Evaluation of the Status of Baseline Sediment Quality standardsfor Lake Sarantangan, Singkawang City, West Kalimantan

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Abstract. Gold mining activities in the Lake Sarantangan area including the Sungai Raya watershed lasted for a long time during the 18th century by Chinese workers from China, gold extraction activities using mercury and without any waste processing, thus increasing the level of sediment toxicity of Lake Sarantangan. This study aims to identify the level of sediment quality of Lake Sarantangan. Measurement of mercury concentration in sediments using the H-VG method was carried out at the Pontianak Industrial Research and Standardization Center Laboratory (BARISTAND). The measurement results show that the mercury concentration of 15 sediment samples shows a concentration value of 0.510 mg / kg - 1.30 mg / kg, from TEL (0.17 ppm), ERL, NOAA-ERL, ANZECC-ERL, ANZECC-ISQG Low, HONGKONG -ISQG Low (0.15 ppm), LEL, MET (0.2 ppm), CBTEC (0.18 ppm), EC-TEL (0.13 ppm), SQO Netherlands Target (0.3 ppm), Hong Kong ISQV-low (0.28), Slightly Elevated Stream Sediments (SESS) (0.07), the concentration of heavy metals in the sediments of Lake Sarantangan has exceeded the quality standard of 13 quality standardscausing the level of toxicity of Lake Sarantangan sediment to be higher.

INTRODUCTION

Sediment in an aquatic environment is a place for heavy metals to settle [1], this is caused by an interaction, namely the coagulation and flocculation processes to form floc which eventually settles to form sediment [2]. Heavy metal in the form of mercury is homogeneously unable to be distributed to various sizes of sediment fractions, this is because sediments in deep water environments generally have a finer fraction consisting of clay minerals, with clay minerals having a negative charge while mercury has a positive charge. so that mercury will stick to the surface of the fraction [3]. The content of heavy metals in the form of mercury in sediments is more dominant than the levels of heavy metals in water bodies [4], this is due to the deposition carried out by mercury. The size of the larger fraction gives a release effect on heavy metals so that heavy metals are not easy to stick to the surface of a larger fraction [5]. With the predominant mercury content in the sediment and in a finer fraction, to assess the quality of the waters, a finer size sediment is selected as an object of quality assessment of a waters. Low water pH conditions will cause the dissolution of metals in the waters [6] so that it enriches the metal content in waters, this will have a negative impact if the aquatic ecosystem cannot reduce it.

Heavy metals in sediments that have passed through the quality standards will affect the level of contamination, pollution, and ecological risks of a waters from a water. Mercury levels in sediment will have an impact on humans if exposed can damage the brain such as tremors, kidneys, and fetuses, vision reduction, hearing loss, and can cause disabilities such as what happened in Japan known as Minamata Deases [7]. Related to quality standards sediment, it was adopted from quality standards recommended by [8] because Indonesia had not yet had a quality guide for sediment. The concentration of mercury in the sediment will affect the level of contamination [9], the pollution load index is the polluted status of an area [10] and also affects the ecological disturbance of an area [9]. This study aims to determine the level of sediment quality of Lake Sarantang, where the level of sediment quality of Lake Sarantang will affect the toxicity of a waters.

METODOLOGY

a. Local Description

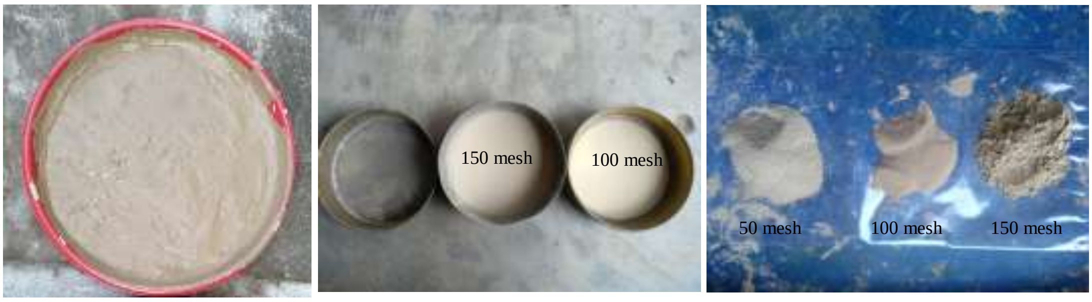
Sarantangan Lake is a natural lake with an area of 156 hectares which is part of the Sungai Raya watershed which has an upstream (upstream) in Bengkayang Regency, while Lake Sarantangan itself is included in the administrative area of Singkawang City. One of the sources of this lake is the river Raya, where illegal gold mining activities lasted for a long time from the 18th century [11]. However, mining activities are also taking place illegally in the Sarangan Lake area, increasing the pollution burden of the Lake itself. The lake is a habitat for several types of fish such as Cork fish (*Channa striata*), Tengkadak (*Barbonymus schwanenfeldii*), Biawan fish (*Helostoma temminckii*), Betutu fish (*Oxyeleotris marmorata*) and giant prawns (*Macrobrachium rosenbergii*) where all these fish are some local fishermen who have lived in the area for a long time.

