A Century long of coral records of heavy metals in coastal water of Wakatobi Marine National Park, South East Sulawesi

A A Lubis1*, A D P Putra1, U Sugiharto1, Lalang2 and N P Zamani3

1 Center for Isotopes and Radiation Applications, National Nuclear Energy Agency, Jl. Lebak Bulus Raya No 49, Jakarta 12440, Indonesia
2 Faculty of Mathematics and Natural Sciences, University of Halu Oleo, South East Sulawesi, Indonesia
3 Department of Marine Science and Technology, Faculty of Fisheries and Marine Science, IPB University, Dramaga, Bogor 16680, West Java, Indonesia

*E-mail: alilubis@batan.go.id

Abstract. Scleractinian corals absorb heavy metals in their skeletons; therefore, corals can be used as environmental recorders due to incorporating certain metals for centuries. The research was conducted in Wakatobi Marine National Park (WMNP) using a core of massive coral Porites sp. to determine heavy metals' concentrations and assess the possible impact on the coastal water. The sample was collected by drilling the coral vertically using a pneumatic tool. Annual banding was determined by using x-ray radiography, continued with sub-sampled from each band, and analyzed using an Inductively Coupled Plasma-Optical Emission Spectrometer (ICP-OES) for heavy metals determination. Enrichment Factor (EF) and Principal Component Analysis (PCA) were applied for assessing possible impact and differentiating between the heavy metals, respectively. The concentrations of heavy metals fluctuated during the period of the year 1917 to 2016, with the average concentration were 0.55 %, 0.07 %, 2.46 ppm, 3.86 ppm, 5.70 ppm, 63.22 ppm, 0.66 ppm, 3.16 ppm, 0.66 ppm, and 42.59 ppm for Sr, Mg, Mn, Ba, Cu, K, Pb, Zn, Cr, and Al, respectively. EF for all heavy metals showed that the coastal area was at the level of very small pollution (EF<2); therefore, it can be used as baseline data.

Keywords: coral, heavy metals, ICP-OES, Porites sp., X-ray radiograph

1. Introduction
Corals record environmental change due to the incorporation of certain heavy metals in their annual skeletal growth bands, which provide annual chronology. Corals are also the richest paleoclimate archives in the tropical seas. The skeletons of corals offer a powerful tool for reconstructing past climate change [1]. Corals prefer to grow in a pristine environment; however, they can be exposed to high metal concentrations due to coastal activities such as nearshore mining, harbor dredging, discharge of industrial and domestic effluents, and overpopulation [2-4]. The incorporation of heavy metals varies due to differences in solubility and the degree of absorbing trace elements into aragonite crystal lattice [3, 5]. The impact of trace metals causes lethal effects on the biological process of corals, such as metamorphosis and fertilization, respiration, and larva settlement [4, 5]. Moreover, trace metals can also result in reduced growth and biodiversity and enhanced mortality [6-8].
The WMNP was established in 1996 and became a UNESCO Biosphere reserve in 2012. The area covers 1.39 million ha comprising 97% of the sea and 3% of the land, making it the second-largest marine national park in Indonesia after Cenderawasih Bay National Park [9,10]. This region has four main islands, namely: Wangi-wangi, Kaledupa, Tomia and Binongko. The WMNP is a part of the Coral Triangle that consists of marine biodiversity hotspots known as Wallacea. The WMNP has about 396 species of hermatypic scleractinian corals and over 900 fish species [7]. This area is also situated at a transition zone between two distinct faunas connected with Australian and Asian continents, which is considered a biological and geological anomaly [8].

Heavy metals are important topics for study due to their potential ability to bioaccumulate and toxic effect in marine environments [9]. Many heavy metals have low natural levels in seawater, but their concentrations have increased in populated areas due to anthropogenic activities [9]. Accordingly, it has caused severe problems to the aquatic organism and humans [14,15]. This study was designated to assess the distribution and possible impact of heavy metals in the coastal water of WMNP. Moreover, to serve as a baseline since the data on the concentration and distribution of heavy metals are still rare in marine fauna (especially corals), and also for future comparisons of contamination by heavy metals within WMNP.

