The characteristics of marine debris and water quality in Palu Bay, Central Sulawesi, Indonesia

[1,2]James Y. Walalangi, [1]Tri D. Lelono, [1]Asus M. Suryanto Hertika, [1]Edi Susilo

[1] Faculty of Fisheries and Marine Science, Brawijaya University, Malang 65145, East Java, Indonesia; [2] Faculty of Animal Husbandry and Fisheries, Tadulako University, Palu 94118, Central Sulawesi, Indonesia. Corresponding author: J. Y. Walalangi, walalangijames@untad.ac.id; E. Susilo, olisuside_fpik@gmail.com

Abstract. This study is aimed at analyzing the marine debris condition in the coastal area of Palu Bay and the correlation of water quality characteristics in the region, such as water temperature, salinity, Total Suspended Solid (TSS), turbidity, BOD_5, COD, $N\text{-}NH_3$, NO_3, and PO_4-P, using Principal Component Analysis (PCA). The study utilized in situ and ex situ water quality measurement instruments. All measured parameters were compared with those of standard quality established by Indonesian government for tourism and biota. Results revealed that organic marine debris was dominated by seagrass pieces, while the inorganic one was dominated by plastic wastes. The water quality characteristics correlation in December 2019 was 82.4% with main factor 1 (F1) of 65.95%, main factor 2 (F2) of 16.45%, and major characteristics of TSS, turbidity, BOD_5, COD, and salinity. In January 2020, the correlation was 61.92% with main factor 1 (F1) of 37.06%, main factor 2 (F2) of 24.86%, and major characteristics of salinity, and TSS. In February 2020, it was 63.89% with main factor 1 (F1) of 38.31%, main factor 2 (F2) of 25.58%, and major characteristics of PO_4-P and COD. Coastal area and river are major media of waste distribution. Increasing waste volume is potential to negatively influence the coastal and marine system.

Key Words: biota, coastal area, PCA, tourism.

Introduction. Marine debris is one of the complex issues in coastal countries (Cesar-Ribeiro et al 2017; Herrera et al 2018). Various human activities produce marine debris and pollutants. The marine debris and pollutants degrade the coastal environment and its surrounding ecosystem (Wilcox et al 2016; Gough 2017; Rial et al 2017).

The developing countries, including Indonesia with the longest coastline in the world, are not also separated from the marine debris problems (Jambeck et al 2015). Similar issues are also supported by Pettipas et al (2016), Vince & Stoett (2018), and Wessel et al (2019) that population growth and human activities need houses, offices, worship facilities, restaurants, and others in the city or near the coastal area will produce wastes. Consequently, these developments will hazard the environment (Jambeck et al 2015; Edahbi et al 2019). Trash threat in marine environment becomes important since it impacts to human life due to marine and human interactions or through transfer mechanisms of food sources, such as fish and mollusks (Wilhelmsson et al 2013; Polasek et al 2017; Owens 2018).

Coastal region has very good accessibility to various economic activities (Baulch & Perry 2014; Susilo & Agung 2015; Vo Dong et al 2018). Becherucci et al (2017) stated that population growth and development intensity make the carrying capacity of coastal ecosystem in providing natural resources and environmental services be threatened to degrade. Trash volume and types can basically become society’s burden due to various negative impacts (Lan et al 2015; Muniz et al 2015; Al-Abdulrazzak et al 2017).

The coastal area of Palu Bay has collected a number of thrash compositions and characteristics as end products of human activities. Walalangi et al (2020) found a number of human activities producing organic or inorganic wastes that eventually give environmental pressures on the coastal area with various types of marine debris (Coe &

Rogers 1997; Acuña-Ruz et al 2018; Andrades et al 2018; Rajendran et al 2018). The pile of trashes in the coastal areas, including Palu city, has exceeded the service capacity and the available waste treatment facility so that trashes pile up in the temporary landfills, watershed, and around the residential area, and finally move to the coastal and marine areas (Loulad et al 2017; Walalangi et al 2020).

According to Agovino et al (2018), Di Nola et al (2018), and Toledo et al (2019) information on pollution status of the coastal waters is very crucial, particularly to people who rely on marine resources. The complex problem of heavy pollution after the natural disaster, earthquake, and tsunami in the coastal area of Palu Bay, requires a comprehensive study (Parura & Rahardyan 2020; Walalangi et al 2020). To minimize the pollution impact, a scientific analysis on waste treatment in the coastal area of Palu Bay is needed. This study is intended to analyze the characteristics of marine debris and water quality in the coastal area of Palu Bay.

Material and Method

Research period and location. This study was conducted in the coastal area of Palu Bay, East and West Palu districts. Each district has different human activities so that the research stations were selected in both districts. Palu Bay is included in the administrative territory of Central Sulawesi Province, Indonesia (Figure 1). The study was done in December 2019, January and February 2020 using line transect quadrat sampling.

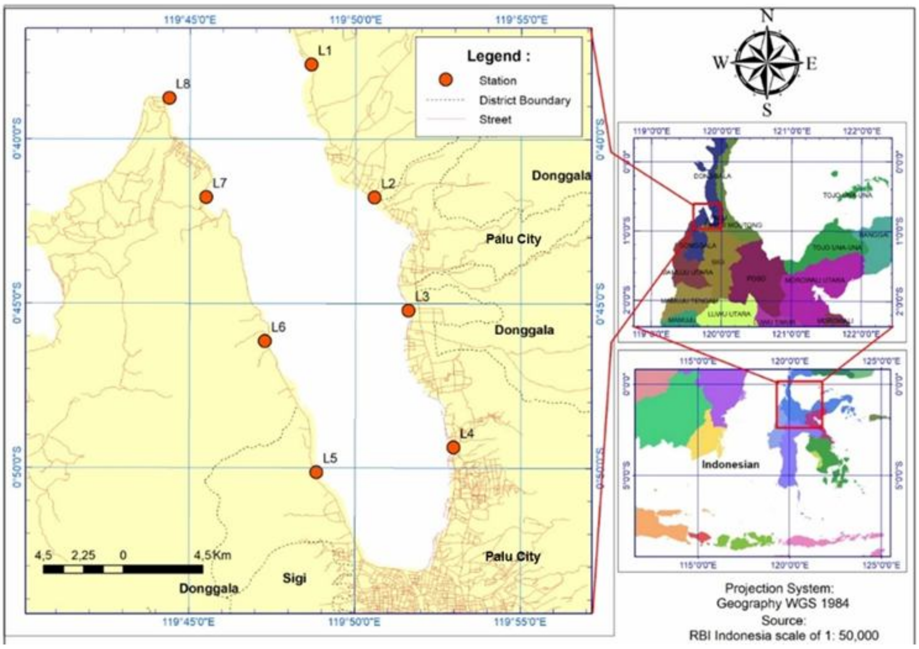

Figure 1. Sampling sites in Palu Bay.

