.005	22300	0.005	0.005
	Mean±SD	-	4500± 4938.01	33483.33± 11275.71	17300± 30715.34	-
Kreo River	Upper	0.005	5000	28500	41900	0.005
	Lower	0.005	0.005	0.005	0.005	0.005
	Mean±SD	-	1266.67± 2103.96	19533.33± 11658.41	17900± 20471.05	-

Note: SD - standard deviation.

The highest Pb concentration was recorded in the BKB River and the lowest in Kreo River, a situation similar to that of Cr. Pb and Cr have similar spatial distribution patterns and differ from the Cu spatial distribution. The mapping of the metal spatial distribution at various sampling stations is presented in Figure 2.

The results of weighted and rated metal concentrations are presented in Tables 3 to 6.

Table 3

Weights and rating of various types of metals in the sediment of Garang watershed

Principal component	*Eigenvalue*	*Relative Eigenvalue*	*Metal*	*Eigen vector*	*Relative Eigen vector*	*Weight*	*Rating*
1	973180291	0.8997269	Pb	0.979	0.198379	0.178487	1.611
2	92634692	0.0856428	Cu	0.968	0.19615	0.016799	1.167
3	15824633	0.0146302	Cr	0.988	0.200203	0.002929	1
4	0	0	Zn	1	0.202634	0	1
5	0	0	Cd	1	0.202634	0	1
Total	1.082E+09	1		4.935	1		

The calculation result of the SPI is 0.0008, indicating that sediment in the Garang watershed is not contaminated by metals. The result of the calculation of the BKB River sediment pollution index is 0.0012, indicating that BKB River sediment status has been uncontaminated by metals.

Table 4

Weights and rating of various metals in Banjir Kanal Barat River sediment

Principal component	*Eigenvalue*	*Relative Eigenvalue*	*Metal*	*Eigen vector*	*Relative Eigen vector*	*Weight*	*Rating*
1	1266432796	0.9526714	Pb	0.995	0.201417	0.191884	2
2	54868873	0.041275	Cu	0.972	0.196761	0.008121	1.333
3	8047287	0.0060536	Cr	0.973	0.196964	0.001192	1
4	0	0	Zn	1	0.202429	0	1
5	0	0	Cd	1	0.202429	0	1
Total	1329348956	1		4.94	1		

The SPI value of the Kreo River is 0.0007. It indicates that the Kreo River sediment has been polluted, but with an uncontaminated status.

Table 5

The weights and rating of various types of metals in the Kreo River sediment

Principal component	*Eigenvalue*	*Relative Eigenvalue*	*Metal*	*Eigen vector*	*Relative Eigen vector*	*Weight*	*Rating*
1	1062640700	0.970602	Pb	0.941	0.217623	0.211225	1.333
2	20016464	0.018283	Cu	0.72	0.166512	0.003044	1
3	12169718	0.011116	Cr	0.663	0.15333	0.001704	1
4	0	0	Zn	1	0.231267	0	1
5	0	0	Cd	1	0.231267	0	1
Total	1.095E+09	1		4.324	1		

The result of the calculation of the Garang River sediment pollution is 0.0007. This is indicating that the Garang River sediment has been polluted with an uncontaminated status.

