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Relationship between organic carbon and sediment properties in mangrove forests of three Bushehr coastal areas

Masoumeh Mahmoudi[1] and Sharareh Pourebrahim[2†]

[1] *Water Resource Quality Management, Khuzestan Water & Power Authority, Ahvaz, Iran*
[2] *Associate Professor, Faculty of Natural Resources, University of Tehran, Tehran, Iran*

†*Corresponding Author Email: sh_pourebrahim@ut.ac.ir*

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ABSTRACT

One of the main ecosystem services of mangroves is enhancing carbon sequestration, most of which is done by sediments. Therefore, recognizing sediment properties is useful to evaluate the factors affecting carbon uptake in mangrove sediments. To identify the relationship between sediment organic carbon (SOC) content and sediment properties, sampling from three mangrove forests in Bushehr (Iran) coastal regions (Asalouyeh, Basatin, and Malegonzeh) was performed at 6 different stations, and the SOC of the samples were measured by Walkley and Black method. The particle diameters were performed by the sieving and hydrometer method and the results were analyzed (Gradistat. v8). The results showed that the highest percent of particles were silt, ranging from 93.6 to 96.6%. Several sediment grain size properties were correlated with SOC. Two factors were analyzed in principal component analyses, which were responsible for 75.8% of the samples attrinbutes. Factor 1 was organic carbon (SOC), skewness, sand, mean size, sediment density, clay, and silt summation (clay & silt). Factor 2 included clay, sorting, and kurtosis. Organic carbon was positively correlated to sorting, clay & silt percent, and grain size (□). Meanwhile, the SOC was negatively correlated to sediment density, C, sand percent, and skewness. Generally, by decreasing the size of the sediment particles, the amount of SOC increased. Areas with fine-grained sediments appear to be able to absorb more organic carbon.

Keywords: Blue carbon, Carbon sequestration, Coastal areas, Ecosystem services, Sediment organic carbon.

1. Introduction

Mangrove provides various ecosystem services such as the provision of nursery grounds for fish, birds, and mammals, nutrient and sediment preservation, storm protection (Alongi, 2008), and carbon storage (Donato et al., 2011; Kauffman et al., 2011; Stringer et al., 2015). Carbon sequestration in mangrove forests has made an important role in CO_2 absorption and global warming decrease. Mangrove is capable for capturing and storing great amounts of carbon in sediment by settling down (Adame et al., 2013; Murdiyarso et al., 2010; Pendleton et al., 2012). High concentrations of carbon are the result of high sedimentation and persistent anaerobic conditions beneath the surface, which decrease organic matter decay and thus causes the formation of precipitated carbon (Ray et al., 2011). Sequestration and storage of carbon in mangroves are continuous and led to the settling great amounts of carbon in forests (Matsui et al., 2012; Pendleton et al., 2012). In many mangrove ecosystems, carbon has a history over a thousand years and these environments become the richest ecosystems on the earth (Donato et al., 2011; Webb et al., 2013). Unlike products and services with commercial value, in the mangrove ecosystem, the benefits of adjusting services like carbon are less implicit (Bouillon et al., 2008; Matsui et al., 2012).

Some mangrove forests have rich organic matter as a result of their high carbon storage (Alongi, 2002). Trees and sediment are the two carbon sources in mangroves (Donato et al., 2012). The sediment source is richer than the tree source (Donato et al., 2011; Kauffman and Donato, 2012; Kauffman et al., 2011). The large mass of sediment sources and the low understanding of its susceptibility to land-use change has made it important to study (Kauffman and Donato, 2012). Despite importance of sediment, this section is less studied compared to other reserves in mangrove ecosystems (Kauffman and Donato, 2012). This may be because of difficulty in obtaining an exact estimate (Donato et al., 2011). In flooded mangrove forests, anaerobic conditions reduce the rate of breakdown of organic substances and accelerate carbon increase (Nguyen et al., 2009). A study conducted by Kauffman et al. (2011) showed that in the Micronesia mangrove forests of the Western Pacific, the sediment was accounted for 70% of the ecosystem carbon. One of the significant factors that caused carbon deposition in mangrove forests compared to terrestrial ones is related to the bed of mangroves which leads to the high rate of sedimentation in the tidal environments. Mangrove trees are recognized pools for catching and settling the fine matter and SOC attached to sediments, because of their branch divisions in both the upper parts and the roots, as well as the existence of aerial roots. According to this, great carbon quantity is in the sediment of mangroves (Donato et al., 2011; Kauffman et al., 2011; Stringer et al., 2015). The slow wave of water in these areas helps to settle suspended solids while the terrestrial trees have none of these surroundings (Kristensen et al., 2008).