Data sorts and analyses. Research variables in the present study were water temperature, salinity, Total Suspended Solid (TSS), turbidity, BOD_5, COD, amonia ($N\text{-}NH_3$), nitrate (NO_3), phosphate ($PO_4\text{-}P$), and organic and inorganic marine debris. There were 8 study sites, 4 points in East Palu district and 4 others in West Palu district. Each study site was sampled once in December 2019, January 2020, and February 2020, respectively. Sample collection and water quality measurements were carried out at each the third week of the month.

Marine debris sampling technique. Field observations are the early step of this study, then the locality was marked using Global Positioning System (GPS). All sampling points were set in the east and west parts of Palu city (Table 1).

Marine debris sample collection was done using 30 m line transect with 2 m x 2 m, and the distance between quadrats was 1 m (Coe & Rogers 1997). This study used 8 sampling lines (L1-L8) with 10 quadrats of each sampling line, so that there were a total

of 80 quadrats. Sample collections were done at the third week of December 2019, January 2020, and February 2020, so that total number of quadrants became 240 units. These were conducted in the intertidal at the lowest tide. Line transects were laid parallel to the coastline. Solid marine debris was put into the plastic bags and sorted with category. The organic wastes consist of seagrass, wood, fruit skin, vegetables, and other biodegradable wastes, while the inorganic wastes are plastic, paper, rubber, styrofoam, glasss, alumunium, and clothes/textile. After separated on the basis of study site, the data were grouped into composition, number, and weight, then analyzed using the following equation (Coe & Rogers 1997):
1. absolute density (no. waste pieces) = no. pieces of each category/area (m^2);
2. absolute density (waste weight) = waste weight of each category/area (m^2).

Table 1

Coordinates of observation station in Palu Bay, Central Sulawesi

Stations		Latitude	Longitude
East Palu	L1	0°37'44.26"S	119°48'39.39"E
	L2	0°41'46.55"S	119°50'33.77"E
	L3	0°45'12.53"S	119°51'35.38"E
	L4	0°49'21.96"S	119°52'57.37"E
West Palu	L5	0°50'7.49"S	119°48'49.34"E
	L6	0°46'8.75"S	119°47'15.73"E
	L7	0°41'46.04"S	119°45'28.98"E
	L8	0°38'45.59"S	119°44'22.42"E

Water quality. Water quality parameters measured were temperature, salinity, TSS, turbidity, BOD_5, COD, NH_3, NO_3-N, and PO_4-P. Seawater was collected from marine environment using 100 mL glass bottle. Each sample bottle was labelled with KA1 – KA8 for each sampling point and brought to the laboratory for further analyses. In this study, water sample was analyzed in Natural Analysis and Environmental Laboratory of Kampus Bumi Tadulako Tondo following Kurniadi et al (2015).

The correlation value of marine debris to the water quality parameters was examined using Principle Components Analysis (PCA) (Schaduw 2018; Khedr et al 2019). This method is intended to determine the optimum axes of the variables projection. To determine the relationship between two variables, a correlation matrix approach that is estimated from synthetic indices the index used is the highest indices of each attribute of the dimension, so that there were 11 indices of 3 replications. PCA is a descriptive statistic method that provides maximum information of a data matrix in graphic form (Schaduw 2018). The matrix consists of organic and inorganic marine debris variables and water quality parameters. Each character was separately analyzed. The closer the euclidean distance between 2 variables is, the higher the similarity of the variable characteristics (Legendre & Legendre 2012).

Results and Discussion

Organic marine debris. Based on number of organic marine debris during December 2019 to February 2020, there were the highest number of marine debris in the locality L8 of East Palu, 2,244 pieces in December 2019, 1,945 pieces in January 2020, and 2,141 pieces in February 2020 (Table 2). Walalangi et al (2020) also found the highest number of organic wastes in West Palu district (L5), 1,049 pieces. This condition could result from the dominance of seagrass wastes in each quadrat. High number of seagrass pieces in L8 could be caused by sufficiently high human activities in the coastal area that could damage the seagrass ecosystem. This site (L8) is well-known as marine tourism of Tanjung Karang and utilized by local or foreign tourists as water tourism destination. According to Parura & Rahardyan (2020), the types of the organic wastes have increased after the tsunami and the liquefaction in the bay of Palu city in 2018. Other technique to detect the organic pollution in marine environment is biomonitoring program (Cesar-Ribeiro et al 2017; Dirrigl et al 2018; Hertika et al 2021a).

Inorganic marine debris. The highest number of inorganic wastes was recorded in December 2019, 874 pieces in L3, January 2020, 997 pieces in L3, and February 2020, 819 pieces in L7, in which plastic wastes dominated each research point, followed with paper, glass, aluminium, rubber, styrofoam, and clothes/textiles. High number of the inorganic wastes in L3 (East Palu district) could result from the presence of several centers of human activities, such as culinary, café, restaurants, and schools, whereas L7 in West Palu district is mining and human residential areas. Walalangi et al (2020) found the highest number of inorganic wastes, 680 pieces, in East Palu district, dominated by plastic wastes. This finding is supported by Jambeck et al (2015), GESAMP (2019), and Rudianto et al (2020) that plastic debris outnumbers the waste types in the coastal areas, such as in Brazil and several regions in Asia.