b. Sediment Collection

The bottom sediment collection of Lake Sarantangan uses transportation in the form of small boats hired from local fishermen to reach 15 collection points. The lake's bottom sediment was collected by diving with the help of a plastic container, this was done because there were many lotuses on the bottom of the lake so it was not possible to use the Grap sampler. Map of points and images of Lake Sarantangan sediment collection can be seen in Figure 1.1.

c. Laboratory Testing

1. **Sample Drying**
   The drying of the sediment sample is done by making a thin layer on a pan or plastic container to accelerate drying at room temperature to prevent excessive mercury evaporation. The picture of sediment drying can be seen in Figure 1.
2. **Sifting**
   Sediment sieving was carried out in dry conditions using a sieve with sizes of 50 mesh (254 μm), 100 mesh (127 μm), and 150 mesh (84 μm). Manual sifting was carried out in the laboratory of the Public Works Office of Singkawang City, West Kalimantan. The sediment sifting image can be seen in Figure 1.



(a) (b) (c)

Figure 1. Drying (a), 100 mesh, 150 mesh sieve (b), Sifting Results (c)

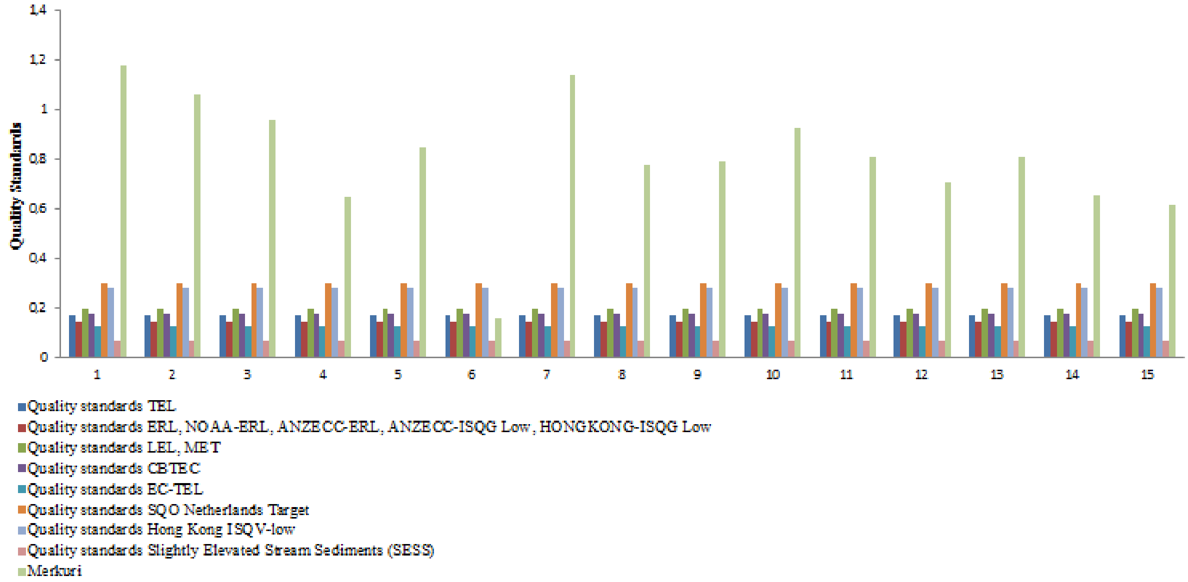
3. **Testing of Mercury Content**
   Measurement of mercury levels in the three measures of Lake Sarantangan sediment fraction using the Atomic Absorption Spectrophotometer (SSA) method equipped with a Hyride Vapor Generator (HVG) with reducing solutions of 5M HCl and 0.4% $NaBH_4$ which was carried out at the BARISTAND Laboratory (Industrial Research and Standardization Institute)) West Kalimantan Province.

d. Analysis of Mercury levels in sediments

Analysis of mercury levels in the sediment to determine the quality of sediment quality, contamination level, pollution load and risk factors using fractions with a size of 84 μm.

