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Effect of regional oceanographic processes to the distribution of radionuclides in the coasts of Kalimantan

W R Prihatiningsih[1]*, H Suseno[1] , M Makmur[1], M Muslim[2] and M N Yahya[1]

[1]Center for Technology of Radiation Safety and Metrology, National Nuclear Energy Agency Jalan Lebak Bulus Raya No. 49, Jakarta Indonesia
[2]Faculty of Fisheries and Marine Science, Diponegoro University, Semarang, Indonesia

Coresponding author: ayu-iu@batan.go.id

Abstract. The present status of marine radioecology condition at the coastal of Kalimantan was determined based on monitoring of the radionuclides concentration in marine compartment of West, South and East Kalimantan. The characteristicof Pacific Ocean contribute to the distribution of radionuclide in Kalimantan from the Indonesian Through Flow (ITF) that passes through the Makassar Strait. The aim of this research is to determine the concentration of radionuclides and regional oceanographic effects on the distribution of radionuclides in the coasts of Kalimantan. Gamma radionuclides activity concentration were measured using High Purity Spetrometer Gamma Detector (HPGe) that is integrated with Genie 2000 software analysis. Modelling processes and field observation from previous study become reflelction of Kalimantan regional sea characteristic. The result of this research shows that the baseline data that represented natural and antrophogenic radionuclides are comparable with other regions in Indonesia. The concentration of natural radionuclides in the sediments showed that there are no contamination of Naturally Occurring Radioactive Material (NORM) and ^{137}Cs.

1. Introduction

The management of Indonesia's marine resources cannot be separated from efforts to protect marine ecosystems from damage. Damage to marine ecosystems is caused by pollution from both the land base and sea base activities. On the other hand, the phenomenon of climate change causes an increase in sea surface temperature and acidification of sea water which has an impact on the cultivation of several types of shells and harmful to coral reefs [1][2]. Currently, there have been many studies on the impact of pollution originating from industrial activities such as heavy metals, POPs, plastics and so on [3][4][5][6][7]. Additionally, the potential threat of the entry of naturally occurring radioactive material (NORM), into the marine water environment originating from the activities of the phosphate industry, petroleum, mining and so on is currently not a concern [8][9]. Indonesia is located between the Pacific Ocean and the Indian Ocean where the mass of Pacific Ocean water flows into the Indian Ocean through Indonesian marine waters carrying radioactive contaminants originating from various nuclear activities in the world [10][11]. Furthermore, the development and operational plans of nuclear power plants in several ASEAN countries have the potential to release radioactive substances into the marine environment and eventually be able to enter Indonesian marine waters.

Among the world's oceans, radionuclide deposition in the Pacific Ocean is very complex compared to other oceans. Previous research [12] describe 68 nuclear bomb attempts carried out in the Pacific Ocean (Bikini and Enewetak) so that they produce not only local fallout but are regionally deposited in the tropospheric and trigger its spread in the Pacific Ocean to the northwest. This spread is similar to the global fall out phenomenon [12]. Conversely, the nuclear accident at Fukushima is thought to have contributed to the entry of anthropogenic radionuclides into the Pacific Ocean where radioactive material enters the marine environment, both originating from direct release and atmospheric deposition [12]. Through the Kuroshio Current, water masses containing radioactive material enter North Pacific Intermediate Water (NPIW) and through global circulation are transported by Mindanao Current to the Indonesian Through Flow (ITF) [13]. The upper thermocline water mass from the Pacific Ocean is transported to the Makassar Strait into Indonesian waters and then transported to the Indian Ocean.