2. Materials and Methods
Living Porites sp. was obtained from Komponaone Island, adjacent to Wangi-wangi Island, WMNP, in April 2016 (Figure 1). The coral was drilled vertically using stainless steel corer with 5 cm in diameter and 50 cm in length. The corer was attached to a pneumatic drill and fed from Self-Contained Underwater Breathing Apparatus (SCUBA) diving tanks. The drilled cores were cleaned with freshwater and oven-dried at 50°C for a minimum of 5 days. Core specimens were cut with a saw to obtain slab 5 mm thickness. Prior to sub-sampling for chemical analyses, each slab was cleaned three times with milli-Q deionized water for 30 minutes in an ultrasonic bath for removing any surface contaminants and dried in an oven at 50°C for a minimum of 5 days [11]. The dried slabs were then X-rayed 40 keV for 1.5 seconds to visualize the annual banding. The x-ray was conducted in the Medical Center and Rontgen Permata Indah, Jakarta [12].

![Figure 1. The map of the studied area in Wakatobi Marine National Park, South-east Sulawesi.](image_url)

Annual banding and linear extension rates were determined from a distance between consecutive high-density bands. Sub-samples were drilled manually using a hand-held drill from each annual banding representing one year. The powders were weighed 20-25 mg and digested with 2 mL of HNO₃ 25% and 8 mL of Milli-Q deionized water. Finally, the concentrations of 10 heavy metals (Sr, Mg, Mn, Ba, Cu, K, Pb, Zn, Cr, and Al) were measured with ICP-OES radial Thermo iCAP 7400 compared quantitatively to the mix of each heavy metal of standard solution from Merck.

Corals can record environmental changes in the coastal [13], as the heavy metals are incorporated into the skeletons during growth [19-21]. Varied techniques have been applied to estimate the metal
pollutions in sediment and coral \cite{22, 23}. EF is frequently used to distinguish the different sources of metals, which can be natural or anthropogenic \cite{15}; using Al and Fe as a reference \cite{16} was calculated from the ratio in the sample and the background. The EF classification may be categorized based on the scale ranging from 1 to 7 (EF < 1 as no pollution, EF <2 as very small pollution, 2 < EF <5 as deficiency to small pollution, EF = 5 to 10 as moderate to high pollution, EF = 10 to 25 as high pollution, EF = 25 to 50 as very high pollution, and EF > 50 as exceptionally high pollution) \cite{15}.

Statistical analysis was conducted using the SPSS ver. 22 package. PCA was used for comparing the pattern between the heavy metals. Using the PCA, a small number of independent factors can be obtained by reducing a large number of correlated variables, which can be used to explain the variance in the data. Before PCA, the normality of each heavy metal was tested using One-Sample Kolmogorov-Smirnov Test. The geochemical behaviors of heavy metals were determined using Pearson correlation. Kaiser-Meyer-Olkin and Bartlett test and covariance matrix were used to validate the PCA. To further identify the geochemical behaviors of heavy metals and the contribution rate for eigenvalue > 1 in principal components, Varimax rotation was applied \cite{13}.

### 3. Results and Discussion
The X-radiograph images were used to mark annual bands and the growth of coral cores. The determination of annual growth bands of corals was determined directly along the main growth axes of a couple of high- and low-density bands. The top of the annual band was aligned to the sampling time (2016). The average thickness of the annual bands of the Porites sample was (9.8 ± 2.0) mm/year for 100 years (1917-2016).