Other factors affecting carbon content in sediment can be related to sedimentation conditions and sediment features. The study and determination of factors affecting the carbon sequestration in mangrove sediments clarify the reason for the great differences between carbon content in terrestrial forest soils and mangrove forest sediments. This knowledge helps to protect mangrove forest sediments and increase carbon storage.

The mangrove forests of Bushehr province are located on the coast of this province in the north of the Persian Gulf. Since Bushehr province is an important center in the oil and gas industry in Iran, the mangrove forests of this province play a strategic role in terms of carbon sequestration ecosystem services. Increasing knowledge about all component sources of carbon and their characteristics leads to suitable local decision-making for more protection and cultivation of mangroves. However, there are no studies on the relationship between SOC (Sediment Organic Carbon) and sediment properties in mangroves of Iran, and the only study on carbon in the Nayband forest (Ghasemi, 2016) studied the carbon only in trees. One of the important factors in the management and development of mangrove forests is the suitable bed (sediments) for the growth of these trees. Therefore, information on the relationship between SOC (organic carbon) supply and sediment properties of these forests is necessary in this regard. Accordingly, to determine the role of sediment properties in SOC in sediments of Bushehr mangrove, the SOC and sediment properties in three mangrove forests were studied in the present study.

2. Materials and Methods

2.1. The study area

Nayband bay on the north coast of the Nayband area is one of the most valuable marine habitats in the Persian Gulf and it is the first national marine park in Iran. The climate of Nayband bay is semi-tropical. The temperature is 12 to 16 ^{0}C in winter, and 36 to 42 ^{0}C in summer, and the rainfall often is 150 mm/year (Lar Consulting Engineers, 2006). Nayband has several beaches, including mangrove and sandy beaches in the northern and eastern parts, and also rocky shores with a narrow margin of the sands in the south of the bay. There are two important bays in Nayband called Asalouyeh and Basatin.

The Asalouyeh bay length is 5250 meters and it flows in low slope lands in the south of Bidkhoon village. This bay is under the influence of the tides and has created a wetland area of 8400 ha. Basatin bay is located on 2 km northeast of Basatin village, which has 3100 meters of length with an adjacent wetland area of 56 hectares (Amiri et al., 2011).

Malegonzeh forest is located in the Mond protected area. This region is geographically situated 146 km southeast of Bushehr province in the plain region next to the Bardkhoon section of Dayer city. Figure 1 shows the position of the study areas on the map. Asalouyeh forest (area of 120 ha) and Basatin forest (area of 37 ha), at 27 28 N - 27 24 N and 52 38 E - 52 41 E, also Malegonzeh (area of 10.3 ha), at 27 50 N and 51 34 E are the three studied forests that are shown on the map.

The results of the geological map and erosion susceptibility of previous studies show that the Nayband region is composed of soft and erosion-sensitive geological formations. Therefore, resistant formations cover only about 12% of the region and the rest are among the formations that are moderately erosive, weak, and very weak. Therefore, the study basin has a high natural potential for erosion and sedimentation (Davoodi and Kazemi, 2018).

2.2. Sampling

Six sediment samples were collected from the stations by a pipe core sampler (60 cm in length). Four samples were collected from the Asalouyeh (A), with larger area than the other two forests and no tree coating. One core of sediment was sampled from each forests of Basatin (B1), and Malegonzeh (M). Sediment samples were transferred to the laboratory in Tehran University and stored at 4 ° C until the analysis can be conducted. The sediment in each core was cut into six deep pieces (10, 20, 30, 40, 50, and 60 cm) for analyzing SOC and sediment properties.

2.3. Organic carbon measurement

The SOC was determined by the modified Walkley and Black method (Liu et al., 2013; Schumacher, 2002; Wang et al. 2013). The homogeneous and sieved (0.5 mm) sample (1 g) was oxidized by 10 ml of 1 N $K_2Cr_2O_2$ solution. The sample was titrated with an ammonium iron sulfate solution [$Fe(NH4)_2SO_4$ * $6H_2O$]. Phenanthroline was used as an indicator. The mentioned process was done for both, the boiled and unboiled blank to calculate the precision and extraction efficiency (Liu et al., 2013; Schumacher, 2002; Wang et al., 2013).