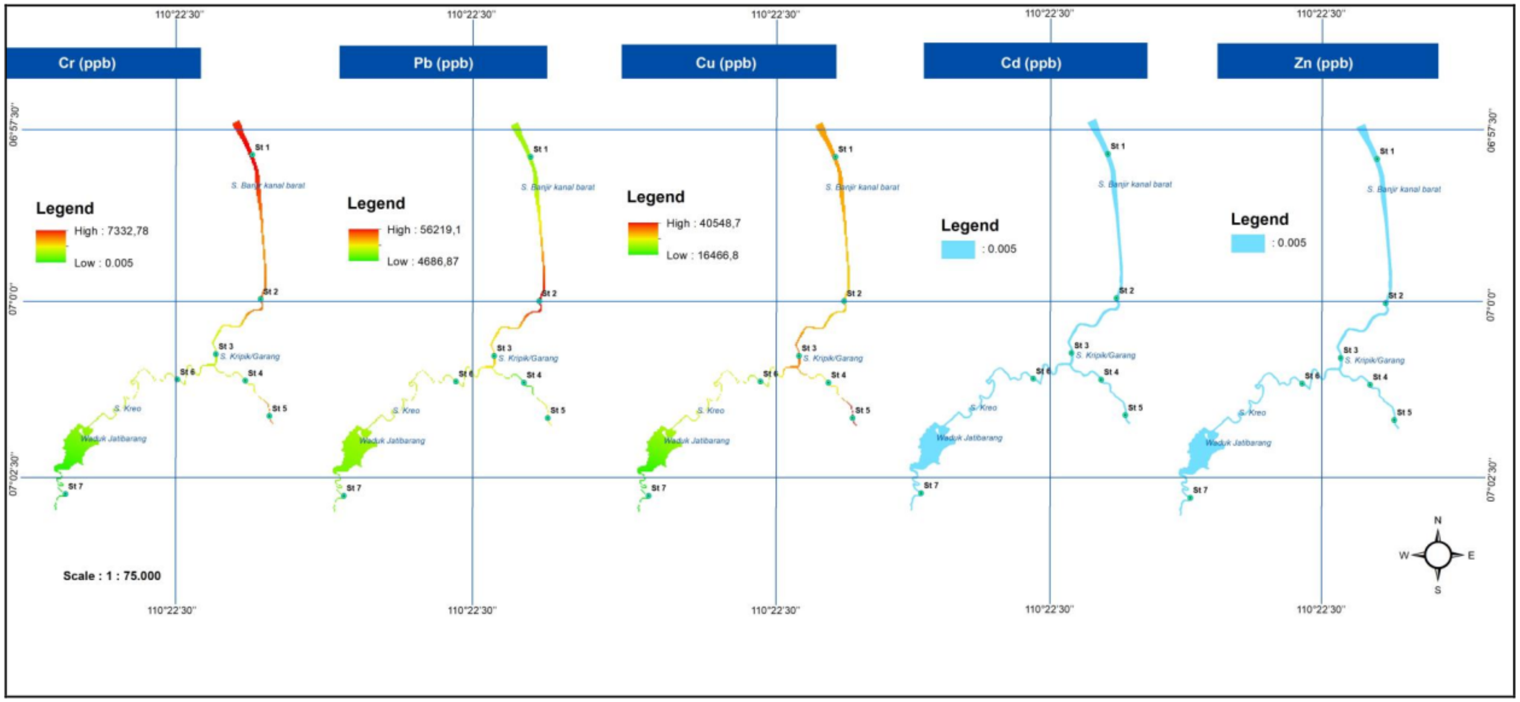

Figure 2. Spatial distribution of various metals in the sediment of the Garang watershed.

Table 6

Weights and rating of different metals in the Garang River sediment

Principal Component	*Eigenvalue*	*Relative Eigenvalue*	*Metal*	*Eigen vector*	*Relative Eigen vector*	*Weight*	*Rating*
1	973180291	0.899727	Pb	0.979	0.198379	0.178487	1.5
2	92634692	0.085643	Cu	0.968	0.19615	0.016799	1.167
3	15824633	0.01463	Cr	0.988	0.200203	0.002929	1
4	0	0	Zn	1	0.202634	0	1
5	0	0	Cd	1	0.202634	0	1
Total	1.082E+09	1		4.935	1		

The measured metal concentration in the sediment is higher than the one measured in the waters. Similar results were obtained by Gawad (2018) in his research in Lake Manzala, Egypt, and Sabbir et al (2018) for Rupsha River, Bangladesh. Bryan & Langston (1992) suggested that the metal concentration in the sediments is usually 3 to 5 times higher than the metal concentration in the water.

Cu concentration in BKB River water ranged from 0.041 mg L^{-1} to 0.5 mg L^{-1}. This concentration has exceeded the Indonesian Water Quality Standard for Freshwater Biota. The concentrations of Cd and Pb were under the detection limit (Haeruddin et al 2019a). Ujianti et al (2018) also measure the concentrations of Cr (0.007-0.025 mg L^{-1}) and Cu (undetectable - 0.15 mg L^{-1}) in the area. The concentrations of Cu and Cr in this study were lower than in the Brantas River. The average Cu and Cr concentrations in the Brantas River are 49 and 50 ppm, respectively (Mariyanto et al 2019). This is likely due to the higher intensity of activities around Brantas River compared with Garang River.