Many trace elements are essential as they are needed in the biological processes. However, they will be potentially toxic to the biota for over the level above specific threshold concentrations. Notably, the impact of heavy metals in the marine environment includes cell growth and regeneration, the reproductive cycles, and the photosynthetic potential of marine organisms \cite{17}. The environmental conditions can be recorded in the skeleton under which the coral has grown. Accordingly, it can provide an annually resolved record related to the changed conditions through the life of the coral. The mean, standard deviation, max, and min of accumulated metal concentration of Sr, Mg, Mn, Ba, Cu, K, Pb, Zn, Cr, and Al are given in Table 1, and the vertical variations are shown in Figure 2. The average concentrations of Sr, Mg, Mn, Ba, Cu, K, Pb, Zn, Cr, and Al were 0.55%, 0.07%, 2.46 ppm, 3.86 ppm, 5.70 ppm, 63.22 ppm, 0.66 ppm, 3.16 ppm, 0.66 ppm, and 42.59 ppm, respectively. The concentration of Sr was higher than other heavy metals, whereas low concentrations of Pb and Cr were detected.

|          | Sr (%) | Mg (%) | Mn (ppm) | Ba (ppm) | Cu (ppm) | K (ppm) | Pb (ppm) | Zn (ppm) | Cr (ppm) | Al (ppm) |
|----------|--------|--------|----------|----------|----------|---------|----------|----------|----------|----------|
| Mean     | 0.55   | 0.07   | 2.46     | 3.86     | 5.70     | 63.22   | 0.66     | 3.16     | 0.66     | 42.59    |
| SD       | 0.03   | 0.01   | 0.18     | 0.58     | 0.56     | 7.84    | 0.27     | 0.41     | 0.13     | 10.70    |
| Min      | 0.47   | 0.06   | 1.97     | 2.34     | 4.28     | 47.67   | 0.17     | 2.32     | 0.30     | 21.75    |
| Max      | 0.65   | 0.09   | 2.76     | 5.99     | 7.07     | 80.37   | 1.26     | 3.96     | 1.02     | 69.83    |

Sr and Mg concentrations were range from 0.47 to 0.65% and 0.06 to 0.09% respectively. The vertical profiles of both Sr and Mg along the core from 1917 to 2016 are quite similar, slightly constant from 1917 to 1990, and continue to increase moderately until 2016. The concentrations of Sr and Mg are higher than other heavy metals; these metals are incorporated into coral skeletons as a function of their atomic radius and valence. As the cations with valence are similar to calcium (calcium carbonate), Sr and Mg are most readily incorporated into the skeleton. Ratio Sr/Ca and Mg/Ca correlate with the sea surface temperature, as these elements record the changing oceanographic conditions at seasonal to decadal time scales (paleoclimate) \cite{1}.
Figure 2. Vertical distributions of heavy metals in coral *Porites* from WMNP.

The concentrations of Mn fluctuated and were comparable to Sr and Mg before 1980 and tended to increase from 1986 to 2016. On the other hand, Ba was slightly declining from 1986 to 2016. Mn is found in the skeleton of coral proportional to the concentration in the seawater; therefore, it has a potential proxy of redox conditions and biological processes in the water column [18, 19]. Moreover, the incorporation of Mn in the coral skeleton is an indicator of detrital inputs [19]. Meanwhile, Ba depends on the concentration of fine-grained particles in the seawater, which can incorporate into the skeleton. Therefore, Ba can be used as a proxy for land-based sediment and riverine sediment flux [20].

Cu is an essential element, in small amounts, plays a role as an enzyme catalyst for the metabolism of coral [21]. The concentration of this metal ranged from 4.28 ppm to 7.07 ppm, with the average was 5.70 ppm. The profile of Cu from the bottom of coral up to the surface fluctuated around its average concentration. The vertical distribution is similar to Pb, which fluctuated at close range to the mean concentration of 0.6 ppm. Coral skeletons record local and global of Pb inputs of industrial heavy metal pollution to the oceans [22]. Contrary to Cu, Pb is the non-essential element, and it is harmful due to its polluting effects and toxicity to the marine organism. Owing to the fact that the study site is located far from the main river run-off in the estuarine area, it probably caused a low Pb value in the coral skeleton. Pb contents in the coral skeleton being influenced by river run-off, and Pb in seawater is absorbed on suspended particles by scavenging processes [23].

