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Characteristics and carbon properties of mangrove soils in Pasuruan and Probolinggo Regency, East Java, Indonesia

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Key words: Mangrove sediment, Carbon, Bulk density, East Java.

Abstract

Mangrove soils are the foundation for mangrove forests and have unique functions and characteristics. This study was performed in the mangrove soils of Pasuruan and Probolinggo Regency, East Java, Indonesia. It aimed to characterize the type of mangrove sediment as well as to estimate the soil bulk density (BD) and % organic carbon (OC). The sediments were sampled up to the depth of 50cm (0-10cm, 10-25cm, and 25-50cm) using a modified stainless steel soil auger with a diameter of 6.5cm. OC measurement was performed using combustion method. The grain size determination was determined using both gradation and hydrometer methods. Based on the proportion of sand, silt and clay particles, the types of sediment were mostly dominated by silty sand followed by sandy silt, and silt, 47%, 20%, and 20% respectively. Meanwhile, the values of BD were between 0.81g cm^{-3} and 1.24g cm^{-3} with an average value of 0.99g cm^{-3}. % OC values varied from 4.7% to 10.16% with an average value of 6.61%. BD was inversely correlated with % OC in which the higher BD likely resulted the lower value of % OC. It might due to the property of finer sediment that has higher affinity to attach organic matter.

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Introduction

Mangroves forests cover an area of 152,361km² around the world which are mostly in tropical intertidal areas, with some forests exist in subtropical regions. The largest extent of the forests flourished in Asia and Africa (42% and 20% respectively), followed by North and Central America (15%), Oceania (12%), and South America (11%). By far, the largest area of mangroves occurred in Indonesia, followed by Australia and Malaysia, 31,894km², 9910km², and 7097km² respectively (Craft, 2016).

Mangrove forests are productive ecotone ecosystems that play important role both to environment and human well-being (Asadi *et al.*, 2018b; Donato *et al.*, 2011), including spawning and nursery ground of many marine organisms, wood and food production, nutrient cycling, ecotourism, carbon (C) storage, and soil formation (Murdiyarso *et al.*, 2015).

Vegetation structure and species composition of mangroves may vary considerably around the world in response to environmental parameters such as salinity, depth, and water flow. Moreover, the substrates, soil or sediment on which mangroves develop nourish and shape mangrove vegetation (Friess, 2019). Mangroves may grow in different types of substrate, soil, and sediment. Mangrove soils are made up of gravel, sand, silt, and clay, transported as sediment and deposited by current and tide of the sea, and water flow of the rivers. Meanwhile, mud in mangrove soils is the mixture of clay and silt which are rich in organic matter (OM) (Asadi *et al.*, 2018a).

The composition of mangrove soils have significant variation at different depths, including variation in quantity of OM. Top-soils are more porous which are able to facilitate aeration and water percolation during low tide. The sub-soils, soils below the surface or topsoil, are typically waterlogged and store a lot of OM (Hossain and Nuruddin, 2016). Previous study of spatial and vertical distribution of mangrove sediments in Labuhan and Sedayulawas mangrove forest, Lamongan, Indonesia showed that there were variations in their sediment types. Bulk density (BD) as well as C content were also highly correlated with the sediment types (Asadi *et al.*, 2018a). The sediment of mangrove forest in Pasuruan and Probolinggo, East Java, Indonesia has distinct properties since the areas are influenced by the sediment material from the mountain streams. Therefore, this study aimed to examine the soils of mangrove ecosystems of Pasuruan and Probolinggo regency, East Java, Indonesia. The grain sizes of soils at depth intervals of 0-10cm, 10-25cm and 25-50cm were measured to classify the mangrove soils based on Wentworth aggregate class. C properties that were C contents and BD were also examined at the same depth intervals.

Materials and methods

Description of the study area.

The field sampling was performed in January 2019 at the mangrove forests of Pasuruan and Probolinggo regency, East Java, Indonesia. The forests of Pasuruan Regency (station 1 and 2) constituted both planted and natural mangroves and were managed by the local communities. Meanwhile, Probolinggo regency (station 3, 4, and 5) had natural mangroves in which no authority was in charge to manage the forests. The mangroves in all research stations were fringe mangroves with an average of 50-100m wide strip along the coastlines. The map and the coordinates of the study areas along with their environmental parameters are presented in Fig. 1 and Table 1 respectively.