RESULT AND DISCUSSION

The results of testing the levels of mercury in the sediment fraction with a size of 84 µm showed that the mercury levels had passed the eight quality standards recommended [8]. As seen in Graph 1.



Graph 1. quality standardssediment at a fraction of 84 µm (150 mesh)

It appears that the mercury content has exceeded the tolerance limit recommended [8]. The high levels of mercury in the sediment represented by the 84 µm fraction will have a sustainable effect resulting in high levels of contamination, pollution load, and will affect the risk load of the ecosystem of a water. In sample 1 with a mercury concentration of 1.18 ppm, when viewed based on the quality of TEL, the concentration of mercury is 6 times higher with a range of 1.01 ppm, (ERL, NOAA-ERL, ANZECC-ERL, ANZECC-ISQG Low, HONGKONG-ISQG Low) mercury concentration 8 times higher with a range of 1.03 ppm, quality standards LEL, MET mercury concentration 6 times higher with a range of 0.98 ppm, quality standards CBTEC mercury concentration 6 times higher with a range of 1 ppm, for quality standards EC- TEL concentration was 9 times higher with a range of 1.05 ppm, in SQG Netherlands the target mercury concentration was 4 times higher with a range of 0.88 ppm, in Hong Kong ISQV-Low the concentration of mercury was 4 times higher with a range of 0.9 ppm, whereas In slightly elevated stream sediments (SESS), the mercury concentration was 17 times higher with a range of 1.11 ppm.

Sample 2 with a mercury concentration of 1.06 ppm, 6 times higher than Bakumutu TEL with a range of 0.89 ppm, mercury concentrations were 7 times higher than quality standards (ERL, NOAA-ERL, ANZECC-ERL, ANZECC-ISQG Low, HONGKONG-ISQG Low) concentrations with a range of 0.91 ppm, mercury concentration was 5 times higher than quality standards LEL, MET with a range of 0.86 ppm, mercury concentration was 6 times higher than quality standars CBTEC with a range of 0.88 ppm, mercury concentrations were 8 times higher than standard EC-TEL products with a range of 0.93 ppm, mercury concentrations were 3 times higher than the SQG Netherlands Target quality standards with a range of 0.76 ppm, mercury concentrations were 4 times higher than Hong Kong's ISQV-Low quality bakumutu with a range of 0.78 ppm, whereas In slightly elevated stream sediments (SESS), the mercury concentration was 15 times higher in the range of 0.99 ppm. Sample 3 with a mercury concentration of 0.958 ppm, when viewed based on the quality of TEL, the concentration of mercury is 5 times higher with a range of 0.788 ppm, (ERL, NOAA-ERL, ANZECC-ERL, ANZECC-ISQG Low, HONGKONG-ISQG Low) the mercury concentration is 6 times more high with a range of 0.808 ppm, mercury concentration was 5 times higher than LEL, MET quality standards with a range of 0.758 ppm, CBTEC quality standards 5 times higher mercury concentration with a range of 0.778 ppm, mercury concentrations were 7 times higher than EC-TEL quality standards with a range of 0.828 ppm, mercury concentration was 3 times higher than the SQG Netherlands Target quality standard with a range of 0.658 ppm, mercury concentration was 3 times higher than the Hong Kong ISQV-Low quality standard with a range of 0.678 ppm, while at the quality standard Slightly Elevated Stream Sediments (SESS) the concentration of mercury was 14 times higher with a range of 0.888 ppm. Sample 4 with a mercury concentration of 0.649 ppm, mercury concentration 4 times higher than the TEL quality standard with a range of 0.479 ppm, (ERL, NOAA-ERL, ANZECC-ERL, ANZECC-ISQG Low, HONGKONG-ISQG Low) mercury concentrations 4 times higher with a range of 0.499 ppm, the mercury concentration was 3 times higher than the LEL quality standard, MET with a range of 0.449 ppm, the mercury concentration was 4 times higher than the CBTEC quality standard with a range of 0.469 ppm, the mercury concentration was 5 times higher than the EC quality standard. TEL with a range of 0.519 ppm, mercury concentration 2 times higher than the SQG Netherlands Target quality standard with a range of 0.349 ppm, mercury concentration 2 times higher than the Hong Kong ISQV-Low quality standard with a range of 0.369 ppm, while the quality standard was Slightly Elevated Stream Sediments (SESS) mercury concentration was 9 times higher in the range of 0.579 ppm.