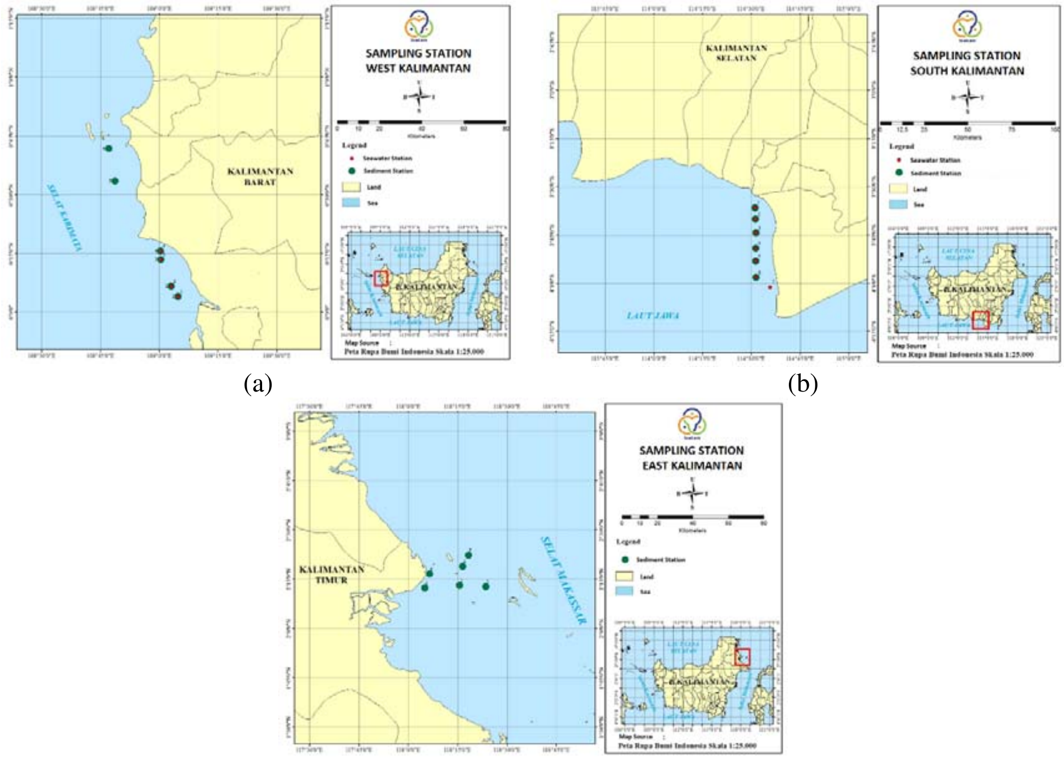
Among anthropogenic radionuclides released into the marine environment, 137Cs is an important indicator of marine environment contamination because of its conservative nature with a relatively long half-life (30 years) [14]. Thus, observation of 137Cs concentration and distribution is needed to monitor contamination in marine environment. In an effort to protect Indonesia's marine waters from the threat of the entry of radioactive substances, a limited sea water environmental monitoring program has been carried out in several Indonesian marine waters [15][16][17][18]. However, those studies do not present NORM data, other than that the role of oceanography in the distribution of radionuclides is also not discussed in depth. This study aims to comprehensively examine the effect of global oceanography on the distribution of radionuclide concentrations in Kalimantan waters. On the other hand, radionuclide data in Indonesian marine waters are still limited to concentration of 137Cs so that a comprehensive mapping of radioactive substances in Indonesian territory is absolutely necessary. Thus, the global impact of radionuclide discharges such as the Fukushima accident and regional impacts of planned nuclear power plants in Malaysia, Vietnam and several other Asian countries can be anticipated earlier.

2. Method

The environmental monitoring activity was carried out to obtain radionuclide data in the territorial waters of Kalimantan (West, South and East Kalimantan) during second quarter of 2017. Observed radionuclides were NORM and 137Cs with measurements using the main equipment Gamma Spectrometer type GX2018 Canberra and type GMX 25P4-76 Ortech equipped with Genie 2000 analytical devices.

Sampling locations as in Figures 1. A total of 2 kg of each sediment sample was taken by Grab Sampler using a random sampling method and then labeled the location and conditions when sampling. Sea surface water samples for the determination of 137Cs were taken as much as 60 l and $CuSO_4$ and $K4Fe(CN)_6$ reagents were added 10 g each. The liquid is stirred so that it is mixed homogeneously and allowed to stand for 2-3 hours until brown coagulant is deposited. After that the brown precipitate is filtered to separate from the filtrate and the precipitate is taken to the laboratory for further treatment. Biota samples were taken 5 kg each from fishermen who pulled over after sailing.