The pattern of heavy metal spread in the Garang watershed can indicate that the sources of Cr and Pb are the activities from upstream. Cu sources allegedly originate from settlements and weathering rocks around the Garang River. The Kreo River has a low concentration of some metals compared to other rivers, due to less human activity around the lower Kreo River.

Land utilization in the upstream of Garang watershed consists of rice fields, settlements, dryland agriculture (dry fields), plantations, and forests (CBS Semarang City 2018a). According to BBWS Pemali Juana (2015), the biggest land cover upstream of the Garang sub-watershed is for dryland agriculture with an area of 2772.02 Ha (33.11%), followed by settlements with 2259.34 Ha (26.99%), and rice fields with 1706.52 Ha (20.59%). The greater size of settlements indicates a functional shift upstream of the Garang River sub-watershed in Semarang regency (Efendi et al 2012). West Ungaran sub-district has a total land area of 3596.03 Ha, and 2/3 are farmland (CBS Semarang Regency 2018). The central part (Gunung Pati sub-district) is dominated by rice fields, moorings, and yards. Furthermore, the downstream (West Semarang sub-district) is dominated by yards and other uses, especially ponds (CBS Semarang City 2018a, 2018b; Wahyuningtyas et al 2017). In Gunung Pati and West Semarang sub-districts, there are also several licensed industries around the BKB River in the Simongan Industrial Area, including the pharmaceutical industry, steel pipe industry, spinning, and various other industries (Kurniawati & Rengga 2016). Agriculture, industrial and domestic wastes are the main anthropogenic sources of heavy metal in the river ecosystem and they are increasing due to the increase in population (Zhang et al 2014; Feng et al 2017; Wang et al 2017; Goher et al 2019). The heavy metal waste from various types of metal industry can be absorbed from the water by the dissolved particulate materials, settle and accumulate in the sediment in great concentrations (Bartoli et al 2012; Fu et al 2014).

The heavy metals are enriched in the sediments through adsorption, complexation, flocculation, and sedimentation (Forstner & Muller 1973; Wang et al 2016). In the event of a change in environmental conditions, the dynamic equilibrium of the water-sediment interface will be broken, and the heavy metals in the sediment will be transferred, transformed and released to the overlying water, which will lead to the pollution of water (Tao et al 2012; Zhang et al 2012; Islam et al 2015). The migration and transformation of heavy metals occur through the mechanisms of dissolution, and desorption (Duddridge & Wainwright 1981; Lin & Chen 1998). Among a variety of influential factors, pH is one of the main factors, and the effect of pH on the speciation of heavy metals is of great significance to the migration and transformation of metals (Riba et al 2004). The change of pH conditions in the system will have a certain impact on the migration and distribution of heavy metals (Gabler 1997).

Pb enters the watersheds, such as the Garang watershed, from activities like lead melting or refining, fuel combustion containing lead additives, and other metal smelting (WHO 1995). Tetraethyl lead and tetramethyl lead are widely used as additives in fuel, both volatile and difficult to dissolve in water. Trialkyl lead is formed in the environment by a tetraalkyl lead reshuffle. Trialkyl compounds are less volatile, and can easily dissolve in water.

The main natural source of Cu is the erosion of mineral rocks generally happening in the river, while the sources derived from human activities are local, especially waste disposal (Libes 1992). Cu is used for power cords and electroplating, mixed metal production, pipes, photography, anti-body stamped paint, and pesticide formulation. The sources of Cu are mining, metal smelting, refining, and coal-burning industries. Cu enters aquatic environments through natural sources, such as rock weathering or soluble Cu minerals (CCREM 1987).

Almost all hexavalent Cr in the environment comes from human activity. Cr compounds are used in manufacturing ferrochrome, metal plating (electroplating), pigment formation, and tanner. Burning fossil fuels and burning waste are a source of Cr in water and air. The Cr cycle in the environment starts from rocks and continues to soils, water, biota, air, and finally, back to the ground. Nonetheless, most Cr (estimated at 6.7x106 kg per year) is released into rivers, by runoff, piling in the seas (WHO 1988).

Metal concentrations that are generally low in sediment cause the rating value and the weight gained to be small. Low metal concentrations cause low sedimentary toxicity, so that the value of the toxic rank is generally 1. This leads to a small SPI value, less than 1. Thus, the sediment is categorized as not contaminated. This condition has been reported by Haeruddin et al (2019b), who stated that the quality of the sediments of Garang watershed is still in good condition.