The corrected dichromate in SOC oxidation was calculated by Equation 1. The SOC percent was calculated using Equation 2. The SOC was calculated by Equation 3 (Liu et al., 2013; Schumacher 2002; Wang et al., 2013,).

$$A= [\text{ml BB-ml sample}) \times (\text{ml UB-ml BB})]/ \text{ml UB}] + (\text{ml BB-ml sample}) \quad [1]$$

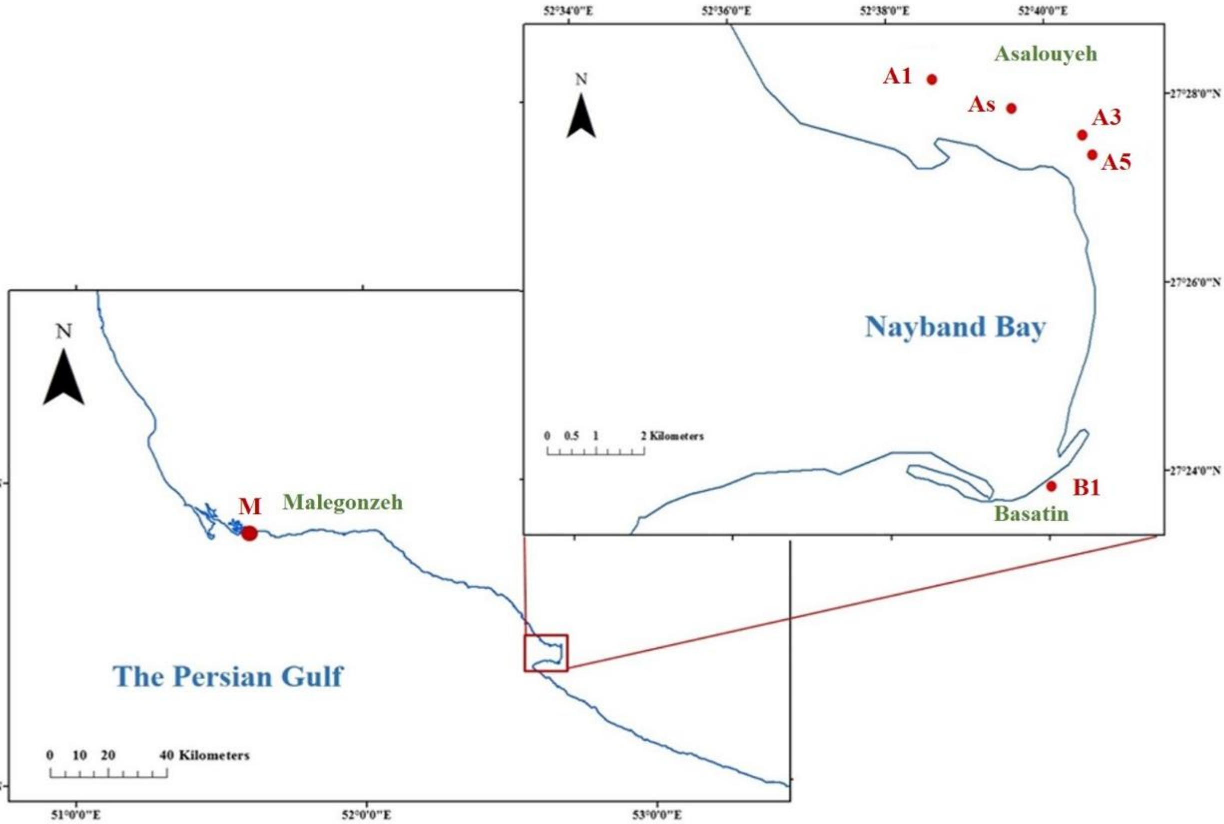

Fig. 1. Location of the studied stations on the map.