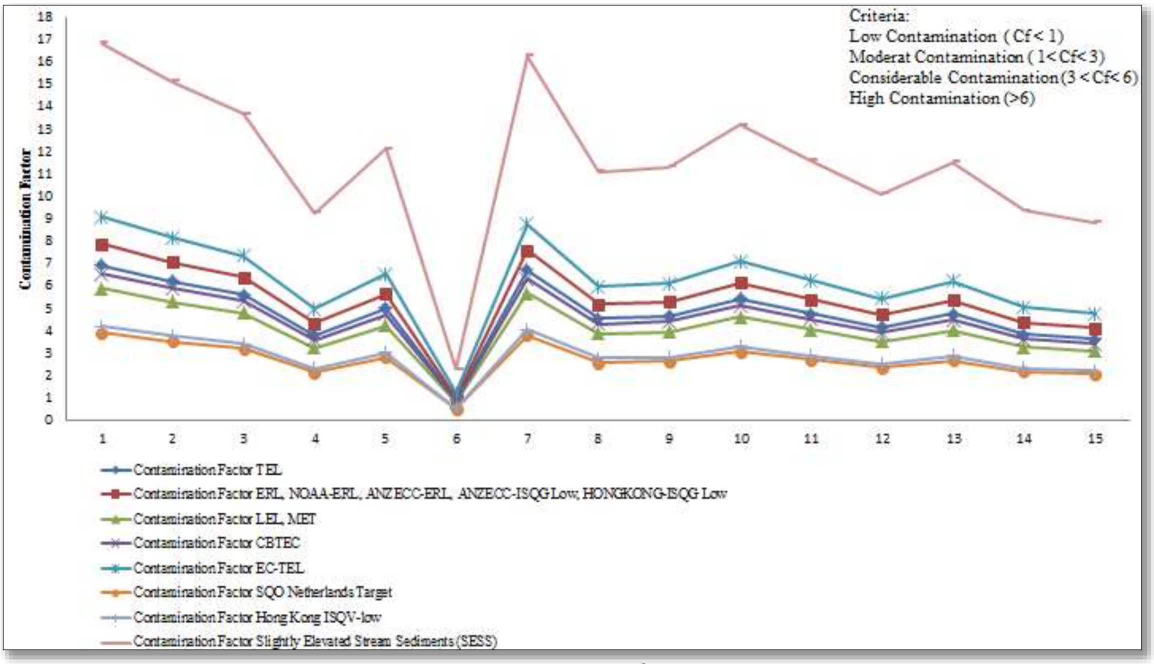
Sample 5 with a mercury concentration of 0.85 ppm, when viewed based on the TEL quality standard, the mercury concentration is 5 times higher with a range of 0.68 ppm, the mercury concentration is 6 times higher than the quality standard (ERL, NOAA-ERL, ANZECC-ERL, ANZECC -ISQG Low, HONGKONG-ISQG Low) with a range of 0.7 ppm, mercury concentrations 4 times higher than LEL quality standards, MET with a range of 0.65 ppm, mercury concentrations 5 times higher than CBTEC quality standards with a range of 0 , 67 ppm, mercury concentration was 7 folds higher than standard EC-TEL with a range of 0.72 ppm, mercury concentration was 3 times higher than the SQG Netherlands target quality standard with a range of 0.55 ppm, mercury concentration was 3 times higher than the standard. Hong Kong ISQV-Low quality with a range of 0.57 ppm, whereas In slightly elevated stream sediments (SESS), the mercury concentration was 12 times higher in the range of 0.78 ppm. Sample 6 with a mercury concentration of 0.16 ppm, when viewed based on the quality of TEL, the concentration of mercury is 1 fold lower with a range of -0.01 ppm, (ERL, NOAA-ERL, ANZECC-ERL, ANZECC-ISQG Low, HONGKONG-ISQG Low) mercury concentration 1 fold higher with a range of 0.01 ppm, quality standards LEL, MET mercury concentration 1 fold lower with a range of -0.04 ppm, quality standards CBTEC mercury concentration 1 fold lower with a range of -0.02 ppm, at quality standards EC-TEL concentration is 1 fold higher with a range of 0.03 ppm, at SQG Netherlands Target mercury concentration is 5 times lower with a range of -0.14 ppm, in Hong Kong ISQV-Low the concentration of mercury is 2 times lower with a range of -0 , 12 ppm, whereas in quality standards Slightly Elevated Stream Sediments (SESS) the mercury concentration was 2 times higher in the range of 0.09 ppm.