Conclusions. The metal concentrations in the measured sediments varied greatly, from concentrations below the detection limit to tens of thousands of ppb. Pb had the highest concentration, followed by Cr and Cu. Cd and Zn concentrations were under the detection limit. The highest Pb concentration was obtained in the BKB River and the lowest in the Kreo River. The highest Cu concentration was in the Garang River and the lowest in the Kreo River, while the highest concentrations of Cr were in the BKB River and the lowest in the Kreo River. Pb and Cr had similar spatial distribution patterns and differed from the spatial spread of Cu. The SPI values indicate that the sediment of Garang watersheds, BKB River, Garang River, and Kreo River, were not contaminated with heavy metals.

Acknowledgments. We are very grateful to the Dean of the Faculty of Fisheries and Marine Sciences, Diponegoro University, who has funded this research by the Research Contract No. 06/UN7.5.10/PP/2019. Sincere thanks are addressed to all friends and reviewers who have assisted this study.

References

Bartoli G., Papa S., Sagnella E., Fioretto A., 2012 Heavy metal content in sediments along the Calore River: relationships with physicochemical characteristics. Journal of Environmental Management 95:S9-S14.

Bryan G. W., Langston W. J., 1992 Bioavailability, accumulation and effects of heavy metals in sediments with special reference to United Kingdom estuaries: a review. Environmental Pollution 76(2):89-131.

Comrey A. L., Lee H. B., 1992 A first course in factor analysis. 2nd edition. Lawrence Erlbaum Associates, Hillsdale, NJ, USA, 442 p.

Duddridge J. E., Wainwright M., 1981 Heavy metals in river sediments - calculation of metal adsorption maxima using Langmuir and Freundlich isotherms. Environmental Pollution Series B, Chemical and Physical 2(5):387-397.
Efendi M., Sunoko H. R., Sulistya W., 2012 [Assessment of community vulnerability to watershed-based climate change (a case study of Garang watershed)]. Journal of Environmental Science 10(1):8-18. [In Indonesian].
Feng X., Zhu X. S., Wu H., Ning C. X., Lin G. H., 2017 Distribution and ecological risk assessment of heavy metals in surface sediments of a typical restored mangrove-aquaculture wetland in Shenzhen, China. Marine Pollution Bulletin 124(2):1033-1039.
Forster U., Wittmann G. T. W., 1981 Metal pollution in the aquatic environment. 2nd edition. Springer, 486 p.
Forstner U., Muller G., 1973 Heavy metal accumulation in river sediments: a response to environmental pollution. Geoforum 4(2):53-61.
Fu J., Zhao C. P., Luo Y. P., Liu C. S., Kyzas G. Z., Luo Y., Zhao D., An S., Zhu H. L., 2014 Heavy metals in surface sediments of the Jialu River, China: Their relations to environmental factors. Journal of Hazardous Materials 270:102-109.
Gabler H. E., 1997 Mobility of heavy metals as a function of pH of samples from an overbank sediment profile contaminated by mining activities. Journal of Geochemical Exploration 58(2-3):185-194.
Gawad S. S. A., 2018 Concentrations of heavy metals in water, sediment and mollusk gastropod, *Lanistes carinatus* from Lake Manzala, Egypt. Egyptian Journal of Aquatic Research 44(2):77-82.
Goher M. E., Ali M. H. H., El-Sayed S. M., 2019 Heavy metals contents in Nasser Lake and the Nile River, Egypt: An overview. The Egyptian Journal of Aquatic Research 45(4):301-312.
Haeruddin, 2006 [Sediment integrated analysis in determining the status of Plumbon-Wakak estuary, Kendal, Central Java]. PhD Thesis, Postgraduate Program, Bogor Agricultural University, Indonesia, 213 p. [In Indonesian].
Haeruddin, Purnomo P. W., Febrianto S., 2019a Pollution load and assimilation capacity of Banjir Kanal Barat (BKB) and Bringin Estuaries in Semarang, Central Java, Indonesia. Pollution Research 38(4):870-879.
Haeruddin, Supriharyono, Ghofar A., Rahman A., 2019b The integrated quality analysis of sediment on Banjir Kanal Barat River as the basis of river environment management. Current World Environment 14(3):463-475.
Islam M. S., Ahmed M. K., Raknuzzaman M., Al Mamun M. H., Islam M. K., 2015 Heavy metal pollution in surface water and sediment: a preliminary assessment of an urban river in a developing country. Ecological Indicators 48:282-291.
Kurniawati H., Rengga A., 2016 [Implementation of Semarang City regional regulation number 14 of 2011 concerning Semarang City spatial planning 2011-2031 (case study of Simongan regional spatial planning)]. Journal of Public Policy and Management Review 5(2):349-364. [In Indonesian].
Libes S. M., 1992 An introduction to marine biogeochemistry. John Willey & Sons, New York, 752 p.
Lin J. G., Chen S. Y., 1998 The relationship between adsorption of heavy metal and organic matter in river sediments. Environment International 24(3):345-352.
Mariyanto, Amir M. F., Utama W., Hamdan A. M., Bijaksana S., Pratama A., Yunginger R., Sudarningsih, 2019 Heavy metal contents and magnetic properties of surface sediments in the volcanic and tropical environment from Brantas River, Jawa Timur Province, Indonesia. Science of The Total Environment 675:632-641.
Marlena B., 2012 [Management of DAS Garang to meet water quality in accordance with the designation]. MSc Thesis, Master of Environmental Sciences Program, Graduate School of Diponegoro University, Semarang, Indonesia, 142 p. [In Indonesian].
Meador J. P., Robisch P. A., Clark R. C., Ernest D. W., 1998 Element in fish and sediment from the Pacific Coast of the United States: result from the national benthic surveillance project. Marine Pollution Bulletin 37:56-66.