Sediment and biota samples (whole part) were dried using an oven in a laboratory at 105 ^{o}C. Drying is carried out until a constant moisture content is obtained, generally for 2-3 days. Subsequently the sediment was mashed until 0.5 micron grain uniformity was obtained and sealed in marinelli beakers for Gamma analysis measurements. Further preparation of the 137Cs analysis in seawater was carried out by drying the precipitate in filter paper as in the treatment of sediments. Measurement of natural radionuclides and 137Cs in water, sediment and biota samples using an integrated Gamma Spectrometer with a Genie 2000 analysis device with a Certified Reference Material (CRM) for quality assurance. Counting have to reach secular equilibrium condition to analyze natural radioactivity of 226Ra and 232Th. The measurement results were compared with regional radio ecological conditions and the influence of oceanography on their distribution was investigated.



(a) (b)

(c)

Figure 1. Sampling station of sediments and seawater Kalimantan: a) West; b) South; c) East.

3. Result and discussion

Kalimantan Island is division geography into West, Central, East and North Kalimantan. West Kalimantan Sea are part of the South China Sea, Natuna Sea and Karimata Strait. Geographically, the area of Central Kalimantan Province is located in the middle of the island of Kalimantan and can be used as a connecting point or interconnection between other provinces on the island of Kalimantan, and it is also close to and directly facing the Java Sea. The waters of South Kalimantan, in general, have different characteristics from eastern Indonesia seas. The South Kalimantan waters, especially of Kerumputan Island, Kotabaru Regency tend to be muddy throughout the season. The turbidity level is quite high due to many riverine inputs (run off) from the mainland to the sea. Those waters are increasingly turbid due to wave activity during southeast monsoon. The waters of Kotabaru Regency and its small islands are very dynamic because they are located between the Java Sea and the Makassar Strait [19][20]. While North Kalimantan, represented by Sebatik Island, borders the Makassar Strait.

Table 1. Natural radioactivity concentration in coastal sediment of Kalimantan.

Location	226Ra	232Th	40K
West Kalimantan	13.09 ± 0.38 - 39.27 ± 1.04	6.92 ± 0.27 - 27.48 ± 0.78	28.58 ± 01.58 - 496.06 ± 19.10
South Kalimantan	9.83 ± 0.31 - 53.46 ± 1.47	16.88 ± 0.50 - 32.91 ± 1.03	45.82 ± 02.10 - 596.83 ± 23.23
East Kalimantan	1.09 ± 0.41 - 29.80 ± 1.02	1.25 ± 0.49 - 32.28 ± 1.08	147.31 ± 06.65 - 192.93 ± 07.57

Table 2. 137Cs radioactivity concentration in seawater and sediment of Kalimantan.

Location	137Cs (Bq.m-3)	
	Sediment	Seawater
West Kalimantan	0.31 ± 0.16 - 1.26 ± 0.06	0.08 ± 0.010 - 0.73 ± 0.06
South Kalimantan	0.41 ± 0.03 - 1.06 ± 0.18	-
East Kalimantan	0.36 ± 0.17 - 2.80 ± 0.03	0.04 ± 0.001 - 1.83 ± 0.02

Table 3. 137Cs radioactivity concentration in biota from Kalimantan.

Biota	137Cs (mBq.Kg-1)
Starry triggerfish (*Abalistes stellaris*)	10.85 ± 0.97
Crimson snapper (*Lutianus erythropterus*)	170.30 ± 12.50
Squip (*Mastigoteuthis flammea*)	106.38 ± 10.11
Local crab *(Portunus sanguinolentus*)	30.52 ± 1.73

