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Vertical Distribution of Microplastics in Coastal Sediments of Bama Resort, Baluran National Park, Indonesia

Muhammad A. Asadi*†, Yody A.P. Ritonga*, Defri Yona* and Asus M.S. Hertika**

*Department of Marine Science, Faculty of Fisheries and Marine Science, University of Brawijaya, Malang 65145, Indonesia

**Department of Water Resources Management, Faculty of Fisheries and Marine Science, University of Brawijaya, Malang 65145, Indonesia

†Corresponding author: Muhammad A. Asadi

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ABSTRACT

Microplastic pollution is widely reported in different marine environments from shorelines to seabed of deep seas which pose an emerging threat to entire marine ecosystems. As the world's second-largest microplastics polluter, an understanding of the distribution of this type of pollution is important for the measurement of the magnitude of environmental risk. In the present study, the abundance and distribution of microplastics in coastal sediments of Bama Resort, Baluran National Park were measured at depths of 0-10 cm, 10-20 cm, and 20-30 cm. Microplastics characterization was performed using a modified flotation method while a sieve analysis was used to assess the particle size of the sediments. Results showed that there were 484 particles with a total average abundance of 116.41 ± 80.78 particles kg^{-1} DW. Fibres shared 37.8% of the total microplastics found with overall average of 43.71 ± 36.52 particles kg^{-1} DW. Overall, Tukey's multiple comparisons test showed significant differences ($P< 0.01$) in vertical distribution of microplastics in which 55.46% of particles were found at the depths of 0-10 cm, whereas at the depths of 20-30 cm, the proportion was only 15.95%. There were two types of sediments, sandy gravel and gravelly sand in which the former type of sediments holds higher microplastic particles due to its grain dominance in upper sediments. These results imply that microplastics pollute coastal sediments of Bama Resorts, BNP, and their deposition increase over time as greater microplastics frequencies were observed in upper and more recent sediment.

INTRODUCTION

In the modern era, plastic material is used in an array of products of different forms, including toys, furniture, and spacecraft as it has many incredible properties such as high strength and durability, versatile, and lightweight (Ling et al. 2017, Martin et al. 2017, Tanaka & Takada 2016). Although the benefits of using plastic products are undeniable, there are adverse effects of plastic pollution in the environment (Van Cauwenberghe et al. 2015). Millions of tons of plastic debris are currently in the marine environment from coastlines to the deep-sea, and by 2025, plastic items in the ocean are expected to accumulate by an order of magnitude (Jambeck et al. 2015, Martin et al. 2017).

In marine environment, larger plastics debris degrade into smaller pieces known as fragmentation. Over time, these plastics begin to weather due to wave action, heat, and photodegradation by ultraviolet radiation wherein those factors can breakdown the structural integrity of plastic debris and reduce to a much smaller size known as secondary microplastics. Meanwhile, plastic particles that are originally manufactured to the size of microplastics (defined as plastics <5mm) are known as primary microplastics (Andrady 2011, Laglbauer et al. 2014, Tanaka & Takada 2016).

A recent study suggests that Indonesia is second only to China as the world's largest contributor to plastic pollution in the ocean. Microplastics are even presented in the pristine area of deep-sea sediment of Western Sumatera at depth of more than 2000 meter (Cordova & Wahyudi 2016). In Bintan Island, Riau Islands Province, Indonesia, 0.45 pieces per m^3 float in 11 beach stations around the island (Syakti et al. 2018). However, as the world's second-largest plastics polluter as well as the world's largest archipelago state with about 3.3 million km^2 of territorial seas (Cordova & Wahyudi 2016, Göltenboth & Erdelen 2006), there still little is known on the microplastics distribution and abundance in most areas of Indonesia.

In Java Island, fishing activities, population growth, and industrializations of coastal areas make its intertidal areas particularly susceptible to microplastics accumulation (Manalu et al. 2017). Therefore, the measurement of microplastics abundance and distribution in Indonesian coastal areas is essential. In this study, microplastics pollution in coastal sediments of Bama Resort, Baluran National Park (BNP) was examined. The park is a nature reserve area which may have a low anthropogenic stressor and microplastics input from its terrestrial area. Therefore, this research is expected to reveal to what extent microplastics distribute in coastal sediments of Java Island. The types of microplastic (fibre/line, foam, pellet, film and fragment) are determined to reveal the dominant types of microplastics in the research station. Particle size analysis of the sediment was also conducted to determine the link between sediment types and microplastics distribution and abundance in coastal sediments of Bama Resort, BNP.