Water temperature. Seawater temperatures of Palu Bay in December 2019 to February 2020 at sites L1 to L8 were good enough and in the range of standard water quality for marine biota and tourism with the highest occurred in January at L5, 31.70^{o}C. This site is located in West Palu district, by the stream of Palu city that has sufficiently high TSS and turbidity. As one of the equatorial regions, water temperature in Palu Bay always tends to rise. The lowest temperature was 28.50^{o}C in February 2020 at site L2 (Table 2). This condition is nearly similar to that in Bunaken National Park waters, 28.96-29.67^{o}C (Schaduw 2018) and Depepra waters, 25-31^{o}C (Hamuna et al 2018) with dominant range of 27-29^{o}C. Temperature has direct and indirect effect in controlling the aquatic ecosystem condition. The direct effect yields animal's tolerance to the temperature condition, while the indirect one occurs through environment, for instance, increase in water temperature up to certain limit will reduce the oxygen solubility and cause mortality (Effendi 2003; Iñiguez et al 2017).

Salinity. The lowest water salinity was recorded in the sampling point L5, 26.40 PSU in December 2019 and the highest in L2 in January and February 2020, 32.55 PSU. The waters approaching to the main river of Palu bay had moderate salinity level, point L4 and L5 (Table 2). This salinity condition in Palu Bay is different from that before the earthquake and tsunami in 2018, the highest of 30.40 PSU and the lowest of 26.70 PSU (Walalangi et al 2020). The salinity level reported by Hamuna et al (2018) in marine environment of Depapre district, Jayapura, is not quite different among the study sites (30-34 PSU) and thus, the salinity conditions have only slight difference. This condition is quite different from that reported by Khedr et al (2019) in northern Suez Bay waters during 2017 with salinity range of 40.09-41.04 PSU. This difference could be caused by different evaporation rate and precipitation.

Total suspended solid (TSS). Mean range of TSS during the study was 23.80 mg L^{-1} (L1 in January 2019) – 45.38 mg L^{-1} (L5 in December 2020). These values are below the standard water salinity, 80 mg L^{-1} (Table 2). The study site with high mean TSS is contributed by water input of gold mining activity from the terrestrial area in the upstream through the main river of Palu city. The site L1 had low TSS in January 2020, and it is influenced by lower human activities in this area than other localities. This condition is still below the seawater standard quality for biota, but has exceeded the standard quality for tourism. Previous finding of Walalangi et al (2020) found TSS concentration of 39.90-43.80 mg L^{-1}, whereas the present study recorded the TSS range of 23.80-45.38 mg L^{-1}. It means that the present finding has wider range of TSS concentration indicated with increased number of organic debris. It is inversely proportional to TSS reported by Khedr et al (2019) that the range and mean seasonal TSS in northern Suez Bay during 2017 is 11.0-29.00 mg L^{-1}. TSS concentration in the rivermouth is affected by sediment and organic matter accumulation from either terrestrial or ocean, and this condition could disturb the biocecological process in this ecosystem (Marlian 2016; Hertika et al 2021b).

Turbidity. Mean turbidity in each locality and research period tended to be above the standard quality (< 5 NTU), but one study site, L1, had turbidity below the standard quality, i.e. 4.37 NTU in December 2019, 4.58 NTU in January 2020, 4.47 NTU in

February 2020. Mean turbidity ranged from 4.37 to 6.48 NTU (Table 2). This high turbidity is, of course, related with material inputs from the terrestrial as sediment from several streams around the bay of Palu city (Walalangi et al 2020). Wiyoto & Effendi (2020) showed that seawater in Riau islands is clear so that the sunlight intensity is sufficient for marine biota, below 5 NTU. The turbidity in the coastal ecosystem highly varies with season, tide, and rainfall (Khedr et al 2019).

BOD_5 and COD. BOD_5 concentration ranged from 0.65 mg L^{-1} in February at L2 to 1.85 mg L^{-1} in January at L8 (Table 2). According to Khedr et al (2019), seawater BOD_5 value can determine the estimation of oxygen content needed to biologically stabilize the organic matter. Mean COD recorded in the present study was still below the standard water quality, 3.19 mg L^{-1} – 8.67 mg L^{-1} in site L2 in February 2020 and L5 in January 2020 respectively. Mean BOD_5 and COD found in this study have not exceeded the standard quality yet. Several sampling points, particularly near the river of Palu city (L3-L6) had higher BOD_5 and COD than other sampling points. BOD_5 recorded in the present study is still below the maximum standard for marine biota recommended in the decree of the Ministry of Living Environment numbered 51/2004. Effendi (2003) stated that BOD_5 and COD are needed as indicator parameter in standard quality of aquatic pollution, since their role is one of the estimators of organic pollution.

Ammonia (NH_3-N). During the study, NH_3-N ranged from 0.001 to 0.002 mg L^{-1} (Table 2). These values are still below the standard water quality established in the decree of the Ministry of Living Environment numbered 51/2004, 0.003 mg L^{-1}. This condition is different from that reported by Hamuna et al (2018) who found high concentration of ammonia in Depapre seawater, Jayapura, 0.8-11.6 mg L^{-1}, far exceeding the standard water quality. The presence of ammonia in the water is an indication of organic material decomposition, especially protein (Marlian 2016).

Nitrate (NO_3). Mean nitrate content in Palu bay ranged from 0.033 to 0.043 L^{-1} (Table 2). This range belongs to olygotrophic waters with NO_3 content between 0 and 1 L^{-1} (Effendi 2003). It is inversely proportional to Prajati & Widiantoro (2019) in Lengkang Island, Riau, that is partly covered by domestic wastes so that mean content of this parameter is above the seawater standard water quality, namely from 0.4 to 1.4 L^{-1}. Effendi (2003) and Kurniadi et al (2015) also found that the water body with high number of organic wastes has higher nitrate content. This condition is in good category based on the environmental standard quality.