The result (Table 1) shows that the concentration of natural and radionuclides in the Kalimantan seafloor sediments, represented by 226Ra, 232Th and 40K are respectively in the range of 1.09 ± 0.41 – 53.46 ± 1.47; 1.25 ± 0.49 – 32.91 ± 1.03; 28.58 ± 01.58 – 596.83 ± 23.23 Bq.kg-1. Anthropogenic radionuclides in sediments represented by 137Cs reveal maximum value of 2.80 ± 0.03 Bq.kg-1 in East Kalimantan waters and minimum value of 0.31 ± 0.16 Bq.kg-1 in West Kalimantan waters (Table 2). The radionuclide 137Cs concentration range in the seawater of Kalimantan is 1.83 ± 0.02 - 0.040 ± 0.001 (Table 2). Measurement of the 137Cs radionuclide in four different types of biota gave varied results. The lowest concentration of 137Cs contained in Starry triggerfish (Abalistes stellaris) was 10.85 ± 0.97, while the highest concentration in Crimson snapper (Lutianus erythropterus) was 170.30 ± 12.50. Other biota such as Squid (Mastigoteuthis flammea) and Local crab (Portunus sanguinolentus) showed 137Cs concentration of 106.38 ± 10.11 and 30.52 ± 1.73 Bq.kg-1, respectively (Table 3). The results of the study in Tables 1,2,3 compared to previous studies on natural and anthropogenic radionuclide both in Indonesian waters and regional waters provide comparable results [21][22][23][24][25][9][15][26]

Table 4. Worldwide radioactivity of natural and anthropogenic radionuclide in sediment (Bq.kg-1).

Area (Ref)	Matrix sample	226Ra	232Th	40K	137Cs
Malaysia [27]	Sediment	51	22	189	-
Northern Coast Oman Sea, Iran [21]	Sediment	14.96 ± 2.23	17.61 ± 3.23	361.6 ± 81.30	0.79 ± 0.59
South West Coast, India [22]	Sediment	68.4	77.2	344.9	-
Coastal of Saudi Arabian gulf [23]	Sediment	11.3	6.7	153.8	0.3
Coast of Xiamen Island, China [28]	Sediment	25.7	41.4	487.6	-
Sarawak, Malaysia [25][9]	Sediment	-	-	142 – 680	<MDA - 7.92
Andaman beach, Thailand [26]	Sediment	1.6 – 83.1	0.3 – 73.9	2.8 - 1376	-

The distribution of anthropogenic radioactive substances in various regions of Indonesia's marine waters is influenced by the geographical location of the aquatic environment. The input of anthropogenic radioactive substances including in Kalimantan Sea comes from the seawater of the Pacific Ocean because there is no significant nuclear activity in Indonesia. According to [29], the source of radioactive substances in the Pacific Ocean and Indian Ocean comes from the global fallout of nuclear weapons experiments in the past. The accident in Fukushima contributed 137Cs in the amount of 2.8-4.2 PBq (release directly to the sea) and 12-15 PBq (atmospheric) to the Pacific Ocean through the Kuroshio Current [30]. The Pacific Ocean is a source of water mass in the Indonesian sea waters whose its entry process is affected by the current of the Pacific Ocean, known as the Indonesian Through Flow (ITF/ITF) [31]. The main sources of this circulation are the South Pacific currents (South Equatorial Currents, SEC) and the North Pacific Currents (North Equatorial Currents, NEC). NEC currents in the northern hemisphere move westward then at 14º N splitting into two moving north and south. The current that moves north becomes Kuroshio heading into Japanese waters and the current that goes south becomes the Mindanao current [31]. The SEC current in the southern hemisphere is moving: (1) westward then at 15° S splitting along the Great Barrier Reef and will become the Great Barrier Reef Undercurrents (GBRUC). The GBRUC current moves along the coast of Papua New Guinea into The New Guinea Coastal Undercurrents (NGCUC). (2) Southward becomes the current of East Australia (East Australia Currents, EAC). The water mass of the NGCUC thermocline layer moves eastward to: Equatorial Undercurrents (EUC), some to North Equatorial Countercurrents (NECC), some to North Subsurface Counter Currents (NSCC) and some cross to the Indonesian seas and thought to enter through the Halmahera Sea. The water mass from the SEC also enter the Indonesian archipelago through the Torres Strait and into the Arafura Sea. The Mindanao current moves south partly into the Sulawesi Sea and partly interacts with the South Equatorial Current (SEC) [31]. The Mindanao current that entered the Sulawesi Sea partly entered the Makassar Strait which is part of Kalimantan Sea and partly deflected east along the north coast of Sulawesi and finally into the Halmahera Sea.