MATERIALS AND METHODS

Description of the study area: The present study was conducted at the intertidal area of Bama resort, BNP. The park is a nature reserve located at the north-eastern extremity of Java with latitude between 7°15'S and 7°45'S and longitude between 114°18'E and 114°27'E (Sabarno 2001). It has a total area of 25,000 ha in which tropical Savannas cover about 40% of the total area. BNP has a long dry period of monsoon (8 months) with precipitation ranges from 900 to 1,600 mm per year (Hernowo et al. 2011, Macdonald & Frame 1988, Wianti 2014). BNP has gained National Park status since 1980 (Van Balen et al. 1995, Wianti 2014), and in 2016, BNP was declared as one of the UNESCO's world network of biosphere reserves (UNESCO 2016). In 26th December 2012, the Directorate General of Nature Protection and Conservation of Indonesia has divided BNP into several zones where the intertidal area of Bama resort is included in marine protected area zone with the size of 1,174.96 ha (ADB, 2018). The intertidal area of Bama resort has a mixed tide type with predominantly semi-diurnal form (unpublished data). Geographic coordinates of the research stations were between -7.842211° and -7.847140° (latitude), and between 114.459845° and 114.463213° (longitude). The map of the study area is presented in Fig. 1.

Sampling: The present study was conducted during the period of low tides in the intertidal area of Bama resort, BNP in October 2018. In each sampling station, 3 sampling plots with the size of 50×50 transect were set up parallel to the coastline with a distance of 25 m. In each transect, a total of 1.5 kg of soil, 1 kg for soil analysis and 0.5 kg for microplastics determination, was collected using a soil auger with a diameter of 7.6 cm and length of 30 cm. In each transect, soil samples were separated based on depth (0-10 cm, 10-20 cm, and 20-30 cm) and placed in plastic bags. The sediment samples were immediately transported for further laboratory analysis in Marine Science laboratory, University of Brawijaya.

Sediments analysis: Sieve shaker procedure was used to separate sediments based on their grain size. This method was chosen as the visual analysis showed that the sediment type of the research area was sand (Asadi et al. 2018). In the

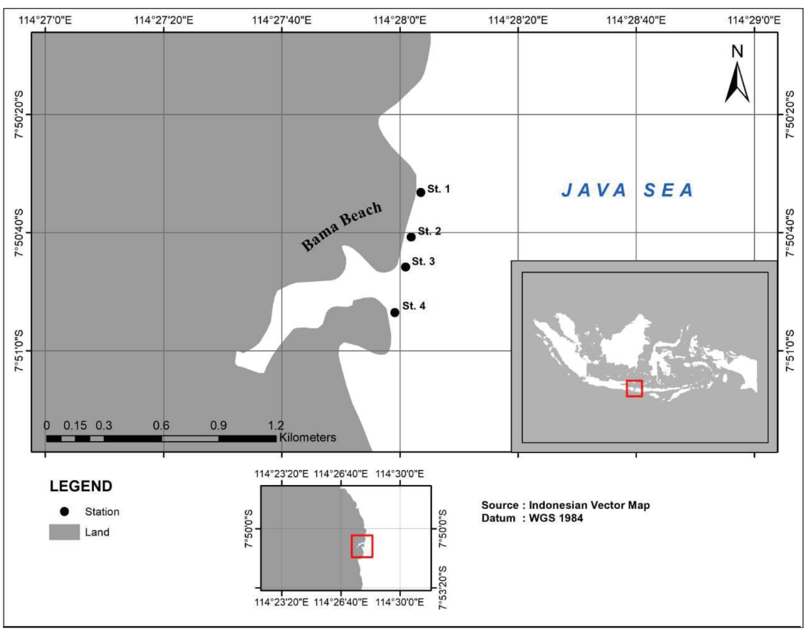

Fig. 1: Map of the sampling stations along the intertidal area of Bama Resort, BNP.

first step of this procedure, all samples were dried using an oven at approximately 90^{o}C for 3 days in order to prepare the sieving processes. In the second step, the samples were passed through some test sieves with different mesh sieves from the size of 5 mm to 45 µm. In order to define the size ranges of the sediments, the samples were then weighted and classed using Wentworth's particle size scale. Shepard's diagram was then used to classify sediments based on the proportions of particles (Asadi et al. 2017, Di Stefano et al. 2010).