Phosphate (PO_4-P). Mean phosphate (PO_4-P) in Palu Bay had the range of 0.011 to 0.012 L^{-1}, that is categorized as good environmental carrying capacity condition for the survivorship of the aquatic biota (Table 2). Based on Hamuna et al (2018), phosphate concentration in Depapre waters ranged from 0.016 to 1.19 mg L^{-1}. These values indicate that phosphate content in Depapre waters, Jayapura, has exceeded the seawater standard water quality. Effendi (2003) stated that phosphate is a very important limiting factor in productive and unproductive waters in determining the amount of phytoplankton.

Correlation between water quality parameters and marine debris. Table 3 demonstrates that the groupings of 9 water quality parameter characteristics during December 2019-February 2020 are sufficiently done using 2 major factors (F1 - F2). These two factors have been able to explain 82.4% (F1 = 65.95%; F2 = 16.45%) of the total characteristics for December, 61.92% (F1 = 37.06%; F2 = 24.86%) of the total characteristics for January, and 63.89% (F1 = 38.31%; F2 = 25.58%) of the total characteristics for February, respectively (Figures 2, 3, and 4).

The correlation value in December exists on the high positive correlation between organic wastes and TSS, turbidity, BOD_5, and COD with the value of 0.9124, whereas the inorganic waste is positively correlated with salinity as much as 0.6994. In January, the organic wastes are positively correlated with salinity (0.6765) and the inorganic wastes have strong positive correlation with TSS (0.6422). In February, the correlation coefficient for organic wastes and PO_4-P was 0.8290 and that for inorganic wastes and

COD was 0.9046 (Table 3). Schaduw (2018) who studied in the waters of Bunaken Island exhibited different condition, F1 = 79.33% and F2 = 14.22% with major variables of temperature and PO_4-P. Khedr et al (2019) stated that total major factor in Suez Bay was 76.937% with main variables of salinity, BOD, and pH. Looking at the correlation between water quality parameters and marine debris, it is apparent that when the organic or inorganic marine debris are abundant, they will affect the water quality in the coastal area that will certainly systematically impact the ecosystem.

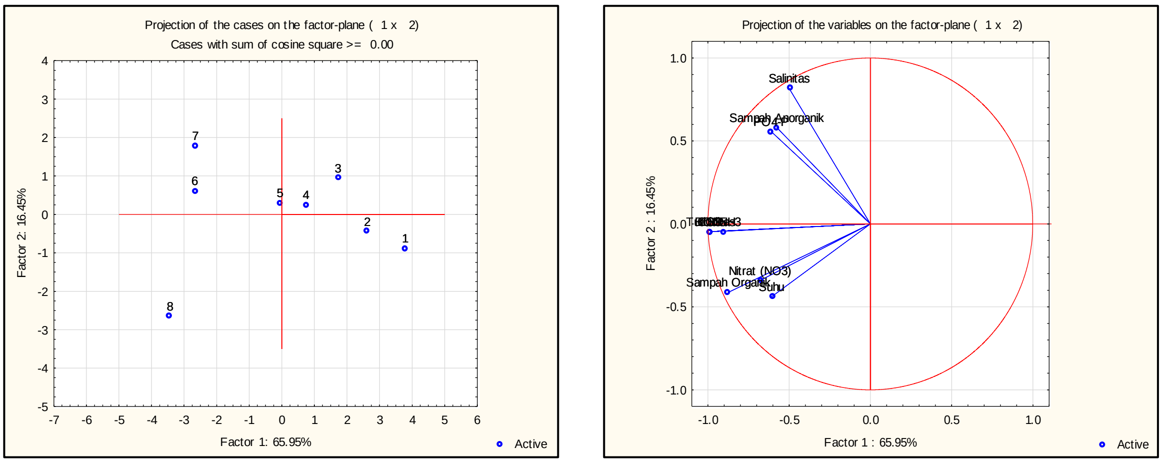

Figure 2. Distribution and grouping of water quality and marine debris characteristics in December 2019.

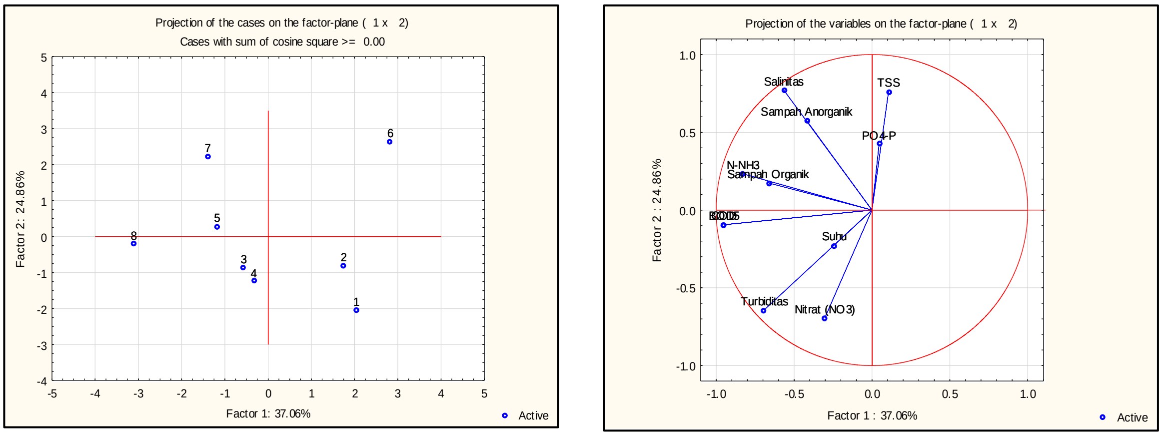

Figure 3. Distribution and grouping of water quality and marine debris characteristics in January 2020.