Riba I., Delvalls T. A., Forja J. M., Gomez-Parra A., 2004 The influence of pH and salinity on the toxicity of heavy metals in sediment to the estuarine clam *Ruditapes philippinarum*. Environmental Toxicology and Chemistry 23(5):1100-1107.
Sabbir W., Rahman M. Z., Hasan M. M., Khan M. N., Ray S., 2018 Assessment of heavy metals in river water, sediment and fish mussel in Rupsha River under Khulna District, Bangladesh. International Journal of Experimental Agriculture 8(1):1-5.
Tao Y., Yuan Z., Wei M., Xiaona H., 2012 Characterization of heavy metals in water and sediments in Taihu Lake, China. Environmental Monitoring and Assessment 184(7):4367-4382.
Togwell A. J., 1979 Sources of heavy metals contamination in a river-lake system. Environmental Pollution 18:131-138.
Ujianti R. M. D., Anggoro S., Bambang A. N., Purwanti F., 2018 Water quality of the Garang River, Semarang, Central Java, Indonesia based on the government regulation standard. IOP Conference Series: Journal of Physics 1025:012037, 9 p.
Wahyuningtyas A., Pahlevari J. E., Darsono S., Budieny H., 2017 [Flood control of the Bringin River on Semarang]. Journal of Civil Engineering 6(3):161-171. [In Indonesian].
Wang A., Kawser A., Xu Y., Ye X., Rani S., Chen K., 2016 Heavy metal accumulation during the last 30 years in the Karnaphuli River estuary, Chittagong, Bangladesh. SpringerPlus 5:2079, 14 p.
Wang X., Ren L. J., Jiao F. C., Liu W. J., 2017 The ecological risk assessment and suggestions on heavy metals in river sediments of Jinan. Water Science and Technology 76(8):2177-2187.
Zhang C., Yu Z., Zeng G., Jiang M., Yang Z., Cui F., Zhu M., Shen L., Hu L., 2014 Effects of sediment geochemical properties on heavy metal bioavailability. Environment International 73:270-281.
Zhang Z. B., Tan X. B., Wei L. L., Yu S. M., Wu D. J., 2012 Comparison between the lower Nansi Lake and its inflow rivers in sedimentary phosphorus fractions and phosphorus adsorption characteristics. Environmental Earth Sciences 66(5):1569-1576.
***APHA (American Public Health Association), 1989 Standard methods for the examination of water and wastewater. 17th edition. American Water Works Association, Water Pollution Control Federation, Washington DC, 3464 p.
***BBWS Pemali Juana, 2015 [Final report on the preparation of data base of Banjir Kanal Barat River, Semarang]. BBWS Pemali Juana, CV Tirta Adinugroho, 146 p. [In Indonesian].
***CBS (Central Bureau of Statistics) Semarang City, 2018a [Semarang municipality in figures 2018]. BPS Semarang City, 195 p. [In Indonesian].
***CBS (Central Bureau of Statistics) Semarang City, 2018b [Gunung Pati District in figures 2018]. BPS Semarang City, 48 p. [In Indonesian].
***CBS (Central Bureau of Statistics) Semarang Regency, 2018 [West Semarang District in figures 2018]. BPS Semarang Regency, 48 p. [In Indonesian].
***CCME, 2001 Canadian Sediment Quality Guidelines for the Protection of Aquatic Life. Available at https://www.pla.co.uk/Environment/Canadian-Sediment-Quality-Guidelines-for-the-Protection-of-Aquatic-Life
***CCREM (Canadian Council of Resource and Environmental Ministers), 1987 Canadian water quality guidelines. Environment Canada, Ottawa.
***MMFA (Ministry of Marine and Fisheries Affairs), 2015 [Final report on the compilation of pollution profiles (Coastal City of Semarang)]. Directorate General of Marine, Coastal and Small Islands, Work Unit of the Coastal and Ocean Directorate, 110 p. [In Indonesian].
***NOAA (National Oceanic and Atmospheric Administration), 1999 Sediment quality guidelines developed for national status and trend programs. NOAA, Assessment Division, Seattle, WA, 13 p.
***SDD (Scottish Development Department), 1976 Development of water quality index (report AR3). Scottish Development Department, Edinburg, UK.