Microplastics analysis: In order to perform microplastics analysis of the sediment, a total amount of 150g of soil sample from each depth (0-10 cm, 10-20 cm and 20-30 cm) of each plot and each station was dried using a Memmert drying oven at temperature of 60^{o}C for 48 hour to obtain dry soil samples. The selected temperature was also meant to prevent microplastics from degradation. As a microplastic has particle < 5 mm, the soil samples were then passed through a sieve test with the size of 5-mm to separate sediment with the size higher than 5 mm. Microplastic particles were extracted from the separated soil samples using the flotation method described by Kazmiruk et al. (2018) and Thompson et al. (2004) with minor modifications. In the method, the mixture of 360 g sodium chloride and filtered seawater was used to prepare a saturated saline solution with a density of 1.35 g cm^{-3}. The solution was then stirred for 2 minutes using a magnetic stirrer. After stirring, the solution was closed with aluminium foil to prevent contamination from the air and allowed to settle for 24 h. Furthermore, the supernatant of the solution was filtered through a 0.3-mm sieve test to separate and obtain identifiable microplastics (Laglbauer et al. 2014, Masura et al. 2015). Microplastic particles were visually observed using a microscope and classified based on their types as fibres, films, foams, nurdles, and fragments (Di & Wang 2018).

RESULTS AND DISCUSSION

Microplastic characterization: Among all 484 particles found, there were 183 fibers (37.8%), 159 films (32.9%), 141 fragments (29.1%), and 1 foam (0.2%). There was no plastic pellet identified within this study which confirmed that all microplastic particles found in the research areas were identified as secondary microplastics. pellets, beads, or nurdles are primary microplastics which were originally manufactured to be < 5 mm in size. They serve as raw materials in the manufacture of plastic products (Martin et al. 2017, Smith et al. 2018, Syakti et al. 2017). The dominance of fibres in sediment in this study was much lower than that of in other studies (Di & Wang 2018, Martin et al. 2017, Willis et al. 2017). Fibres constituted 85% of total microplastics in the bottom waters and sediment of the Irish continental shelf (Martin et al. 2017). In sediment of urban estuaries of Australia, fibres even contributed 87% of total items observed (Willis et al. 2017). Synthetic fibres make up a large proportion of microplastic pollution in urban areas (Hernandez et al. 2017), while intertidal area of Bama Resort is part of marine protected zone of BNP which is relatively remote area, strictly protected and managed for conservation (Wianti 2014), therefore, in the study area, there might a lack of fibres pollution from nearby households. These fibres might settle in the sediment of intertidal area of Bama resort prior to the ubiquitous of plastics throughout the marine environment.

Furthermore, microplastic particles were found in a variety of colours. Clear or transparent, white, blue, and red were most common with 44, 38, 32, and 20 particles respectively which shared 24%, 21%, 18%, and 11% respectively. Meanwhile black, brown, green, orange, and yellow were least common with 16, 12, 8, 6, and 4 particles respectively which constituted 9%, 7%, 5%, 3%, and 2% respectively. In sediments of the Three Gorges Reservoir, China, the most dominant colour was also transparent (Di & Wang 2018), while it was the second most dominant colour in many coastal waters of Indonesia (Syakti et al. 2017). Transparent colour of microplastics is partly a result of bleaching and discolouring of microplastics due to prolonged exposure of ultraviolet light (Kalogerakis et al. 2017). Photographs of microplastics found in the research stations are presented in Fig. 2.