Sample 7 with a mercury concentration of 1.14 ppm, when viewed based on the TEL quality standard, the mercury concentration was 7 times higher with a range of 0.97 ppm, mercury concentration was 7 times higher than the quality standard (ERL, NOAA-ERL, ANZECC-ERL, ANZECC -ISQG Low, HONGKONG-ISQG Low) with a range of 0.99 ppm, mercury concentrations are 6 times higher than LEL quality standards, METs are 0.94 ppm range, mercury concentrations are 6 times higher than CBTEC quality standards with a range of 0 , 96 ppm, for EC-TEL bakumutu the concentration was 9 times higher with a range of 1.01 ppm, in SQG Netherlands the target mercury concentration was 4 times higher in the range of 0.84 ppm, in Hong Kong ISQV-Low the concentration of mercury was 4 times higher with a range of 0.86 ppm, while for the quality standard of Slightly Elevated Stream Sediments (SESS) the concentration of mercury was 16 times higher with a range of 1.07 ppm. Sample 8 with a mercury concentration of 0.777 ppm, when viewed based on TEL quality standards, the concentration of mercury is 5 times higher with a range of 0.607 ppm, (ERL, NOAA-ERL, ANZECC-ERL, ANZECC-ISQG Low, HONGKONG-ISQG Low) 5-fold mercury concentration higher with a range of 0.627 ppm, mercury concentration 4 times higher than the LEL quality standard, MET with a range of 0.577 ppm, mercury concentration 4 times higher than the CBTEC quality standard with a range of 0.597 ppm, mercury concentration 6 times higher than the quality standard EC-TEL with a range of 0.647 ppm, mercury concentration 2 times higher than the SQG Netherlands Target quality standard with a range of 0.477 ppm, mercury concentration 3 times higher than the Hong Kong ISQV-Low quality standard with a range of 0.497 ppm, while the Slightly Elevated quality standard Stream sediments (SESS) mercury concentrations were 11 times higher in the range 0.707 ppm.

Sample 9 with a mercury concentration of 0.793 ppm, when viewed based on TEL quality standards, the concentration of mercury is 5 times higher with a range of 0.623 ppm, (ERL, NOAA-ERL, ANZECC-ERL, ANZECC-ISQG Low, HONGKONG-ISQG Low) 5-fold mercury concentration higher with a range of 0.643 ppm, mercury concentration 4 times higher than LEL quality standards, MET with a range of 0.593 ppm, mercury concentrations 4 times higher than CBTEC quality standards with a range of 0.613 ppm, mercury concentration 6 times higher than quality standards EC-TEL range is 0.663 ppm, mercury concentration is 2 times higher than the SQG Netherlands Target quality standard with a range of 0.493 ppm, mercury concentration is 3 times higher than the Hong Kong ISQV-Low quality standard with a range of 0.513 ppm, while the Slightly Elevated Stream quality standard Sediments (SESS) mercury concentrations were 11 times higher in the range 0.723 ppm. Sample 10 with a mercury concentration of 0.924 ppm, when viewed based on TEL quality standards, the concentration of mercury is 5 times higher with a range of 0.754 ppm, (ERL, NOAA-ERL, ANZECC-ERL, ANZECC-ISQG Low, HONGKONG-ISQG Low) mercury concentrations of 6 times higher with a range of 0.774 ppm, mercury concentration 4 times higher than the LEL quality standard, MET with a range of 0.65 ppm, mercury concentration 5 times higher than the CBTEC quality standard with a range of 0.744 ppm, mercury concentration 7 times higher than EC-TEL quality standard with a range of 0.794 ppm, mercury concentration 3 times higher than the SQG Netherlands Target quality standard with a range of 0.624 ppm, mercury concentration 3 times higher than the Hong Kong ISQV-Low quality standard with a range of 0.644 ppm, while the quality standard Slightly Elevated Stream Sediments (SESS) mercury concentrations were 13 times higher in the range 0.854 ppm. Sample 11 with a mercury concentration of 0.811 ppm, when viewed based on TEL quality standards, the concentration of mercury is 5 times higher with a range of 0.641 ppm, (ERL, NOAA-ERL, ANZECC-ERL, ANZECC-ISQG Low, HONGKONG-ISQG Low) 5-fold mercury concentration higher with a range of 0.661 ppm, mercury concentration 4 times higher than the LEL quality standard, MET with a range of 0.611 ppm, mercury concentration 5 times higher than the CBTEC quality standard with a range of 0.631 ppm, mercury concentration 6 times higher than the quality standard EC-TEL with a range of 0.681 ppm, the concentration of mercury is 3 times higher than the SQG Netherlands Target quality standard with a range of 0.511 ppm, in Hong Kong ISQV-Low the concentration of mercury is 3 times higher with a range of 0.531 ppm, while the quality standard is Slightly Elevated Stream Sediments (SESS) mercury concentrations were 11 times higher with a range of 0.741 ppm.