where; *A*: titer volume of corrected dichromate, *ml UB*: the titer volume of unboiled blank, *ml BB*: the titer volume of boiled blank, ml sample: the titer volume of sample

$$\% \text{ Organic C} = [A \times MFe^{2+} \times (0.3)] / \text{weight of dried soil (g)}] \times 100 \quad [2]$$

where; *A*: titer volume of corrected dichromate, *MFe2⁺*: molarity of Iron ammonium sulfate, 0.3 is carbon equivalent

$$\text{SOC (kg } h^{-1}) = 10000 \times \text{BD (g } cm^{-3}) \times \text{soil depth (cm)} \times \%\text{SOC} \quad [3]$$

where; *BD*: The density of sediment dry weight

2.4. Sediment properties

The density of the dry sediment (g cm^{-3}) was determined by dividing the dry weight of the sample into the sampling volume (sampler cylinder volume). The particle size of the sediment is determined by a combination of the mesh and hydrometer. 120 grams of the sample was treated with 40% H_2O_2 and dried again. 100 gr of the sediment samples were passed through 707, 300, 150, and 63-micron mesh (Yang et al., 2014). The residue on each mesh was weighed. 50 g of passed sample of the last mesh was placed in a balloon and was rotated with 100 ml of 4% sodium hexametaphosphate for 24 hours. Then, the samples were transferred to a 1-liter cylinder and filled volume to 1 liter with water. Samples were read using a 151H sedimentology hydrometer. The data were analyzed by Gradistat. v8 and the mean particle size, □ index, clay, sand percent, silt percent, skewness, kurtosis, and sorting have gained the formulas described by folk and ward, 1957.

2.5. Statistical analysis

To analyze the data, SPSS 25 IBM, USA software was used. The data normality was checked by Shapiro Wilk. The SOC between stations was compared by One-way ANOVA ($P<0.05$). To determine the difference between similar groups, the Tukey post hoc test was used. The Pearson correlation test was used at a significant level of 0.05 to verify the correlation between SOC and sediment factors at different stations. Factor analysis was used to determine the main factors of SOC and sediment factors, including particle size, □, skewness, kurtosis, sorting, and clay, sand, and silt percent in all stations.

Table 1. The SOC content and sediment properties in the study area.

	Station A1	Station A3	Station A5	Station As	Station B1	Station M
SOC (g cm^{-2})	15.53±3.94	10.42±3.74	17.42±3.83	7.39±2.12	12.14±2.89	10.21±1.60
%SOC	1.17±0.30	0.83±0.37	1.33±0.30	0.53±0.17	0.95±0.28	0.89±0.18
%Clay	1.75±0.30	1.08±0.35	1.67±0.19	1.48±1.73	1.77±0.41	0.80±0.55
%Clay&Silt	97.93±0.48	94.52±2.42	98.27±0.36	94.90±2.56	97.52±1.02	97.07±0.90
%Silt	96.48±0.39	93.58±2.27	96.60±0.28	94.12±1.74	95.75±1.04	96.28±0.96
%Sand	1.75±0.27	5.33±2.60	1.73±0.33	4.50±2.20	2.48±0.98	2.93±0.90
□	5.70±0.06	5.50±0.08	5.70±0.04	5.56±0.11	5.70±0.04	5.67±0.08
Mz	19.35±0.66	22.17±1.24	19.25±0.55	21.31±1.64	19.41±0.81	19.69±1.09
Sor	1.43±0.04	1.37±0.05	1.42±0.03	1.41±0.07	1.44±0.05	1.35±0.05
Sk	0.22±0.06	0.31±0.04	0.21±0.03	0.30±0.03	0.18±0.02	0.12±0.06
Ku	0.59±0.04	0.59±0.06	0.59±0.02	0.59±0.08	0.58±0.04	0.55±0.03
Sed.D(g cm^{-3})	1.28±0.11	1.32±0.18	1.31±0.04	1.33±0.03	1.29±0.11	1.16±0.09

SOC (Organic Carbon), Mz (Mean size µm), □ (Particle size), Sor (Sorting), Sk(Skewness), Ku (Kurtosis), Sed.D (Sediment Density)