***ten Brink M. B., Bothner M. H., Manheim F. T., Butman B., 1997 Contaminant metals in coastal marine sediments: a legacy for the future and a tracer of modern sediment dynamics. Proceedings of the US Geological Survey (USGS) Sediment Workshop, February 4-7, USGS, Geologic Division, Coastal, and Marine Program: Woods Hole Field Center, Woods Hole, MA 02543.
***US-EPA (United States-Environmental Agency), 2004 Contaminated sediments: major contaminated sediments. EPA-823-R-04-007.
***WHO (World Health Organization), 1988 Environmental health criteria no 61, chromium. IPCS, World Health Organization, Geneva, 197 p.
***WHO (World Health Organization), 1995 Environmental health criteria no 165, lead, inorganic. IPCS, World Health Organization, Geneva, 300 p.

Received: 27 February 2020. Accepted: 12 May 2020. Published online: 18 September 2020.
Authors:
Haeruddin, Department of Aquatic Resources, Faculty of Fisheries and Marine Sciences, Universitas Diponegoro, Prof. H. Sudarto, SH street, No. 1, Tembalang District, 50275 Semarang City, Indonesia, e-mail: haeruddindaengmile@lecturer.undip.ac.id
Supriharyono, Department of Aquatic Resources, Faculty of Fisheries and Marine Sciences, Universitas Diponegoro, Prof. H. Sudarto, SH street, No. 1, Tembalang District, 50275 Semarang City, Indonesia, e-mail: pries1950@gmail.com
Arif Rahman, Department of Aquatic Resources, Faculty of Fisheries and Marine Sciences, Universitas Diponegoro, Prof. H. Sudarto, SH street, No. 1, Tembalang District, 50275 Semarang City, Indonesia, e-mail: arifbintaryo@live.undip.ac.id
Abdul Ghofar, Department of Aquatic Resources, Faculty of Fisheries and Marine Sciences, Universitas Diponegoro, Prof. H. Sudarto, SH street, No. 1, Tembalang District, 50275 Semarang City, Indonesia, e-mail: aghofar099@gmail.com
Sigit Bayhu Iryanthony, Master Study Program of Coastal Resources Management, Department of Aquatic Resources, Faculty of Fisheries and Marine Sciences, Universitas Diponegoro, Prof. H. Sudarto, SH street, No. 1, Tembalang District, 50275 Semarang City, Indonesia, e-mail: sigitbayhuiryanthony@gmail.com

How to cite this article:
Haeruddin, Supriharyono, Rahman A., Ghofar A., Iryanthony S. B., 2020 Spatial distribution and heavy metal pollution analysis in the sediments of Garang watershed, Semarang, Central Java, Indonesia. AACL Bioflux 13(5):2577-2587.