Sample 12 with a mercury concentration of 0.708 ppm, when viewed based on TEL quality standards, the concentration of mercury is 4 times higher with a range of 0.538 ppm, (ERL, NOAA-ERL, ANZECC-ERL, ANZECC-ISQG Low, HONGKONG-ISQG Low) mercury concentrations of 5 times higher with a range of 0.558 ppm, mercury concentration 3 times higher than the LEL quality standard, MET with a range of 0.508 ppm, mercury concentration 4 times higher than the CBTEC quality standard with a range of 0.528 ppm, mercury concentration 5 times higher than the quality standard EC-TEL with a range of 0.578 ppm, mercury concentration 2 times higher than the SQG Netherlands Target quality standard with a range of 0.408 ppm, mercury concentration 2 times higher than the Hong Kong ISQV-Low quality standard with a range of 0.428 ppm, while the Slightly Elevated quality standard Stream sediments (SESS) mercury concentrations were 10 times higher in the range 0.638 ppm. Sample 13 with a mercury concentration of 0.808 ppm, when viewed based on TEL quality standards, the concentration of mercury is 5 times higher with a range of 0.638 ppm, (ERL, NOAA-ERL, ANZECC-ERL, ANZECC-ISQG Low, HONGKONG-ISQG Low) mercury concentration 7 times higher with a range of 0.688 ppm, mercury concentration 4 times higher than the LEL quality standard, MET with a range of 0.608 ppm, mercury concentration 4 times higher than the CBTEC quality standard with a range of 0.628 ppm, mercury concentration 6 times higher than the quality standard EC-TEL with a range of 0.678 ppm, mercury concentration 2 times higher than the SQG Netherlands quality standard High target with a range of 0.508 ppm, mercury concentration 3 times higher than the Hong Kong ISQV-Low quality standard with a range of 0.528 ppm, while at Slightly quality standards Elevated Stream Sediments (SESS) mercury concentrations were 11 times higher with a range of 0.738 ppm.

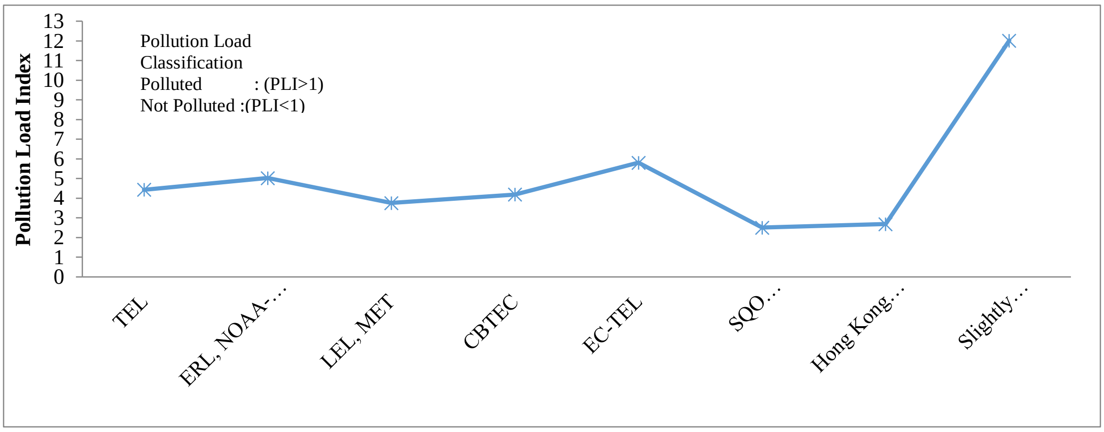
Sample 14 with a mercury concentration of 0.656 ppm, when viewed based on the quality of TEL, the concentration of mercury is 4 times higher with a range of 0.486 ppm, (ERL, NOAA-ERL, ANZECC-ERL, ANZECC-ISQG Low, HONGKONG-ISQG Low) the mercury concentration is 4 times more high with a range of 0.506 ppm, mercury concentration 3 times higher than the LEL quality standard, MET with a range of 0.456 ppm, mercury concentration 3 times higher than the CBTEC quality standard with a range of 0.476 ppm, mercury concentration 5 times higher than the EC quality standard -TEL with a range of 0.526 ppm, mercury concentration 2 times higher than the SQG Netherlands Target quality standard with a range of 0.356 ppm, mercury concentration 2 times higher than the Hong Kong ISQV-Low quality standard with a range of 0.376 ppm, while for raw slightly elevated stream sediments (SESS) mercury concentration was 9 times higher in the range of 0.586 ppm. Sample 15 with a mercury concentration of 0.619 ppm, when viewed based on TEL quality standards, the concentration of mercury is 3 times higher with a range of 0.449 ppm, (ERL, NOAA-ERL, ANZECC-ERL, ANZECC-ISQG Low, HONGKONG-ISQG Low) 4-fold mercury concentration higher with a range of 0.469 ppm, mercury concentration 3 times higher than the LEL quality standard, MET with a range of 0.419 ppm, mercury concentration 3 times higher than CBTEC quality standard with a range of 0.439 ppm, mercury concentration 5 times higher than the quality standard EC-TEL with a range of 0.489 ppm, mercury concentration 2 times higher than the SQG Netherlands Target quality standard with a range of 0.319 ppm, mercury concentration 2 times higher than the Hong Kong ISQV-Low quality standard with a range of 0.339 ppm, while the Slightly Elevated quality standard Stream sediments (SESS) mercury concentrations were 9 times higher in the range of 0.549 ppm. The value of mercury concentration in the sixth sample (6) which dominantly meets the quality standard, which originally from 8 quality standards, there are 5 quality standards that meet the quality of the environment. The high concentration of mercury in the sediment will have an impact on the value of contamination factors, risk factors, and pollution loads. An overview of the contamination value of Lake Sarangan can be seen in Figure 1. The average contamination factor status of the 15 sediment samples shows that the contamination status falls within the criteria of moderate to high. The highest contamination factor value is found in sample 1 with quality standard guidelines derived from Slightly Elevated Stream Sediments (SESS).