The average concentration of Zn was 3.16 ppm, with the minimum and maximum concentrations were 2.32 ppm and 3.96 ppm, respectively. Profile Zn along the core was comparable to Cu, which
fluctuated on its average concentration. Zn plays a vital role in the growth and cell metabolism of most animals, including corals; therefore, Zn as an element is essentially needed by living organisms [21].

The concentration of Cr varied from 0.30 ppm to 1.02 ppm with an average of 0.66 ppm. Due to its low biogeochemical mobility, Cr should reduce its toxicity potential [24]. The sources of Cr in air and water are from waste incineration, burning fossil fuels, and the industries of ferrochrome production, electroplating, pigment production, and tanning [25].

K and Al had similar vertical profiles in the fluctuation of the concentration; however, the trend of K tended to decrease from 1916 to 2016 while Al showed a vertical line at the same period. Together with Mg and Ca, K is the most abundant dissolved seawater component in relation to the formation and elemental composition of biogenic and abiogenic marine carbonates [26]. Meanwhile, Al is one of the main components of continental rock, soil and weathering products [27]. Al concentration is frequently used to normalize the other elements in order to eliminate the influence of the source of elements in the marine environment [29, 30].

**Table 2.** The enrichment factor of heavy metals in coral *Porites* from WMNP.

|        | Sr  | Mg  | Mn  | Ba  | Cu  | K   | Pb  | Zn  | Cr  |
|--------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Mean   | 0.98| 0.93| 0.90| 0.89| 1.09| 0.88| 0.84| 0.98| 1.11|
| SD     | 0.25| 0.25| 0.22| 0.24| 0.29| 0.25| 0.41| 0.27| 0.31|

**Figure 3.** Enrichment factors of heavy metals.

EF is a common method for normalizing in classifying heavy metals. The calculation of EF uses reference element Al for estimating whether the heavy metals are originated from anthropogenic activities [16]. The mean and standard deviation of EF of Sr, Mg, Mn, Cu, K, Pb, Zn, and Cr are given in Table 2 and Figure 3. Based on the average, the EF of Sr, Mg, Mn, Ba, K, Pb, and Zn are categorized as a non-pollution (EF < 1), and Cu and Cr as very small pollution (EF < 2). However, in combining with the standard deviation as shown in Figure 3, EF all metals are classified as very small pollution (EF < 2), which consider that all metals originated through anthropogenic activities with the classification of very small pollution. These EFs could correlate with the slight change in annual percent cover of hard coral massive in WMNP, which, based on the study, was conducted using remote sensing between 2009 and 2016 [29].

Based on the EF's results, the statistical analysis was conducted to identify the correlation among heavy metals for comparing the pattern between heavy metals. The results of the One-Sample Kolmogorov-Smirnov Test for all heavy metals were normal distribution (α > 0.05). The result of the Pearson correlation is shown in Table 3. The metal pairs had positive correlation (ρ<0.05): Sr-Mg (0.67), Sr-Ba (0.37), Sr-Cu (0.49), Sr-Al (0.24), Mg-Cu (0.40), Mn-Zn (0.40), Mn-Cr (0.32), Mn-Al (0.36), Ba-K (0.44), Ba-Zn (0.28), Cu-Zn (0.38), K-Zn (0.44), Zn-Cr (0.22) and Cr-Al (0.23). Meanwhile, the negative correlation was only Mn-Pb (-0.27). Based on all correlations, only Sr-Mg had a significant
correlation because they have similar geochemical behaviors. Sr-Cu, Ba-K, and K-Zn were moderate correlations, and the rest had weak correlations. The appearance of the positive correlation between metals demonstrated that they could be derived from related sources. In contrast, the negative correlation between them indicated that they could be of different geochemical behaviors and sources [30]. To distinguish the temporal behavior of heavy metals, the PCA analysis with Varimax rotation and the score of the rotated principal component space is used, and the results are given in Table 4.