Spatial distribution and heavy metal pollution

ORIGINALITY REPORT

14%	%	14%	%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Al-Ouran, Nedal. "Environmental assessment, documentation and spatial modeling of heavy metal pollution along the Jordan Gulf of Aqaba using coral reefs as environmental indicator", Universität Würzburg, 2005. Publication	1%
2	Yanhao Zhang, Haohan Zhang, Zhibin Zhang, Chengying Liu, Cuizhen Sun, Wen Zhang, Taha Marhaba. "pH Effect on Heavy Metal Release from a Polluted Sediment", Journal of Chemistry, 2018 Publication	1%
3	Wenzhong Tang, Baoqing Shan, Wenqiang Zhang, Hong Zhang, Lishuo Wang, Yuekui Ding. "Heavy Metal Pollution Characteristics of Surface Sediments in Different Aquatic Ecosystems in Eastern China: A Comprehensive Understanding", PLoS ONE, 2014 Publication	1%

4	He Xiao, Asfandyar Shahab, Jieyue Li, Beidou Xi, Xiaojie Sun, Huijun He, Guo Yu. "Distribution, ecological risk assessment and source identification of heavy metals in surface sediments of Huixian karst wetland, China", Ecotoxicology and Environmental Safety, 2019 Publication	1 %
5	"From Sources to Solution", Springer Nature, 2014 Publication	1 %
6	Aderonke O. Oyeyiola, Mary I. Akinyemi, Ifechukwude E. Chiedu, Oluwatoyin T. Fatunsin, Kehinde O. Olayinka. "Statistical analyses and risk assessment of potentially toxic metals (PTMS) in children's toys", Journal of Taibah University for Science, 2018 Publication	1 %
7	Trevor Dube, Grace Mhangwa, Caston Makaka, Bridget Parirenyatwa, Tinashe Muteveri. "Spatial variation of heavy metals and uptake potential by Typha domingensis in a tropical reservoir in the midlands region, Zimbabwe", Environmental Science and Pollution Research, 2019 Publication	1 %
8	The Handbook of Environmental Chemistry, 2016.	1 %

Publication

9 Jain, C.K.. "Distribution of trace metals in the Hindon River system, India", Journal of Hydrology, 20011115 1%

Publication

10 Anu Joy, P P Anoop, R Rajesh, Angel Mathew, Anu Gopinath. "Spatial Distribution and Contamination Assessment of Trace Metals in the Coral Reef Sediments of Kavaratti Island in Lakshadweep Archipelago, Indian Ocean", Soil and Sediment Contamination: An International Journal, 2019 <1%

Publication

11 Neda Tešan Tomić, Slavko Smiljanić, M. Jović, M. Gligorić, D. Povrenović, A. Došić. "Examining the Effects of the Destroying Ammunition, Mines and Explosive Devices on the Presence of Heavy Metals in Soil of Open Detonation Pit; Part 2: Determination of Heavy Metal Fractions", Water, Air, & Soil Pollution, 2018 <1%

Publication

12 Otitoloju A. Adebayo, Don - Pedro N. Kio, Oyewo O. Emmanuel. "Assessment of potential ecological disruption based on heavy metal toxicity, accumulation and distribution in media of the Lagos Lagoon", African Journal of Ecology, 2007 <1%

Publication

13	Yong Niu, Yuan Niu, Yong Pang, Hui Yu. "Assessment of Heavy Metal Pollution in Sediments of Inflow Rivers to Lake Taihu, China", Bulletin of Environmental Contamination and Toxicology, 2015 Publication	<1 %
14	Lopez-Delgado, A.. "Sorption of heavy metals on blast furnace sludge", Water Research, 199804 Publication	<1 %
15	Rohana Chandrajith. "Geochemistry of mercury in sediments from Lake Biwa in Japan", Lakes and Reservoirs Research and Management, 9/1996 Publication	<1 %
16	Zengqiang Zhang, Jim J. Wang, Amjad Ali, Ronald D. DeLaune. "Heavy metal distribution and water quality characterization of water bodies in Louisiana’s Lake Pontchartrain Basin, USA", Environmental Monitoring and Assessment, 2016 Publication	<1 %
17	Fábio Joel Kochem Mallmann, Danilo Rheinheimer dos Santos, Marcos Antonio Bender, Elci Gubiani et al. "Modeling Zinc and Copper Movement in an Oxisol under Long-Term Pig Slurry Amendments", Vadose Zone Journal, 2017	<1 %