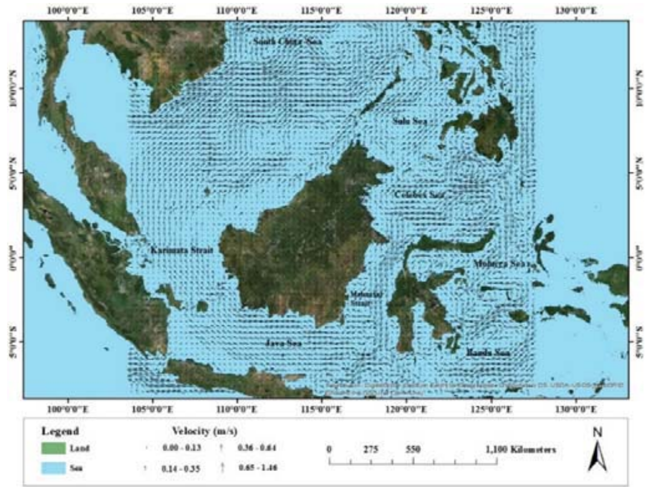


Figure 2. Dynamical current surrounding Kalimantan on Southeast Monsoon.

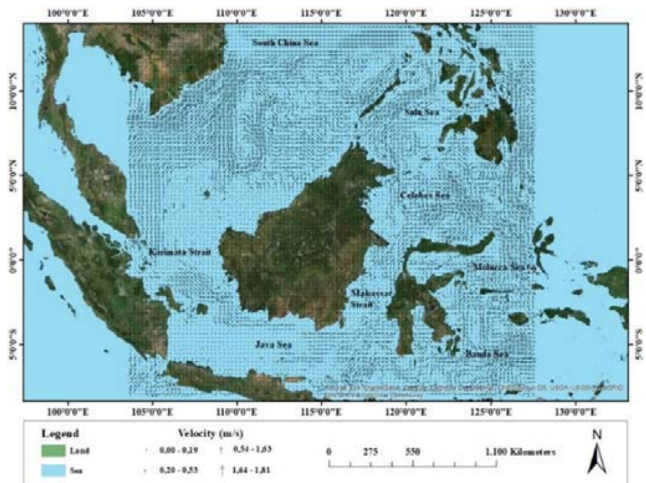


Figure 3. Dynamical current surrounding Kalimantan on West Monsoon.

The dynamics of the Indonesian Through Flow are very much affected by the season and have high variability (Figure 2 and 3). During the southeast monsoon the tide is strong, and during the west monsoon the tide weakens. At the surface layer the water mass dynamics of the cross current water is influenced by surface winds. During the southeast monsoon surface water masses move from the Banda Sea to the Flores Sea, then continue the passage to the Java Sea as part of south sea of Kalimantan and finally to the South China Sea. During the west monsoon the water mass moves from the Malacca Strait as part of west sea of Kalimantan then through Java Sea into the Flores Sea and finally into the Banda Sea.

The monitoring results showed there was no 134Cs radionuclides found in water, sediments and biota from Kalimantan. Based on the results, the value of the ratio of 134Cs and 137Cs is 0 which is a character of global fallout. The waters of Kalimantan are affected by the water mass originating from the Makassar Strait and the water mass of the South China Sea. In the Indonesian sea current system, water mass transportation from north Kalimantan to Luzon Island is part of Mindoro transportation. Upon reaching the Java Sea, part of the seawater of South China Sea Through Flow (SCSTF) joins with water from the Makassar Strait. South China Sea (SCS) water mass enters the Indonesian sea through the Luzon Strait leading to the Karimata Strait. The currents around Kalimantan and the Philippines modulate upper layer circulation in the Makassar Strait and can extend to the Banda Sea. South China Sea (SCS) water mass has been detected in part of Kalimantan waters. The South China Sea is a semi-closed tropical sea located between mainland Asia in the north and west, the Philippine Islands in the east, Kalimantan in the southeast, and Indonesia in the south (Chu & Lu, 1998). Contrastingly, the waters of East Kalimantan show the character of ITF thermocline water from the Makassar Strait. According to [32] ITF Makassar annual cycle at 3 depth levels representing mixed layers (25 m), thermocline (92 m) and bottom thermocline (318 m) shows a consistent flow pattern. ITF flow patterns along its main axis are following the slope of the seabed topography along the western edge of the strait. From the north entrance of the strait, the ITF leads southwest to around 2° S latitude. Then, the flow turns to the southeast along the slopes of the narrow shelf of Kalimantan. Based on this, the 137Cs are derived from the water mass of the South China Sea thermocline. Therefore, because it comes from the global fallout, the concentration is quite comparable.