Microplastics abundance: The number of total microplastics varied from 35.80 ± 20.07 particles kg^{-1}dry weight (DW) at station 3 to 178.45 ± 144.30 particles kg^{-1}DW at station 4 with a total average of 116.41 ± 80.78 particles kg^{-1}DW (Table 1). The results of this study reveal that microplastics pollution has become pervasive in intertidal area of Bama Resort, BNP. The abundance of microplastics in this study area was slightly higher than that found in coastal sediments of Muara Badak, Kutai Kertanegara, Indonesia which had averages of 105 particles kg^{-1}DW (Dewi et al. 2015). Although, there might be no or little direct input of microplastics from terrestrial areas of BNP, microplastics might settle in its coastal sediments from surrounding water column as buoyant microplastics can be transported by winds and surface currents, recaptured by coastal sediments. In Great Pacific Garbage Patch, a remote subtropical waters between California and Hawaii, microplastic particles even increase and accumulate exponentially (Lebreton et al. 2018). Meanwhile, in coastal sediments of Jakarta Bay, Indonesia, microplastic particles are two hundred times higher than in coastal sediments of Bama Resort in which as many as 18,405 to 38,790 particles kg^{-1} DW were

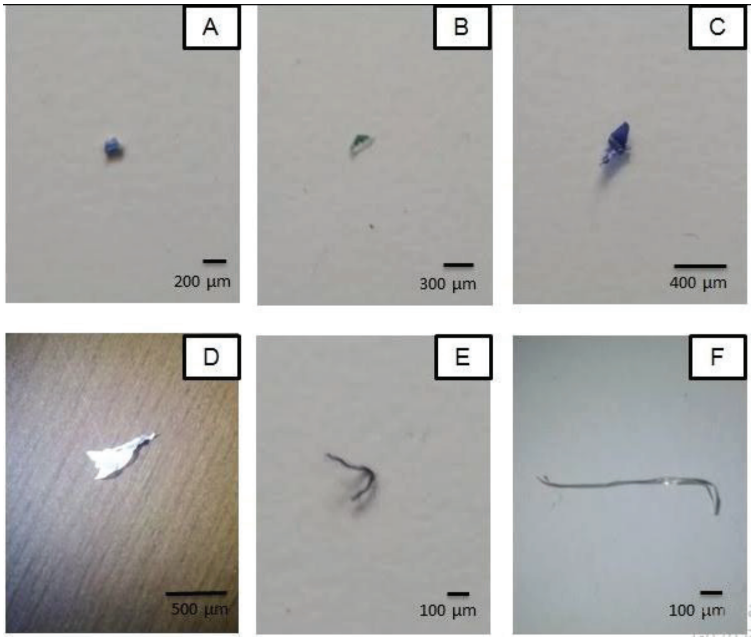

Fig. 2: The photographs of some microplastic particles found in coastal sediments of Bama Resort, BNP. Fragments (A, B), Films (C, D), Fibres (E, F).

Table 1: Microplastics abundance in the sediment of intertidal area of Bama Resort, BNP at each station at depths of 0-10 cm, 10-20 cm, 20-30 cm.

Station	Depth (cm)	Microplastics abundance (particles kg^{-1} dry weight)				Total
		Fragments	Fibers	Films	Foams	
1	0-10	88.50 ± 1.73	97.35 ± 2.65	76.70 ± 0.58	0	
	10-20	60.87 ± 2.00	34.78 ± 3.00	31.88 ± 1.53	0	153.13 ± 102.12
	20-30	20.11 ± 2.08	28.74 ± 0.58	20.47 ± 1.15	0	
2	0-10	24.02 ± 1.53	69.07 ± 3.79	54.05 ± 2.65	0	
	10-20	18.18 ± 1.73	30.30 ± 2.31	42.42 ± 1.53	0	98.27 ± 56.63
	20-30	17.86 ± 0	14.88 ± 1.15	15.02 ± 0.58	9.09 ± 0.58	
3	0-10	8.93 ± 0	5.95 ± 1.15	8.77 ± 0	0	
	10-20	21.21 ± 1.15	21.02 ± 0.58	15.02 ± 0.58	0	35.80 ± 20.07
	20-30	2.90 ± 0.58	11.59 ± 1.15	12.01 ± 1.53	0	
4	0-10	101.09 ± 2.52	153.01 ± 8.50	87.43 ± 2.52	0	
	10-20	26.88 ± 1.53	40.32 ± 1.00	56.45 ± 4.00	0	178.45 ± 144.30
	20-30	14.62 ± 0.58	17.54 ± 2.00	38.01 ± 2.31	0	
Average		33.76 ± 23.50	43.71 ± 36.52	38.19 ± 19.47	0.75 ± 1.30	116.41 ± 80.78

found in coastal sediments of the Bay.