**Table 3.** Pearson correlation coefficients $r$ between heavy metals in coral *Porites* from WMNP.

|   | Sr  | Mg  | Mn  | Ba  | Cu  | K   | Pb  | Zn  | Cr  | Al  |
|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Sr | 1   |     |     |     |     |     |     |     |     |     |
| Mg | 0.67* | 1   |     |     |     |     |     |     |     |     |
| Mn | 0.04 | 0.05 | 1   |     |     |     |     |     |     |     |
| Ba | 0.37* | 0.15 | -0.08 | 1   |     |     |     |     |     |     |
| Cu | 0.49* | 0.40* | 0.09 | 0.16 | 1   |     |     |     |     |     |
| K  | 0.19 | 0.20 | 0.16 | 0.44* | 0.20 | 1   |     |     |     |     |
| Pb | 0.02 | 0.14 | -0.27* | 0.03 | 0.04 | -0.03 | 1   |     |     |     |
| Zn | 0.15 | 0.05 | 0.40* | 0.28* | 0.38* | 0.44* | -0.18 | 1   |     |     |
| Cr | -0.02 | -0.07 | 0.32* | 0.01 | 0.08 | 0.17 | 0.03 | 0.20* | 1   |     |
| Al | 0.24* | 0.01 | 0.36* | 0.14 | 0.14 | 0.17 | -0.10 | 0.19 | 0.23* | 1   |

**Table 4.** Value of rotated component analysis of heavy metals in coral.

|                  | PC1  | PC2  | PC3  | PC4  |
|------------------|------|------|------|------|
| Eigenvalue       | 2.74 | 1.82 | 1.18 | 1.04 |
| % of variance    | 27.36| 18.19| 11.81| 10.40|
| Cumulative % variance | 27.36| 45.55| 57.36| 67.76|
| Sr               | 0.87 | 0.02 | 0.18 | 0.00 |
| Mg               | 0.86 | -0.05| 0.02 | 0.09 |
| Mn               | 0.07 | 0.73 | -0.03| -0.41|
| Ba               | 0.18 | -0.14| 0.87 | 0.07 |
| Cu               | 0.69 | 0.20 | 0.17 | -0.03|
| K                | 0.10 | 0.19 | 0.80 | -0.00|
| Pb               | 0.09 | -0.05| -0.02| 0.90 |
| Zn               | 0.12 | 0.41 | 0.58 | -0.34|
| Cr               | -0.13| 0.77 | 0.09 | 0.30 |
| Al               | 0.17 | 0.61 | 0.10 | -0.09|

The total variance of rotated principal components was 67.76%, with eigenvalue > 1. Rotate PC1 with an eigenvalue of 2.74 accounted for 27.36% of the variation. Rotated PC1 explained Sr, Mg, and Cu, indicating similar vertical patterns. PC2 accumulated for 18.19%, correlated with Mn, Cr, and Al. PC3 of 11.81%, and correlated with Ba, K, and Zn. Meanwhile, PC4 accumulated for 10.40%, correlated with Pb. Moreover, in the fourth component, only Pb had a large load and measurement among all other elements.
4. Conclusion