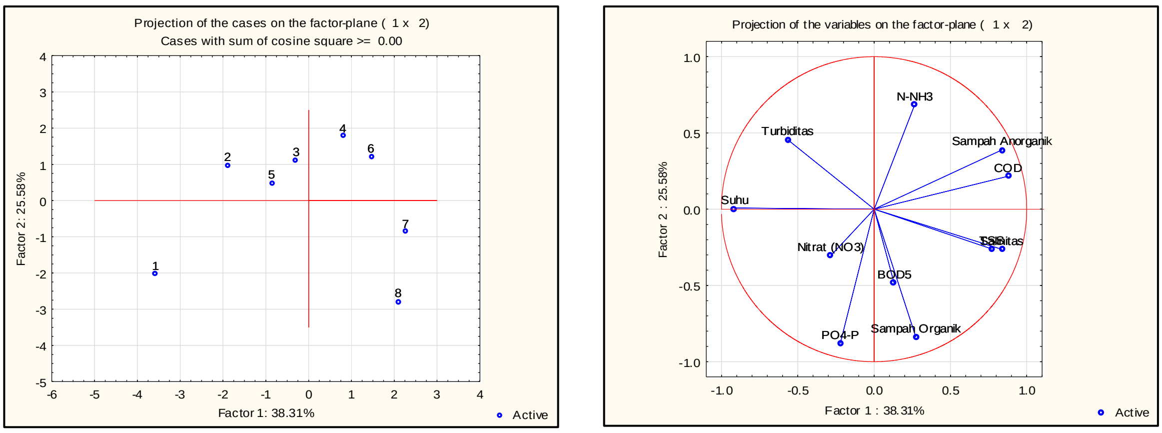

Figure 4. Distribution and grouping of water quality and marine debris characteristics in February 2020.

Table 2

Mean value of water quality parameters in the coastal area

	Parameter unit	*Natural temperature (^{0}C)*	*Salinity (PSU)*	*TSS (mgL^{-1})*	*Turbidity (NTU)*	*BOD_5 ($mg\ L^{-1}$)*	*COD ($mg\ L^{-1}$)*	*NH_3.N ($mg\ L^{-1}$)*	*NO_3 ($mg\ L^{-1}$)*	*PO_4-P ($mg\ L^{-1}$)*	*Organic waste (pieces)*	*Inorganic waste (pieces)*
December	L1	29.70	31.50	24.80	4.37	1.27	6.26	0.002	0.037	0.012	391	70
	L2	29.60	32.30	25.00	6.29	1.24	6.08	0.002	0.035	0.012	477	373
	L3	29.80	30.65	38.20	6.45	1.46	7.19	0.002	0.039	0.012	745	874
	L4	30.80	26.60	39.40	6.33	1.29	6.39	0.002	0.037	0.012	1,018	711
	L5	31.00	26.40	45.38	6.26	1.62	7.99	0.002	0.037	0.012	1,102	710
	L6	30.60	29.40	42.71	6.14	1.37	6.58	0.001	0.033	0.011	1,262	747
	L7	29.60	30.80	29.10	5.37	0.79	3.87	0.001	0.035	0.011	1,179	822
	L8	29.00	31.50	26.40	5.20	1.48	4.88	0.001	0.033	0.012	2,244	565
January	L1	29.90	31.40	23.80	4.58	1.02	5.08	0.002	0.033	0.011	437	111
	L2	29.80	32.55	25.20	6.32	1.14	5.62	0.002	0.037	0.012	359	498
	L3	30.00	30.40	39.70	6.48	1.35	6.64	0.001	0.041	0.012	488	997
	L4	31.50	29.60	39.20	6.55	1.54	7.58	0.002	0.043	0.012	585	822
	L5	31.70	28.80	43.80	6.40	1.76	8.67	0.001	0.039	0.012	695	803
	L6	30.50	29.30	42.61	6.45	1.37	6.58	0.002	0.037	0.011	740	846
	L7	30.20	30.70	35.10	5.37	1.71	8.42	0.001	0.035	0.011	716	945
	L8	29.50	30.70	26.40	5.40	1.85	7.68	0.001	0.040	0.011	1,945	668
February	L1	28.80	30.40	25.60	4,47	1.28	6.39	0.002	0.033	0.011	1,369	41
	L2	28.50	32.55	25.70	5,32	0.65	3.19	0.002	0.035	0.012	415	414
	L3	29.00	30.40	39.90	6,48	1.79	8.83	0.001	0.033	0.012	653	743
	L4	29.50	26.70	41.40	6,40	1.27	6.28	0.001	0.035	0.012	922	689
	L5	30.20	27.80	43.80	6,30	1.31	6.49	0.002	0.039	0.012	1,049	659
	L6	30.50	30.30	41.51	6,35	1.44	7.06	0.001	0.037	0.012	904	681
	L7	30.50	31.80	31.30	6,45	1.59	7.79	0.002	0.033	0.012	1,000	819
	L8	29.50	30.50	27.40	5,20	1.38	6.85	0.002	0.035	0.011	2,141	624
Walalangi et al (2020)	L3	29.00	30.40	39.90	6,48	1.79	8.83	0.001	0.033	0.012	653	743
	L4	29.50	26.70	41.40	6.40	1.27	6.28	0.001	0.035	0.012	922	689
	L5	30.20	27.80	43.80	6.30	1.31	6.49	0.002	0.039	0.012	1,049	659
	L6	30.50	30.30	41.51	6.35	1.44	7.06	0.001	0.037	0.012	904	681

Note: Standard water quality according to the Decree of the Ministry of Living Environment Numbered 51/2004 for: 1) Aquatic biota: temperature (28-32^{o}C), salinity (< 34 PSU), TSS (80 mg L^{-1}), turbidity (< 5 NTU), BOD_5 (> 45 mg L^{-1}), COD (> 80 mgL^{-1}), NH_3.N (0.003 mg L^{-1}), NO_3 (0.008 mg L^{-1}), PO_4-P (0.015 mg L^{-1}); 2) Tourism: TSS (20 mg L^{-1}), turbidity (< 5 NTU), BOD_5 (> 45 mg L^{-1}), COD (> 80 mgL^{-1}), NO_3 (0.008 mg L^{-1}).