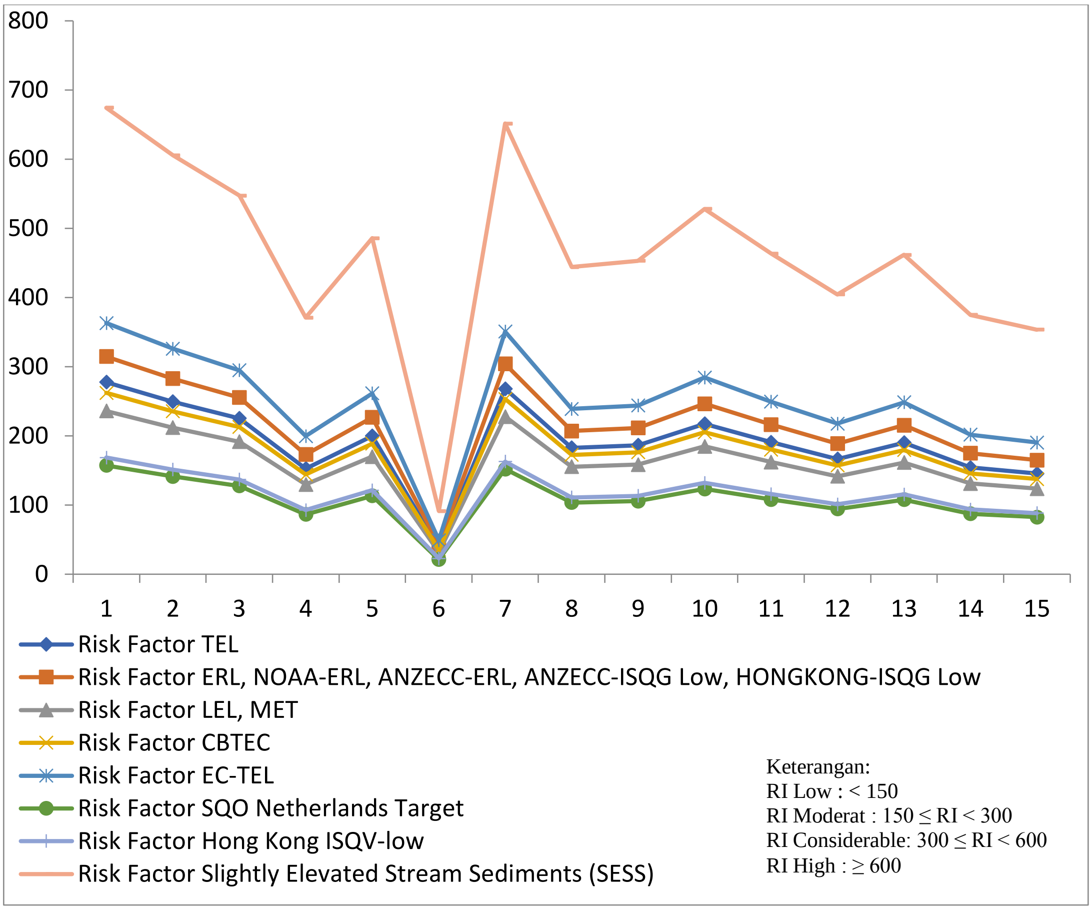
Graph 2. Contamination Factor Value at fraction 84 μm (150 mesh)