The concentrations of heavy metals in coral Porites from WMNP were ranked as follow: Sr>Mg>K>Al>Cu>Ba>Zn>Mn>Cr>Pb as the average concentrations were 0.55%, 0.07%, 63.22 ppm, 42.59 ppm, 5.70 ppm, 3.86 ppm, 3.16 ppm, 2.46 ppm, 0.66 ppm, and 0.66 ppm, respectively. The vertical profiles of all heavy metals showed no significant increase for 100 years (1917-2016). These results were verified by the enrichment factors (EF<2) were categorized as very small pollution during the same period. From both vertical profiles and EFs all heavy metals can be concluded that the coastal water of WMNP categorized in the level of very small pollutions. According to the correlation between heavy metals, a significant positive correlation was given by Sr-Mg as these metals are used for proxies related to climate change. A moderate correlation was Sr-Cu, Ba-K, and K-Zn, while the others were weak correlations. The temporal behaviors of heavy metals based on the PCA analysis expressed that Sr, Mg, and Cu in the first component, Mn, Cr, and Al in the second component, Ba, K, and Zn in the third component, and Pb in the fourth component. These different components were supported by the similarity in the vertical profiles of heavy metals in each component.

Acknowledgments

The authors are grateful to the National Nuclear Energy Agency of Indonesia for funding this research through DIPA and the support from the International Nuclear Energy Agency through National Technical Cooperation IAEA TC-INST7006 and IAEA CRP K41015. We also acknowledge the support from WMNP Authority for granting permission to conduct the research in WMNP.