Table 3

Correlation of water quality parameters with organic and inorganic marine debris in December 2019, January 2020, and February 2020

Variable	*Temperature*	*Salinity*	*TSS*	*Turbidity*	*BOD_5*	*COD*	*$N\text{-}NH_3$*	*NO_3*	*$PO_4\text{-}P$*	*Organic wastes*	*Inorganic wastes*
December 2019											
Temperature	1.0000	0.1260	0.5989	0.5989	0.5989	0.5989	0.5286	0.3897	0.2263	0.6407	-0.0884
Salinity	0.1260	1.0000	0.4508	0.4508	0.4508	0.4508	0.3810	-0.0223	0.7838	0.0780	0.6994
TSS	0.5989	0.4508	1.0000	1.0000	1.0000	1.0000	0.8452	0.6048	0.5040	0.9124	0.5794
Turbidity	0.5989	0.4508	1.0000	1.0000	1.0000	1.0000	0.8452	0.6048	0.5040	0.9124	0.5794
BOD5	0.5989	0.4508	1.0000	1.0000	1.0000	1.0000	0.8452	0.6048	0.5040	0.9124	0.5794
COD	0.5989	0.4508	1.0000	1.0000	1.0000	1.0000	0.8452	0.6048	0.5040	0.9124	0.5794
N-NH3	0.5286	0.3810	0.8452	0.8452	0.8452	0.8452	1.0000	0.7482	0.7454	0.7286	0.3160
NO3	0.3897	-0.0223	0.6048	0.6048	0.6048	0.6048	0.7482	1.0000	0.3637	0.6914	0.2453
PO4-P	0.2263	0.7838	0.5040	0.5040	0.5040	0.5040	0.7454	0.3637	1.0000	0.1794	0.4039
Organic wastes	0.6407	0.0780	0.9124	0.9124	0.9124	0.9124	0.7286	0.6914	0.1794	1.0000	0.3826
Inorganic wastes	-0.0884	0.6994	0.5794	0.5794	0.5794	0.5794	0.3160	0.2453	0.4039	0.3826	1.0000
January 2020											
Temperature	1.0000	-0.0894	0.1331	0.0483	0.2796	0.2796	0.1582	0.6492	0.0678	-0.2060	0.1409
Salinity	-0.0894	1.0000	0.4508	-0.0996	0.4383	0.4383	0.5313	-0.3071	0.4132	0.6765	0.6286
TSS	0.1331	0.4508	1.0000	-0.5647	-0.1200	-0.1200	0.1091	-0.4138	0.0000	-0.3461	0.6422
Turbidity	0.0483	-0.0996	-0.5647	1.0000	0.7185	0.7185	0.4125	0.5416	-0.4875	0.3582	-0.0604
BOD5	0.2796	0.4383	-0.1200	0.7185	1.0000	1.0000	0.7334	0.2451	-0.0917	0.5325	0.2653
COD	0.2796	0.4383	-0.1200	0.7185	1.0000	1.0000	0.7334	0.2451	-0.0917	0.5325	0.2653
N-NH3	0.1582	0.5313	0.1091	0.4125	0.7334	0.7334	1.0000	0.0486	0.0000	0.4567	0.5261
NO3	0.6492	-0.3071	-0.4138	0.5416	0.2451	0.2451	0.0486	1.0000	-0.2431	0.0467	-0.0481
PO4-P	0.0678	0.4132	0.0000	-0.4875	-0.0917	-0.0917	0.0000	-0.2431	1.0000	0.4536	-0.2547
Organic wastes	-0.2060	0.6765	-0.3461	0.3582	0.5325	0.5325	0.4567	0.0467	0.4536	1.0000	0.1101
Inorganic wastes	0.1409	0.6286	0.6422	-0.0604	0.2653	0.2653	0.5261	-0.0481	-0.2547	0.1101	1.0000
February 2020											
Temperature	1.0000	-0.7728	-0.8267	0.4998	0.0076	-0.6349	-0.4071	0.2050	0.1335	-0.2651	-0.6601
Salinity	-0.7728	1.0000	0.5095	-0.3950	0.2066	0.7057	-0.0519	-0.3348	0.0387	0.5618	0.5868
TSS	-0.8267	0.5095	1.0000	-0.6369	0.1065	0.4820	0.2130	-0.1375	0.1588	0.3565	0.4035
Turbidity	0.4998	-0.3950	-0.6369	1.0000	-0.1964	-0.3492	0.2234	-0.4784	-0.1362	-0.3310	-0.4152
BOD5	0.0076	0.2066	0.1065	-0.1964	1.0000	0.1936	-0.4655	0.1803	0.2082	0.2537	0.0519
COD	-0.6349	0.7057	0.4820	-0.3492	0.1936	1.0000	0.1765	-0.4539	-0.4492	0.0566	0.9046
N-NH3	-0.4071	-0.0519	0.2130	0.2234	-0.4655	0.1765	1.0000	-0.1936	-0.4472	-0.3667	0.4020
NO3	0.2050	-0.3348	-0.1375	-0.4784	0.1803	-0.4539	-0.1936	1.0000	0.1443	-0.0574	-0.1654
PO4-P	0.1335	0.0387	0.1588	-0.1362	0.2082	-0.4492	-0.4472	0.1443	1.0000	0.8290	-0.6243
Organic wastes	-0.2651	0.5618	0.3565	-0.3310	0.2537	0.0566	-0.3667	-0.0574	0.8290	1.0000	-0.1373
Inorganic wastes	-0.6601	0.5868	0.4035	-0.4152	0.0519	0.9046	0.4020	-0.1654	-0.6243	-0.1373	1.0000

Conclusions. The organic marine debris was dominated by seagrass pieces, then other waste types, such as vegetable, fruit, fish bone, leaves, branches, etc., while the inorganic waste consisted of plastic, glass, clothes/textile, aluminium, rubber, paper, and styrofoam. Plastic wastes were the most recorded in this study. PCA on the water quality parameters showed several positive correlations, such as TSS, turbidity, BOD_5, and COD to the organic wastes, whereas salinity was positively correlated with inorganic wastes in December. In January 2020, the correlation was found between organic waste and salinity and inorganic waste and TSS. In February 2020, there was positive correlation between the organic waste and PO_4-P, then inorganic waste and COD. There was significant difference in number of marine debris before and after the tsunami in the coastal area of Palu city. The source of marine debris is certainly from the wastes of human activities. Coastal waters and river are major media for waste distribution in the bay of Palu city. The culinary activities along the beach have also contributed to producing the wastes. The waste piles will continuously rise if the waste treatment is not considered, and eventually will reduce the aesthetical value of the coastal and marine areas of Palu bay.