4. Conclusion

Natural radionuclide concentrations in sediments indicate on a background level or no NORM and no anthropogenic radionuclide (137Cs) contamination in sea water, sediments and biota. Based on an analysis of regional sea current mechanisms, radionuclides in seawater of Kalimantan derived from global fall out. The Kalimantan sea water base data represented by the West, South and East Kalimantan regions are worldwide comparable to other regions in Indonesia and other regional regions.

References

[1] Wendling C C, Huhn M, Ayu N, Bachtiar R, Juterzenka K von and Lenz M 2013 Habitat degradation correlates with tolerance to climate-change related stressors in the green mussel Perna viridis from West Java, Indonesia *Mar. Pollut. Bull.*

[2] Lacoue-Labarthe T, Nunes P A L D, Ziveri P, Cinar M, Gazeau F, Hall-Spencer J M, Hilmi N, Moschella P, Safa A, Sauzade D and Turley C 2016 Impacts of ocean acidification in a warming Mediterranean Sea: An overview Reg. *Stud. Mar. Sci.*

[3] Lillicrap A, Springer T and Tyler C R 2016 A tiered assessment strategy for more effective evaluation of bioaccumulation of chemicals in fish *Regul. Toxicol. Pharmacol.*

[4] Danis B, Cattini C, Teyssié J L, Villeneuve J P, Fowler S W and Warnau M 2006 Coplanar and non-coplanar congener-specificity of PCB bioaccumulation and immunotoxicity in sea stars *Aquat. Toxicol.* **79** 105–13

[5] Hosono T, Su C C, Delinom R, Umezawa Y, Toyota T, Kaneko S and Taniguchi M 2011 Decline in heavy metal contamination in marine sediments in Jakarta Bay, Indonesia due to increasing environmental regulations *Estuar. Coast. Shelf Sci.*

[6] Bryan G W and Langston W J 1992 Bioavailability, accumulation and effects of heavy metals in sediments with special reference to United Kingdom estuaries: a review *Environ. Pollut.*