References

[1] Gagan M K, Ayliffe L K, Beck J W, Cole J E, Druffel E R M, Dunbar R B and Schrag D P 2000 New views of tropical paleoclimates from corals Quat. Sci. Rev. 19 45–64
[2] Fallon S J, White J C and McCulloch M T 2002 Porites corals as recorders of mining and environmental impacts: Misima Island, Papua New Guinea Geochim. Cosmochim. Acta 66 45–62
[3] Hwang J S, Dahms H U, Huang K L, Huang M Y, Liu X J, Khim J S and Wong C K 2018 Bioaccumulation of trace metals in octocorals depends on age and tissue compartmentalization PLoS One 13 1–17
[4] Reichelt-Brushett A J and Michalek-Wagner K 2005 Effects of copper on the fertilization success of the soft coral Lobophytmum compactum Aquat. Toxicol. 74 280–4
[5] Mitchelmore C L, Verde E A and Weis V M 2007 Uptake and partitioning of copper and cadmium in the coral Pocillopora damicornis Aquat. Toxicol. 85 48–56
[6] Dunstan I and Frenke G L R 2017 the Magnificent Seven: Indonesia’s Marine National Parks ed I Dunstan and G L R Frenke (Jakarta: Ministry Environment and Forestry Indonesia, UNDP Indonesia)
[7] Haapkyli J, Seymour A S, Trebilco J and Smith D 2007 Coral disease prevalence and coral health in the Wakatobi Marine Park, south-east Sulawesi, Indonesia J. Mar. Biol. Assoc. The United Kingdom 87 403–14
[8] Horton B P, Whittaker J E, Thomson K H, Hardbattle M I J, Kemp A, Woodroffe S A and Wright M R 2005 The development of a modern foraminiferal data set for sea-level reconstructions, Wakatobi marine national park, Southeast Sulawesi, Indonesia J. Foraminifer. Res. 35 1–14
[9] Jambeck J R, Geyer R, Wilcox C, Siegler T R, Perryman M, Andrady A, Narayan R and Law K L 2015 Plastic waste inputs from land into the ocean Science 347 768–71
[10] Simul Bhuyan M 2016 Heavy Metals Status in Some Commercially Important Fishes of Meghna River Adjacent to Narsingdi District, Bangladesh: Health Risk Assessment Am. J. Life Sci. 4 60
[11] Arman A, Zamani N and Watanabe T 2013 Study to Determination the Age and Extension Rate of Corals in Related to Climate Change by X-ray J. Apl. Isot. dan Radiasi 9 1–10
[12] Arman A, Putra A D P, Shintianata D and Sugiharto U 2020 Heavy Metals in Annual Band of Skeleton Coral Platygyra sp. in Pari Island, Kepulauan Seribu: Comparison between Recent and Mid-Holocene A Sci. J. Appl. Isot. Radiat. 16 37–46
[13] Song Y, Yu K, Zhao J, Feng Y, Shi Q, Zhang H, Ayoko G A and Frost R L 2014 Past 140-year environmental record in the northern South China Sea: Evidence from coral skeletal trace metal variations Environ. Pollut. 185 97–106
[14] Shen G T and Boyle E A 1987 Lead in corals: reconstruction of historical industrial fluxes to the surface ocean Earth Planet. Sci. Lett. 82 289–304
[15] Ahamad M I, Song J, Sun H, Wang X, Mehlood M S, Sajid M, Su P and Khan A J 2020 Contamination level, ecological risk, and source identification of heavy metals in the hyporheic zone of the Weihe river, China Int. J. Environ. Res. Public Health 17
[16] Ramos R, Cipriani R, Guzman H M and Garcia E 2009 Chronology of mercury enrichment factors in reef corals from western Venezuela Mar. Pollut. Bull. 58 222–9
[17] Haynes D and Johnson J E 2000 Organochlorine, heavy metal and polyaromatic hydrocarbon pollutant concentrations in the Great Barrier Reef (Australia) environment: A review Mar. Pollut. Bull. 41 267–78
[18] Shen G T, Campbelp T M, Dunbar R B, Wellington G M, Colgan M W and Glynn P W 1991 Paleochemistry of manganese in corals from the Galapagos Islands Coral Reefs 91–100
[19] Linn L J, Delaney M L and Druffel E R M 1990 Trace metals in contemporary and seventeenth-century Galapagos coral: Records of seasonal and annual variations Geoichim. Cosmochim. Acta 54
[20] McCulloch M, Fallon S, Wyndham T, Hendy E, Lough J and Barnes D 2003 Coral record of increased sediment flux to the inner Great Barrier Reef since European settlement Nature 421 727–30
[21] Nyström M, Nordemar I and Tedengren M 2001 Simultaneous and sequential stress from increased temperature and copper on the metabolism of the hermatypic coral Porites cylindrica Mar. Biol. 138 1225–31
[22] Shen G T and Boyle E A 1988 Determination of lead, cadmium and other trace metals in annually-banded corals Chem. Geol. 67 47–62
[23] Boonkanta M, Pumijumnong and N, Pumijumnong N, Studies R, Pumijumnong and N, Pumijumnong N and Studies R 2013 Heavy metal accumulation in the skeleton of Porites lutea from Ngam Island, Trat Province, Thailand J. Environ. Res. 35 43–53
[24] Muniz P, Venturini N and Gomez-Erace M 2004 Spatial distribution of chromium and lead in the benthic environment of coastal areas of the Río de la Plata estuary (Montevideo, Uruguay) Braz. J. Biol. 64 103–16
[25] Owen R B and Sandhu N 2000 Heavy Metal Accumulation and Anthropogenic Impacts on Tolo Harbour, Hong Kong Mar. Pollut. Bull. 40
[26] Mitsuguchi T and Kawakami T 2012 Potassium and other minor elements in Porites corals: Implications for skeletal geochemistry and paleoenvironmental reconstruction Coral Reefs 31 671–81
[27] Gang X U, Jian L I U, Shaofeng P E I, Xianghuai K, Gang H U and Maosheng G A O 2015 Source identification of aluminum in surface sediments of the Yellow Sea off the Shandong Peninsula Acta Ocean. Sin. 34 147–53
[28] Lewis F G, Windom H L, Ryan J O E D and Burney L C 1990 Interpretation of Metal Concentrations in Estuarine Sediments of Florida Using Aluminum as a Reference Element Estuaries 13 227–35
[29] Azhar A, Damar A, Bengen D G and Atmadipoera A S 2018 Shallow-water habitat change detection of kaledupa island, Wakatobi National Park (Wnp) for 14 years JITKT 10 475–88 (in Bahasa Indonesia)
[30] Nour H E S and Nouh E S 2020 Using coral skeletons for monitoring of heavy metals pollution in the Red Sea Coast, Egypt Arab. J. Geosci. 13