Tukey's multiple comparisons test of Two-way ANOVA showed significant differences ($P < 0.01$) in the abundance of microplastics among fibres, fragments, films, and foams (Table 2). Fibres were the highest microplastics concentration with overall average of 43.71 ± 36.52 particles kg^{-1} DW, while foams had the least microplastics abundance with overall average of 0.75 ± 1.30 particles kg^{-1} DW (Table 1). In sediments of European waters, the overall average of microfibres concentration range from 52.60 to 157.92 items per kg DW (Gago et al. 2018). In Baynes Sound and Lambert Channel, British Columbia, Canada, microfibres

Table 2: Tukey's multiple comparison test of the overall average of microplastic types abundance (N=12).

Tukey's multiple comparisons test	Mean Diff,	95.00% CI of diff,	Significant?	Summary	Adjusted P Value
Fragments vs. Fibers	-9.948	-10.99 to -8.907	Yes	****	<0.0001
Fragments vs. Films	-4.171	-5.212 to -3.13	Yes	****	<0.0001
Fragments vs. Foams	33.01	31.97 to 34.05	Yes	****	<0.0001
Fibers vs. Films	5.778	4.736 to 6.819	Yes	****	<0.0001
Fibers vs. Foams	42.96	41.91 to 44	Yes	****	<0.0001
Films vs. Foams	37.18	36.14 to 38,22	Yes	****	<0.0001

concentration range from 100 to 300 items per kg DW (Kazmiruk et al. 2018). Microfibres are the most dominant microplastics pollution along coastal areas and have been documented to permeate the ocean's deepest points (Barrows et al. 2018). Microfibres enter marine environment via wastewater effluent and diverse non-point sources in which more than 60% of microfibres are from synthetic textiles (Almroth et al. 2018, Barrows et al. 2018). Synthetic fibres are not biodegradable in which polypropylene is the most common polymer type of microfibres found in water and sediments (Xu et al. 2018). Each 6-kilo of laundry could release more than 700,000 synthetic fibres (Napper & Thompson 2016), therefore, microfibres will continue to pollute marine environment as over 9 million tons of textile are manufactured annually (Barrows et al. 2018).

Meanwhile, fragments had an overall average of 33.76 ± 23.50 particles kg^{-1} DW in which station 4 had the highest concentration with an average of 70.29 ± 72.53 particles kg^{-1} DW (Table 1). These values were much lower than that found in the coastal sediments of Muara Badak, East Kalimantan, Indonesia, in which fragments ranged from 100.2 to 236 particles kg^{-1} DW (Dewi et al. 2015). Mussels and planktivorous fish have been reported to ingest microfibres up to 15 particles per individual of fish (Digka et al. 2018, Tanaka & Takada 2016). Fragments are among secondary microplastics derived from the degradation of larger plastic debris through natural weathering processes (Tanaka & Takada 2016). A vast majority of fragments observed during this study exhibited bleach and discolouration patterns as results of photodegradation and other weathering processes.

Microplastics distribution: Tukey's multiple comparisons test of Two-way ANOVA showed that there were significant differences ($P< 0.01$) in vertical and horizontal distribution of fragments, fibres, and films. Foams were not significant differences ($P >0.99$) in vertical distribution between depths of 0-10 cm and 10-20 cm. Horizontal distribution of foams showed significant differences ($P< 0.01$) between station 1 and 2, 2 and 3, and 2 and 4. Meanwhile, deeper sediments resulted in fewer microplastic particles in which overall 55.46% of them were found at depths of 0-10 cm, while 28.58% and 15.95% were observed at depths 10-20 cm and 20-30 cm respectively.

There were 81.34 ± 4.02 particles kg^{-1} DW of fibres at depths of 0-10 cm while they were only 18.18 ± 1.22 particles kg^{-1} DW at depths of 20-30 cm. Fragments at depths of 0-10 cm were 55.63 ± 1.44 particles kg^{-1} DW, while they were only 31.78 ± 1.60 particles kg^{-1} DW and 13.87 ± 0.81 particles kg^{-1} DW at depths of 10-20 cm and 20-30 cm respectively (Fig. 3). The results demonstrated that microplastics have been polluted the coastal areas of BNP since the past couple of decades as microplastics settled in coastal sediments prior to the presence of plastics in the marine environment. Moreover, these microplastics settle in the sediments at faster rate in the current period of time as greater plastic frequencies were found in more recent sediments. However, a study of the age of sediment and the rate of sedimentation is needed to reveal the deposition time of microplastics in the research area (Willis et al. 2017).