Publication

18	Lili Cui, Jing Ge, Yindi Zhu, Yuyi Yang, Jun Wang. "Concentrations, bioaccumulation, and human health risk assessment of organochlorine pesticides and heavy metals in edible fish from Wuhan, China", Environmental Science and Pollution Research, 2015 Publication	<1 %
19	Iris R. Pit, Stefan C. Dekker, Tobias J. Kanters, Martin J. Wassen, Jasper Griffioen. "Mobilisation of toxic trace elements under various beach nourishments", Environmental Pollution, 2017 Publication	<1 %
20	P. Madejón. "Bioavailability and accumulation of trace elements in soils and plants of a highly contaminated estuary (Domingo Rubio tidal channel, SW Spain)", Environmental Geochemistry and Health, 11/08/2008 Publication	<1 %
21	P.K.S Shin, W.K.C Lam. "Development of a Marine Sediment Pollution Index", Environmental Pollution, 2001 Publication	<1 %
22	Rui Li, Xianqiang Tang, Weijie Guo, Li Lin, Liangyuan Zhao, Yuan Hu, Min Liu. "Spatiotemporal distribution dynamics of	<1 %

heavy metals in water, sediment, and zoobenthos in mainstream sections of the middle and lower Changjiang River", Science of The Total Environment, 2020
Publication

23	Xiaowen Niu, Sivaranjani Madhan, Marie A. Cornelis, Paolo M. Cattaneo. "Novel three-dimensional methods to analyze the morphology of the nasal cavity and pharyngeal airway", The Angle Orthodontist, 2021 Publication	<1 %
24	"Toxicology of Metals", Springer Science and Business Media LLC, 1995 Publication	<1 %
25	Al-Rasheid, K.A.S.. "Distribution and Abundance of Interstitial Ciliates in Southampton Water in Relation to Physicochemical Conditions, Metal Pollution and the Availability of Food Organisms", Estuarine, Coastal and Shelf Science, 199507 Publication	<1 %
26	Avni Malsiu, Ilir Shehu, Trajče Stafilov, Fatmir Faiku. "Water quality and sediment contamination assessment of the Batllava Lake in Kosovo using fractionation methods and pollution indicators", Arabian Journal of Geosciences, 2020 Publication	<1 %

27	Azza Khaled, Hoda H.H. Ahdy, El Sayed A.E. Hamed, Hamdy O. Ahmed, Fatma A. Abdel Razek, Mamdouh A. Fahmy. "Spatial distribution and potential risk assessment of heavy metals in sediment along Alexandria Coast, Mediterranean Sea, Egypt", The Egyptian Journal of Aquatic Research, 2021 Publication	<1 %
28	Caroline W. Maina, Joseph K. Sang, James M. Raude, Benedict M. Mutua. "Geochronological and spatial distribution of heavy metal contamination in sediment from Lake Naivasha, Kenya", Journal of Radiation Research and Applied Sciences, 2019 Publication	<1 %
29	Jianbo Liao, Jian Chen, Xuan Ru, Jundong Chen, Haizhen Wu, Chaohai Wei. "Heavy metals in river surface sediments affected with multiple pollution sources, South China: Distribution, enrichment and source apportionment", Journal of Geochemical Exploration, 2017 Publication	<1 %
30	R M D Ujianti, S Anggoro, A N Bambang, F Purwanti. "Water quality of the Garang River, Semarang, Central Java, Indonesia based on the government regulation standard", Journal of Physics: Conference Series, 2018	<1 %

Publication

31	Thomas P O'Connor. "The NOAA national status and trends program", Marine Pollution Bulletin, 1998 Publication	<1 %
32	Saravanan, Desmet, Neelakanta Pillai Kanniperumal, Ramasamy, Shumskikh, Grosbois. "Geochemical Footprint of Megacities on River Sediments: A Case Study of the Fourth Most Populous Area in India, Chennai", Minerals, 2019 Publication	<1 %
33	Hongbin Yin. "Distribution, sources and ecological risk assessment of heavy metals in surface sediments from Lake Taihu, China", Environmental Research Letters, 10/01/2011 Publication	<1 %
34	Rongyu Li, Guo Yu Qiu, Minwei Chai, Xiaoxue Shen, Qijie Zan. "Effects of conversion of mangroves into gei wai ponds on accumulation, speciation and risk of heavy metals in intertidal sediments", Environmental Geochemistry and Health, 2018 Publication	<1 %

Exclude quotes	On	Exclude matches	Off

Exclude bibliography On