Acknowledgements. We would greatly appreciate the Ministry of Research and Technology, Directore General of Higher Education, that has provided BPPDN scholarship of 2017, Dean of Faculty of Fisheries and Marine Science, the Director of Post-Graduate School of Brawijaya University, Head of Environmental Laboratory of Tadulako University, and Rector Tadulako University who facilitated this research.

Conflict of interest. The authors declare that there is no conflict of interest.

References

Acuña-Ruz T., Uribe D., Taylor R., Amézquita L., Guzman C. M., Merrill J., Martínez P., Voisin L., Mattar B. C., 2018 Anthropogenic marine debris over beaches: spectral characterization for remote sensing applications. Remote Sensing of Environment 217(62):309-322.

Agovino M., D'Uva M., Garofalo A., Marchesano K., 2018 Waste management performance in Italian provinces: efficiency and spatial effects of local governments and citizen action. Ecological Indicators 89:680-695.

Al-Abdulrazzak D., Galland G. R., McClenachan L., Hocevar J., 2017 Opportunities for improving global marine conservation through multilateral treaties. Marine Policy 86:247-252.

Andrades R., Santos R. G., Joyeux J., Chelazzi D., Cincinelli A., Giarrizzo T., 2018 Marine debris in Trindade Island, a remote island of the South Atlantic. Marine Pollution Bulletin 137:180-184.

Baulch S., Perry C., 2014 Evaluating the impacts of marine debris on cetaceans. Marine Pollution Bulletin 80(1-2):210-221.

Becherucci E. M., Rosenthal F. A., Pon J. P. S., 2017 Marine debris in beaches of the Southwestern Atlantic : an assessment of their abundance and mass at different spatial scales in northern coastal Argentina. Marine Pollution Bulletin 119(1):299-306.

Cesar-Ribeiro C., Rosa H. C., Rocha D. O., dos Reis C. G. B., Prado T. S., Muniz D. H. C., Carrasco R., Silva F. M., Martinelli-Filho J. E., Palanch-Hans M. F., 2017 Light-stick: a problem of marine pollution in Brazil. Marine Pollution Bulletin 117(1-2):118-123.

Coe J. M., Rogers D. B., 1997 Marine debris: sources, impacts, and solutions. Springer-Verlag, New York, USA, pp. 110-115.

Di Nola M. F., Escapa M., Ansah J. P., 2018 Modelling solid waste management solutions: the case of Campania, Italy. Waste Management 78:717-729.

Dirrigl Jr. F. J., Badaoui Z., Tamez C., Vitek C. J., Parsons J. G., 2018 Use of the sea hare (*Aplysia fasciata*) in marine pollution biomonitoring of harbors and bays. Marine Pollution Bulletin 129(2):681-688.

Edahbi M., Plante B., Benzaazoua M., 2019 Environmental challenges and identification of the knowledge gaps associated with REE mine wastes management. Journal of Cleaner Production 212:1232-1241.

Effendi H., 2003 [Water quality study for aquatic resources and environmental management]. Yogyakarta: Kanisius, Indonesia, pp. 5-8. [in Indonesian]
GESAMP, 2019 Guidelines for the monitoring and assessment of plastic litter in the ocean. IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP/ISA Joint Group of Experts on the Scientifc Aspects of Marine Environmental Protection. Reports and Studies GESAMP No. 99, 130 pp.
Gough A., 2017 Educating for the marine environment: challenges for schools and scientists. Marine Pollution Bulletin 124(2):633-638.
Hamuna B., Tanjung R. H. R., Suwito S., Maury H. K., Alianto A., 2018 [Study on seawater qualityand pollution index based on physico-chemical parameters in the waters of Depapre district, Jayapura]. Jurnal Ilmu Lingkungan 16(1):35-43. [in Indonesian]
Herrera A., Asensio M., Martínez I., Santana A., Packard T., Gómez M., 2018 Microplastic and tar pollution on three Canary Islands beaches: an annual study. Marine Pollution Bulletin 129(2):494-502.
Hertika A. M. S., Arfiati D., Lusiana E. D., Putra R. B. D. S., 2021a [Analysis on the relationship of water quality and blood glucose level of *Gambusia affinis* in Brantas River]. Journal of Fisheries and Marine Research 5(3):522-530. [in Indonesian]
Hertika A. M. S., Kusriani K., Indrayani E., Putra R. B. D. S., 2021b Density and intensity of metallothionein of *Crassostrea* sp. as biomarkers of heavy metal contamination in the Northern coast of East Java, Indonesia. Egyptian Journal of Aquatic Research 47(2):109-116.
Iñiguez M. E., Conesa J. A., Fullana A., 2017 Pollutant content in marine debris and characterization by thermal decomposition. Marine Pollution Bulletin 117(1-2):359-365.
Jambeck J. R., Geyer R., Wilcox C., Siegler T. R., Perryman M., Andrady A., Narayan R., Law K. L., 2015 Plastic waste inputs from land into the ocean. Science 347(6223): 768-771.
Khedr A. I., Soliman Y. A., El-Sherbeny E. F., Hamed M. A., Ahmed M. A., Goher M. E., 2019 Water quality assessment of the northern part of Suez Gulf (Red Sea, Egypt), using principal component analysis. Egyptian Journal of Aquatic Biology and Fisheries 23(4):527-538.
Kurniadi B., Hariyadi S., Adiwilaga E. M., 2015 [Buaya River water quality in Bunyu Island, North Kalimantan at tidal condition]. Jurnal Ilmu Pertanian Indonesia 20(1):53-58. [in Indonesian]
Lan D., Liang B., Bao C., Ma M., Xu Y., Yu C., 2015 Marine oil spill risk mapping for accidental pollution and its application in a coastal city. Marine Pollution Bulletin 96(1-2):220-225.
Legendre P., Legendre L., 2012 Numerical ecology: developments in enviromental modelling. Springer, Heidelberg, Berlin, pp. 505-523.
Loulad S., Houssa R., Rhinane H., Boumaaz A., Benazzouz A., 2017 Spatial distribution of marine debris on the seafloor of Moroccan waters. Marine Pollution Bulletin 124(1): 303-313.
Marlian N., 2016 [Abundance variation analysis of the nutrients nitrogen, phospate, silicate (N, P and Si) in waters of Meulaboh Bay, West Aceh]. Acta Aquatica 3(1):1-6. [in Indonesian]
Ministry of Living Environment of Indonesia (MLEI), 2004 [Decree of the Ministry of Living Environment numbered 51/MENLH/2004 concerning the establishment of seawater quality standard in living environmental regulations]. Jakarta. [in Indonesian]
Muniz P., Venturini N., Borja A., 2015 Marine pollution and assessment of marine status in Latin America. Marine Pollution Bulletin 91(2):401-402.
Owens K. A., 2018 Using experiential marine debris education to make an impact: collecting debris, informing policy makers, and influencing students. Marine Pollution Bulletin 127(6883):804-810.
Parura C. P. T., Rahardyan B., 2020 Evaluation of post-earthquake, tsunami, and liquefaction disaster waste management in Palu. E3S Web of Conferences 148: 06003.
Pettipas S., Bernier M., Walker T. R., 2016 A Canadian policy framework to mitigate plastic marine pollution. Marine Policy 68:117-122.
Polasek L., Bering J., Kim H., Neitlich P., Pister B., Terwilliger M., Nicolato K., Turner C., Jones T., 2017 Marine debris in five national parks in Alaska. Marine Pollution Bulletin 117(1-2):371-379.