[7] Andral B, Stanisiere J Y, Sauzade D, Damier E, Thebault H, Galgani F and Boissery P 2004 Monitoring chemical contamination levels in the Mediterranean based on the use of mussel caging *Mar. Pollut. Bull.*
[8] Ahmad N, Jaafar M S, Bakhash M and Rahim M 2015 An overview on measurements of natural radioactivity in Malaysia *J. Radiat. Res. Appl. Sci.* **8** 136–41
[9] Yii M W, Zaharudin A and Abdul-Kadir I 2009 Distribution of naturally occurring radionuclides activity concentration in East Malaysian marine sediment *Appl. Radiat. Isot.* **67** 630–5
[10] Gordon A L and Kamenkovich V M 2010 "Modeling and Observing the Indonesian Throughflow" a special issue of dynamics of atmosphere and ocean *Dyn. Atmos. Ocean.* **50** 113–4
[11] Rosenfield D, Kamenkovich V, O'Driscoll K and Sprintall J 2010 Validation of a regional Indonesian Seas model based on a comparison between model and INSTANT transports *Dyn. Atmos. Ocean.* **50** 313–30
[12] Duran E B, Povinec P P, Fowler S W, Airey P L and Hong G H 2004 137Cs and 239+240Pu levels in the Asia-Pacific regional seas *Journal of Environmental Radioactivity*
[13] Povinec P P, Aoyama M, Fukasawa M, Hirose K, Komura K, Sanchez-Cabeza J A, Gastaud J, Ješkovský M, Levy I and Sýkora I 2011 137Cs water profiles in the South Indian Ocean - An evidence for accumulation of pollutants in the subtropical gyre *Prog. Oceanogr.*
[14] Figueira R C L, Tessler M G, De Mahiques M M and Cunha I I L 2006 Distribution of 137Cs, 238Pu and 239 + 240Pu in sediments of the southeastern Brazilian shelf-SW Atlantic margin *Sci. Total Environ.*
[15] Suseno H and Prihatiningsih W R 2014 Monitoring137Cs and134Cs at marine coasts in Indonesia between 2011 and 2013 *Mar. Pollut. Bull.* **88** 319–24
[16] Suseno H, Wahono I B and Muslim 2015 Radiocesium monitoring in Indonesian waters of the Indian Ocean after the Fukushima nuclear accident *Mar. Pollut. Bull.* **97** 539–43
[17] Suseno H, Wahono I B, Muslim M and Yahya M N 2017 Status of 137Cs concentrations in sea water at the inlets of the Indonesian Through Flow (ITF) *Reg. Stud. Mar. Sci.* 10
[18] Suseno H and Wahono I B 2018 Present status of 137Cs in seawaters of the Lombok Strait and the Flores Sea at the Indonesia Through Flow (ITF) following the Fukushima accident *Mar. Pollut. Bull.*
[19] Salim D, Yuliyanto Y and Baharuddin B 2017 Karakteristik parameter oseanografi fisika-kimia perairan Pulau Kerumputan Kabupaten Kotabaru Kalimantan Selatan *J. Enggano*
[20] Kusumawati 2015 pemetaan batimetri untuk mendukung alur pelayaran di perairan Banjarmasin, Kalimantan Selatan *J. Oceanogr.*
[21] Darabi-Golestan F, Hezarkhani A and Zare M R 2017 Assessment of226Ra,238U,232Th,137Cs and40K activities from the northern coastline of Oman Sea (water and sediments) *Mar. Pollut. Bull.* **118** 197–205
[22] Karunakara N, Somashekarappa H M and Siddappa K 2005 Natural radioactivity in South West Coast of India *Int. Congr. Ser.* 1276 346–7
[23] Al-Ghamdi H, Al-Muqrin A and El-Sharkawy A 2016 Assessment of natural radioactivity and 137Cs in some coastal areas of the Saudi Arabian gulf *Mar. Pollut. Bull.* **104** 29–33
[24] Huang Y, Lu X, Ding X and Feng T 2015 Natural radioactivity level in beach sand along the coast of Xiamen Island, China *Mar. Pollut. Bull.*
[25] Yii M W, Zaharudin A and Norfaizal M 2007 Concentration of radiocaesium 137Cs and 134Cs in sediments of the Malaysian marine environment *Appl. Radiat. Isot.* **65** 1389–95
[26] Malain D, Regan P H, Bradley D A, Matthews M, Al-Sulaiti H A and Santawamaitre T 2012 An evaluation of the natural radioactivity in Andaman beach sand samples of Thailand after the 2004 tsunami *Appl. Radiat. Isot.* **70** 1467–74
[27] Muhammad B G, Jaafar M S, Rahman A A and Ingawa F A 2012 Determination of radioactive elements and heavy metals in sediments and soil from domestic water sources in northern peninsular Malaysia *Environ. Monit. Assess.* **184** 5043–9
[28] Huang Y, Lu X, Ding X and Feng T 2015 Natural radioactivity level in beach sand along the coast of Xiamen Island, China *Mar. Pollut. Bull.* **91** 357–61

[29] Povinec P P, Aarkrog A, Buesseler K O, Delfanti R, Hirose K, Hong G H, Ito T, Livingston H D, Nies H, Noshkin V E, Shima S and Togawa O 2005 90Sr, 137Cs and 239,240Pu concentration surface water time series in the Pacific and Indian Oceans - WOMARS results *J. Environ. Radioact*. **81** 63–87

[30] Kaeriyama H 2017 Oceanic dispersion of Fukushima-derived radioactive cesium: a review *Fish. Oceanogr.*

[31] Gordon A L, Huber B A, Metzger E J, Susanto R D, Hurlburt H E and Adi T R 2012 South China Sea throughflow impact on the Indonesian throughflow *Geophys. Res. Lett.*

[32] Atmadipoera A, Molcard R, Madec G, Wijffels S, Sprintall J, Koch-Larrouy A, Jaya I and Supangat A 2009 Characteristics and variability of the Indonesian throughflow water at the outflow straits Deep. *Res. Part I Oceanogr. Res. Pap*. **56** 1942–54

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