Sediment characteristics and microplastics abundance: Based on Wentworth scale, there were only two classes of sediments found in the sampling stations which were sand and gravel while silt and clay were not observed during laboratory analysis. Shepard's diagram classified the sediments based on the proportion of grain classes in each depth of each station in which sandy gravel types were found at the upper sediments while gravelly sand types were mostly found in the deeper sediments. Microplastic particles commonly have positive correlations with finer sediments (Ling et al. 2017). However, microplastics in this study were more ubiquitous in the coarser sediment (sandy gravel) than in the finer sediment (gravelly sand) which hold microplastics with a total average of 161.63 ± 117.64 particles kg^{-1} DW and 71.02 ± 40.44 particles kg^{-1} DW respectively. Therefore, in this study, sediment depths were much more correlated with the abundance of microplastics than that of

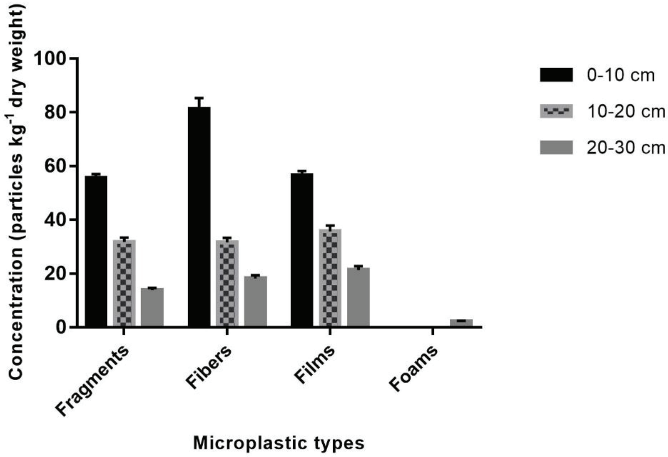

Fig. 3: Vertical distribution of microplastics at depths of 0-10 cm, 10-20 cm, and 20-30 cm.

Table 3: Total abundance of microplastics based on depths and sediment types.

Sediment types	Station	Depths (cm)	Total abundance (particles kg^{-1}DW)
Sandy gravel	1	0-10 cm	262.54 ± 4.96
	1	10-20 cm	127.54 ± 6.53
	2	10-20 cm	90.91 ± 5.57
	3	0 -10 cm	23.65 ± 1.15
	4	0-10 cm	341.53 ± 13.54
	4	10-20 cm	123.66 ± 6.53
	Average		161.63 ± 117.64
Gravelly sand	1	20-30 cm	68.32 ± 3.81
	2	0-10 cm	147.15 ± 7.96
	2	20-30 cm	56.76 ± 2.31
	3	10-20 cm	57.25 ± 2.31
	3	20-30 cm	26.5 ± 3.26
	4	20-30 cm	70.18 ± 4.89
	Average		71.02 ± 40.44

the types of sediments as more microplastics were found in the upper or younger sediments (Table 3).

CONCLUSION

Microplastics pollution was widespread in the coastal sediments of Bama Resort, BNP. There were 484 microplastics found in which fibres and films shared 37.8% and 32.9% of the total particles respectively. Transparent, white, and blue were most common colour of microplastics found with occurrences of 24%, 21%, and 18% respectively. Microplastics abundance varied from 35 to 178 particles kg^{-1} DW with a total average of 116 particles kg^{-1} DW in which fibres had an overall average of 43 particles kg^{-1} DW.

Vertical distribution of microplastics within the sediments column showed significant differences among depths in which more microplastics found in the more recent (upper) sediment. A total 55.46% of microplastics found at depths 0-10 cm whereas only 15.95% of total particles were found at depths of 20-30 cm. Sandy gravel sediments hold higher microplastics than that of gravely sand; therefore, the higher concentration of microplastics in the former sediments was due to their dominance in the upper layer of sediment. Moreover, it is concluded that microplastics might pollute the coastal sediments of Bama Resort, BNP since some decades ago and the rate of contamination increases in more recent years.

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