The high concentration of mercury in the sediments of Lake Sarantangan will affect the status of the level of contamination, can be seen in Figure 1. The contamination graph shows that the high level of contamination of Lake Sarantanagan is caused by gold processing activities using mercury, where the processing waste is directly disposed of in the water body. The high level of contamination in the standard standard Slightly Elevated Stream Sediment (SESS) is because the tolerance value given is lower than that of other quality standards, which is 0.07 ppm. ppm. In general, the level of contamination by Lake Sarangan is classified as medium to high. The level of contamination cannot yet determine that an area can be classified as a polluted area, but to see a polluted area or not, a pollution load index calculation can be used [10]. Judging from the pollution load index graph based on the eight (8) quality standards, Lake Sarangan is classified as polluted, but the highest polluted status of Lake Sarantangan comes from quality standards Slightly Elevated Stream Sediment (SESS) and EC-TEL.

The polluted status of Lake Sarangan which is calculated from the eight (8) quality standards has a sustainable effect on the ecology by calculating the value of risk factors. Average risk factors indicate that the potential for ecological disturbance [9] Moderate to high Lake Sarangan depends on the referred species. Ecological disturbances will affect the balance of the food chain to the ecosystem in the Sarangan Lake coverage.



Graph 3. Pollution Load Index at a fraction of 84 μm (150 mesh)



Graph 4. Risk Factor Value at fraction 84 µm (150 mesh)

CONCLUSION

Analysis of the quality status of the Lake Sarantangan sediments from the eight reference quality standards gives an idea that the mercury concentration in the sediments of Lake Sarigny has crossed the limit of quality standards which has an impact on the high level of contamination of Lake Sarigny, and provides information that the condition of Lake Sarigny is being polluted. The contamination of Sarangan Lake will affect ecological sustainability. The ecological disturbance of Lake Sarantangan has a chain effect, namely disruption of the food chain and the ecosystem in it.

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REFERENCES

[1] Peng, S.H., W.X. Wang,X. Li Andy Y.F. Yen. (2004). Metal partitioning in river sediments measured by sequential extraction and biomimetic approaches. *Chemosphere*. Vol 57 : 839-851

[2] Hammer, M.J. (2008). *Water and Wastewater Technology*. New Jersey: Pearson Prentice Hall.

[3] Solomons, W, Rooij, N.M.D, Kerdijk, H, Bril, J. (1987). Sedimens as a source for contaminants?. *Hyrobiologia Journal*. 149:13-30

[4] Syahminan. (2015). *Pollution status of heavy metals lead (Pb) and Cadmium (Cd) in sediments in western Dumai waters, Riau* [Thesis]. Bogor: IPB.

[5] Roussiez, V., Ludwig, W., Probst, J.L., Moncao, A. (2005). Background levels of heavy metals in surficial sediments of the Gulf of Lions (NW Mediterranean): An approach based on ^{133}Cs normalization and lead isotope measurements. *Journal Enviromental Pollution*, Vol 138:167-177
[6] Sucahyo, A.P.A., Waterman Sulistyana Bargawa, Muhammad Nurcholis, Teddy Agung Cahyadi. (2018). *Wetland application for acid mine water management*. Kurvatek, Vol 03; 41-46
[7] Sukandarrumidi, Maulana, F.W. & Rakhman, A.N. (2017). *Geotoksikologi*. Yogyakarta: Gadjah Mada University Press.
[8] Burton, G.A. (2002). Sediment quality criteria in use around the world. *Jurnal limnology*, Vol 3; 65-75.
[9] Hakanson, L. (1980). An Ecological Risk Index For Aquatic Pollution Control. A Sedimentological Approach. *Journal Water Research*, Vol 14: 975-1001.
[10] Tomlinson, D.L., Wilson, J.G., Harris, C.R., dan Jeffrey, D.W. (1980). Problems in the assessment of heavy-metal levels in estuaries and the formation of a pollution index. *Biologische Anstalt Helgoland*, Vol 33: 566-575.
[11] Romiyanto, Barus, B & Sudad U. (2015). A spatial model of land damage and water pollution due to unlicensed gold mining activities in the Sungai Raya watershed, West Kalimantan. *Jurnal Teknik Lingkungan*, Vol 17 (2); 47-53.