Sample collections and laboratory procedure of soil

In each station, there were 3 sampling plots, in which a total of fifteen plots was established in the whole research areas. Samples were collected using a stainless steel soil auger with diameter of 6.5-cm. Soils were divided by depths interval of 0-10cm, 10-25cm and 25-50cm, totaling 45 soil samples from all research stations. Each sample was placed in a sealed plastic bag and was stored in a cool box. The samples were then immediately transported to Marine Science laboratory, University Brawijaya for further soil analysis.

In the laboratory, each soil sample was dried using an oven at 60^{0}C for 48-96 hours to obtain a constant dry weight.

The analysis of particle size distribution was performed using both gradation and hydrometer method in which coarser soil was performed using the former method while the finer soil was conducted using the latter method (ASTM, 2016; Das, 2009). Furthermore, Wentworth grain size chart and Shepard's diagram were used to classify soil samples based on soil class diameter and their proportion (Asadi *et al.*, 2018a). Meanwhile, the loss-on-ignition method (LOI) was used to determine OM through combustion of each sample at very high temperature. In brief, a total of 2 gram of each sample was burnt at 550^{0}C for 3 hours using a laboratory furnace.

All soil samples were reweighed to obtain OM of the samples (Asadi *et al.*, 2018a; Kauffman and Donato, 2012).

Soil analysis

Soil samples were analyzed to obtain the values of bulk density (BD) and the percentage of organic C. BD was performed using this following formula:

$$\text{Soil BD (g cm}^{-3}) = \frac{\text{Oven-dry sample mass (g)}}{\text{Sample volume (cm}^3)} \quad (1)$$

Meanwhile, the percentage of organic C was determined by converting OM using a conversion factor of 1.724 as OM contained 58% of organic C (Schumacher, 2002).

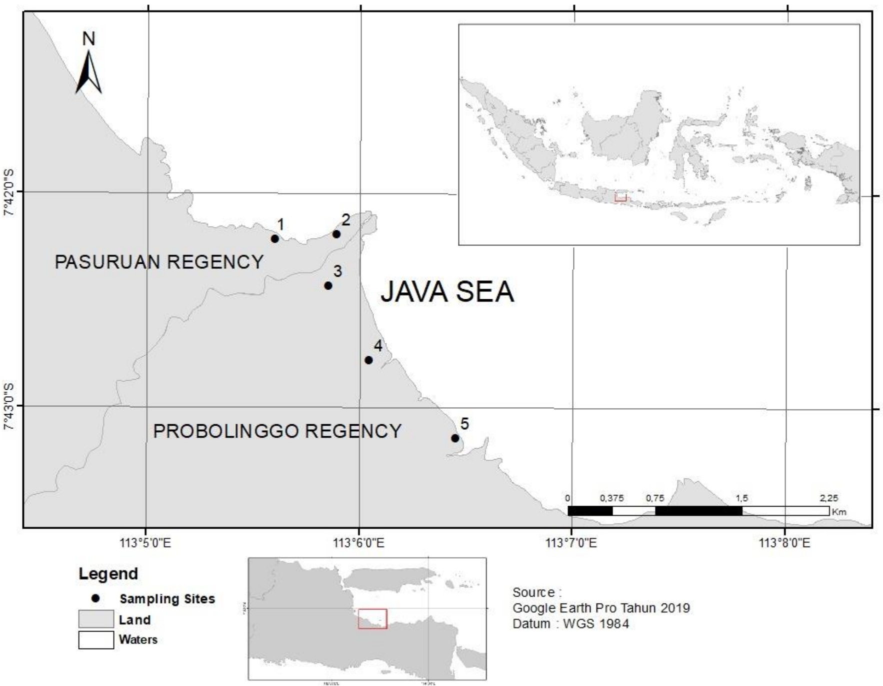


Fig. 1. The sampling stations map of mangrove forests of Pasuruan and Probolinggo, East Java, Indonesia.

Table 1. Coordinates, salinity, and soil pH of each research stations.