Prajati G., Widiantoro S., 2019 [Identification of seawater quality related with waste treatment in Lengkang Kecil Island]. JTERA Jurnal Teknologi Rekayasa 4(2):203-208. [in Indonesian]
Rajendran V., Nirmaladevi D. S., Srinivasan B., Rengaraj C., Mariyaselvam S., 2018 Quality assessment of pollution indicators in marine water at critical locations of the Gulf of Mannar Biosphere Reserve, Tuticorin. Marine Pollution Bulletin 126:236-240.
Rial D., León V. M., Bellas J., 2017 Integrative assessment of coastal marine pollution in the Bay of Santander and the Upper Galician Rias. Journal of Sea Research 130:239-247.
Rudianto R., Yudaningtyas E., Lelono T. D., Kasitowati R. D., 2020 Utilization of plastic waste processing for oil fuel at Tambaan Beach, Pasuruan City. IOP Conference Series: Earth and Environmental Science 524(1):012006.
Schaduw J. N., 2018 [Distribution and water quality characteristics of small island mangrove ecosystem of Bunaken National Park]. Majalah Geografi Indonesia 32(1): 40-49. [in Indonesian]
Susilo E., Agung R., 2015 [Socio-ecological aspects-based institution and personal]. Universitas Brawijaya Malang, Profil Proyek Coofish Banyuwangi 1998/1999 2005. Banyuwangi. [in Indonesian]
Toledo M., Gutiérrez M. C., Siles J. A., Martín M. A., 2019 Odor mapping of an urban waste management plant: chemometric approach and correlation between physico-chemical, respirometric and olfactometric variables. Journal of Cleaner Production 210:1098-1108.
Vince J., Stoett P., 2018 From problem to crisis to interdisciplinary solutions: plastic marine debris. Marine Policy 96:200-203.
Vo Dong P. A., Azzaro-Pantel C., Cadene A. L., 2018 Economic and environmental assessment of recovery and disposal pathways for CFRP waste management. Resources, Conservation and Recycling 133:63-75.
Walalangi J. Y., Lelono T. D., Suryanto A. M., Damar A., Effendi H., Susilo E., 2020 Composition analysis of organic and inorganic waste and the impacts of coastal city in Palu-Central Sulawesi. IOP Conference Series: Earth and Environmental Science 441(1):012125.
Wessel C., Swanson K., Weatherall T., Cebrian J., 2019 Accumulation and distribution of marine debris on barrier islands across the northern Gulf of Mexico. Marine Pollution Bulletin 139:14-22.
Wilcox C., Mallos N. J., Leonard G. H., Rodriguez A., Hardesty B. D., 2016 Using expert elicitation to estimate the impacts of plastic pollution on marine wildlife. Marine Policy 65:107-114.
Wilhelmsson D., Thompson R. C., Holmström K., Lindén O., Eriksson-Hägg H., 2013 Marine pollution. In: Managing ocean environments in a changing climate: sustainability and economic perspectives. Noone K. J., Sumaila U. R., Diaz R. J. (eds), Elsevier Inc., pp. 127-169.
Wiyoto W., Effendi I., 2020 [Analysis of water quality for mariculture in Moro, Karimun, Riau Islands with principle component analysis]. Journal of Aquaculture and Fish Health 9(2):143-154. [in Indonesian]

Received: 14 December 2021. Accepted: 17 January 2022. Published online: 30 January 2022.
Authors:
James Yosep Walalangi, Faculty of Fisheries and Marine Science, Brawijaya University, Malang 65145, East Java, Indonesia; Faculty of Animal Husbandry and Fisheries, Tadulako University, Palu 94118, Central Sulawesi, Indonesia, e-mail: walalangijames@untad.ac.id
Tri Djoko Lelono, Faculty of Fisheries and Marine Science, Brawijaya University, Malang 65145, East Java, e-mail: t.djoko@ub.ac.id
Asus Maizar Suryanto Hertika, Faculty of Fisheries and Marine Science, Brawijaya University, Malang 65145, East Java, e-mail: asusmaizar@ub.ac.id
Edi Susilo, Faculty of Fisheries and Marine Science, Brawijaya University, Malang 65145, East Java, e-mail: olisuside_fpik@ub.ac.id

How to cite this article:
Walalangi J. Y., Lelono T. D., Hertika A. M. S., Susilo E., 2022 The characteristics of marine debris and water quality in Palu Bay, Central Sulawesi, Indonesia. AACL Bioflux 15(1):261-271.