Station	Longitude	Latitude	Soil pH	Salinity
1	113.093379°	-7.703761°	6.83±0.29	29.33±1.53
2	113.097858°	-7.703401°	6.67±0.29	32.33±1.53
3	113.097595°	-7.707181°	6.50±0.00	32.00±1,00
4	113.100380°	-7.713456°	6.67±0.29	28.67±1.53
5	113.107424°	-7.719216°	6.50±0.00	28.33±1.15

Result

Soil Characteristics

Sand dominated soils in all depths of station 1, 2, and 4 with values > 50%. Silt constituted > 75% and > 45% of soils in all depth of station 3 and 5 respectively. On average, at the depth of 0-10cm, 10-25cm, and 25-50cm, sand contributed 47.96%, 47.68%, and 46.99% of total soil types respectively with a total average of 47.54%. Meanwhile, on average, clay contributed only 10.28% with the highest concentration at depth 25-50cm with concentration of 10.57% (Fig. 2). Based on the proportion of sand, silt and clay particles, the soils were classified using Shepard's diagram.

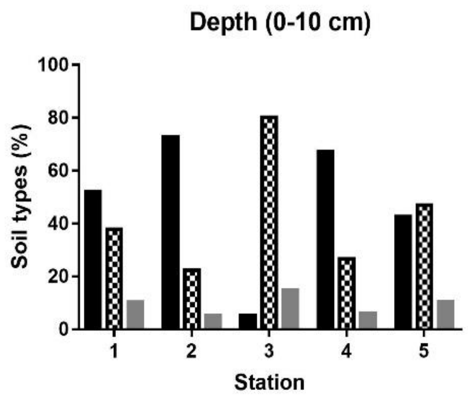
The texture of samples were silty sand in all depths of station 1 and 2, silt in station 3, sandy silt in station 4. Meanwhile, in station 5, the soil types were sand in the depths of 0-10cm and 25-50cm, and silty sand in the depth of 10-25cm.

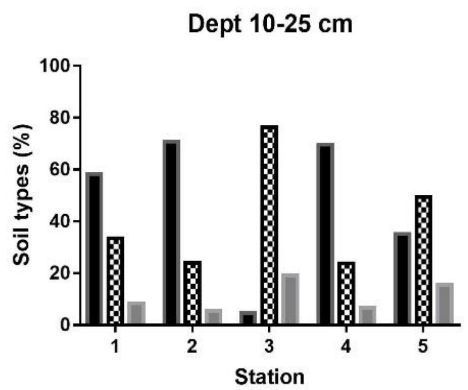
Bulk density and %C organic

BD varied from 0.81g cm^{-3} at depth of 25-50cm of station 3 to 1.24g cm^{-3} at depth of 25-50cm of station 1 (Table 2). Two-way ANOVA showed no significant differences in BD and %OC among depths and stations (P >0.05). However, linear regression of BD and %OC showed significance with P <0.001 (total number of data=45). BD was moderately inversely correlated with %organic C with R^2=0.62 and Y = -8.02*X + 14.62. The higher BD likely resulted lower %organic C (Fig. 3).

Table 3. The average of BD and %OC in each depth of each stations.

Station	Depth (cm)	BD (g cm^{-3})	OC (%)
1	0-10	1.05	7.11
	10-25	1.07	6.32
	25-50	1.24	5.23
2	0-10	1.20	4.70
	10-25	1.16	5.12
	25-50	1.09	6.05
3	0-10	0.84	9.55
	10-25	0.77	10.09
	25-50	0.81	10.16
4	0-10	1.10	4.81
	10-25	0.89	6.13
	25-50	1.04	4.91
5	0-10	1.03	5.47
	10-25	0.85	6.43
	25-50	0.84	7.08





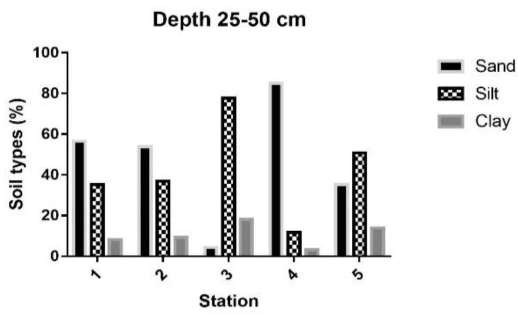


Fig. 2. The percentage of soil types (sand, silk, and clay) at each depth and station.

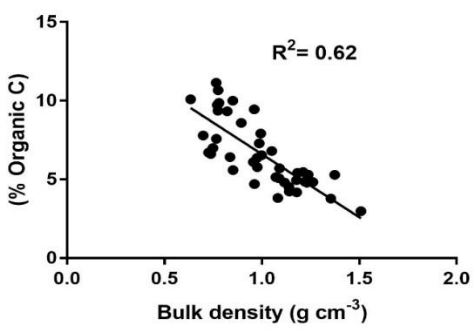


Fig. 3. Linear regression of % organic C and bulk density (g cm^{-3}), Y = -8.02*X + 14.62.

Table 2. Soil classification using the Shepard's diagram.

	Station				
Depth (cm)	1	2	3	4	5
0-10	silty sand	silty sand	silt	sandy silt	sand
10-25	silty sand	silty sand	silt	sandy silt	silty sand
25-50	silty sand	silty sand	silt	sandy silt	sand

Discussion

Mangrove soil Characteristics

In mangrove ecosystems, physical properties of soils may vary considerably even at the local scales which depend on hydro-environmental setting of the ecosystems (Das, 2009; Hossain and Nuruddin, 2016). In mangrove forest of Labuhan, Lamongan, Indonesia, for example, silt dominated the distribution of grain size in most research stations in which there was also a station that was mostly characterized by sand (Asadi *et al*., 2018b). The dominance of silts are observed in most mangrove soils worldwide. In Zhangjiang estuary, China, silt even made up 61-72% of soils (Xue *et al*., 2009). In mangrove forest of Sunderbans, India, silt constituted 36-62% of soils (Hossain and Nuruddin, 2016). In Sedayulawas (artificial riverine mangroves), Lamongan, Indonesia, sand was not even observed in all research stations (Asadi *et al*., 2018a)

However, in this study, sands dominated soil types with a total average of 47.54%. As sands contribution in station 1 and 2 was less than 75% with considerable amount of silt, the soil was categorized as silty sand. Meanwhile, in all depths of station 3, and in depths of 0-10cm and 25-50cm of station 5, the concentration of silt and sand were more than 75%. Therefore, the soils were categorized as silt and sand respectively (ASTM, 2016). The mangrove forests in the current study were mostly fringe mangroves; therefore, it is expected that sand and gravel from the adjacent marine environments are constantly transported to the mangrove forests. However, the sand and gravel characteristics in most research stations and plots showed that the sediments were mostly dark gray or black color; therefore, the sediments were typically from mountain ranges. Water flow from the rivers constantly transport sand material from the mountain streams to the mangrove or coastal areas (Matenco and Andriessen, 2013).

Bulk density and %C organic

BD was not directly correlated with %OC. However, BD tends to have an inverse correlation with % OC. In Labuhan (natural fringe mangrove forests), Lamongan, East Java, Indonesia, the average BD was 0.73g cm^{-3} while the average % OC was 6.39%. Meanwhile, in its neighbor mangrove forest, Sedayulawas riverine mangrove forests, the average of BD and % OC were 0.96g cm^{-3} and 3.67% respectively (Asadi *et al*., 2018a). In fringe mangrove of Can Gio Mangrove Biosphere Reserve (CGMBR) and the Kien Vang Protection Forest (KVPF), Vietnam, BD also had an inverse correlation with %C. The BD of both areas were 0.54g cm^{-3} and 0.65g cm^{-3} respectively, while the % C were 4.65% and 3.87% respectively (Nam *et al*., 2016)

On average, the lowest BD was in the station 3 (0.80g cm^{-3}) in which it also had the highest % OC (9.93%). Moreover, the highest BD also had the lowest % OC (1.15g cm^{-3} and 5.29% respectively). Soil with higher amount of % OC is attributed to lower mass of soil and BD (Asadi *et al*., 2018a). BD is correlated with the relative proportion of sand, silt, and clay which is determining the particles and the pore spaces. BD calculation is the measurement of soil weight in relation to the volume of soil which tends to increase with the compactness of the soil. Some studies showed that the % OC increase with decreasing grain size based on characteristic of fine-grained soils that has higher affinity to adsorb OM (Yang *et al*., 2016).

Conclusions

The type of soil in the mangrove forest of Pasuruan and Probolinggo Regency, East Java, Indonesia was dominated by sand in which 47% of soil in the whole research areas was in the form of silty sand. Dark grey or black was dominated the color of sediment which was typically pyroclastic sand from the surrounding mountain, especially Bromo mount.

It was transported to the mangrove ecosystem via the mountain streams and rivers. The depths of sediment did not affect the values of BD and % OC. However, it showed that the % OC significantly decreased with increasing the soil BD. It may due to the fact that the finer grain or type of sediment hold higher amount of % OC in which this type of sediment also typically has less value of BD.

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