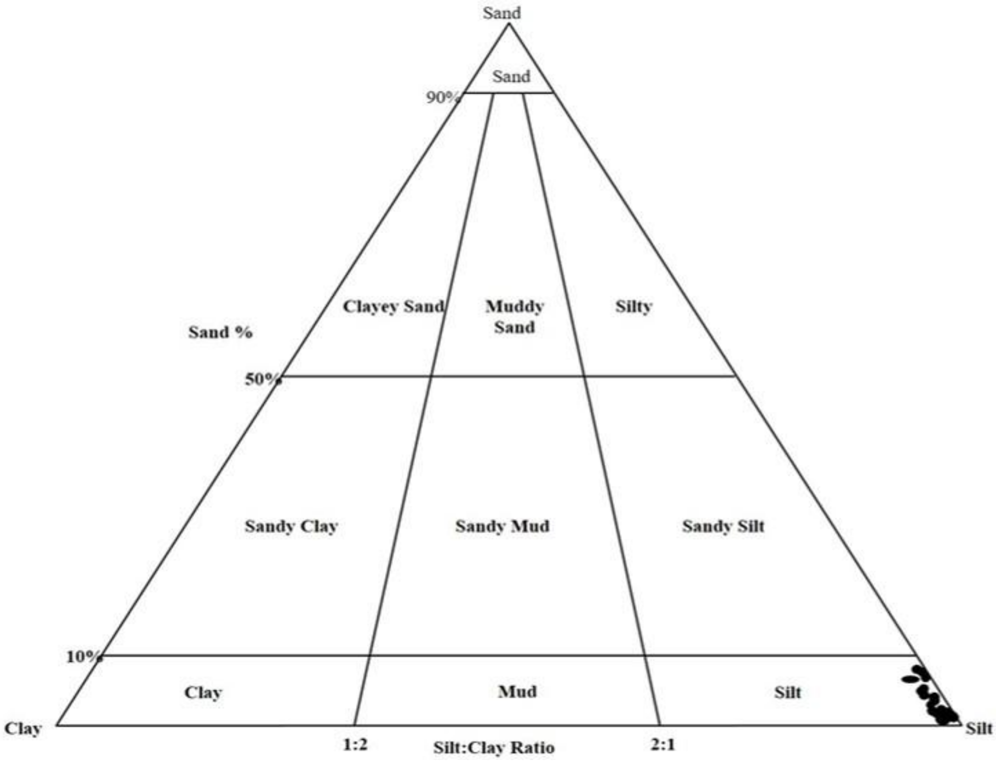

Fig. 2. Sediment texture triangle in the studied sediments.

3. Results

The results of SOC measurements at 6 stations showed that the SOC percent in sediment varied from 0.53% to 1.33%. The average SOC percent at stations A1, A3, A5, As, B1 and M were 1.17, 0.83, 1.33, 0.53, 0.95 and 0.89, respectively. Station As had the lowest amount of SOC and Station A5 had the highest amount of SOC ($P<0.05$).

Table 1 shows SOC content and the factors related to the sediment particle size at the stations. The sediment texture in all samples was silty, ranged 93.58 - 96.60 %. The amount of clay and sand was low in all samples. Figure 2 shows the sediment texture triangle in the study areas.

Several factors related to the sediment particle's s

Table 2. The correlation of SOC with the sediment factors distribution in the study area.

	SOC	Mz	□	Sor	Sk	%Sand	%Silt	%Clay	%Clay&Silt
Station A1	(g cm^{-3})	-0.467	0.499	.853*	0.121	0.039	-0.64	.910*	-0.09
	%	-0.492	0.528	.869*	0.108	-0.01	-0.616	.920**	-0.064
Station A3	(g cm^{-3})	-.857*	.862*	0.032	0.412	-.851*	.839*	.886*	0.789
	%	-0.785	0.793	0.144	0.408	-0.75	0.735	.812*	0.676
Station As	(g cm^{-3})	-.812*	0.773	0.23	-0.529	-.875*	.902*	0.572	0.672
	%	-0.643	0.614	0.042	-0.585	-0.745	.849*	0.33	.838*
Station A5	(g cm^{-3})	-.947**	.946**	0.803	-0.538	-.821*	0.442	.881*	.812*
	%	-.919**	.918**	.861*	-0.447	-0.758	0.343	.925**	0.757
Station B1	(g cm^{-3})	-.891*	0.752	0.222	-0.671	-.826*	0.658	0.342	0.811
	%	-.813*	0.669	0.171	-0.679	-0.732	0.594	0.264	0.714
Station M	(g cm^{-3})	-0.636	0.622	0.00	-.921*	-.869*	.929**	-0.191	.869*
	%	-0.564	0.547	-0.124	-.923*	-0.697	.894*	-0.422	0.697

Mz (mean size, µm), □ (Mean size, □).

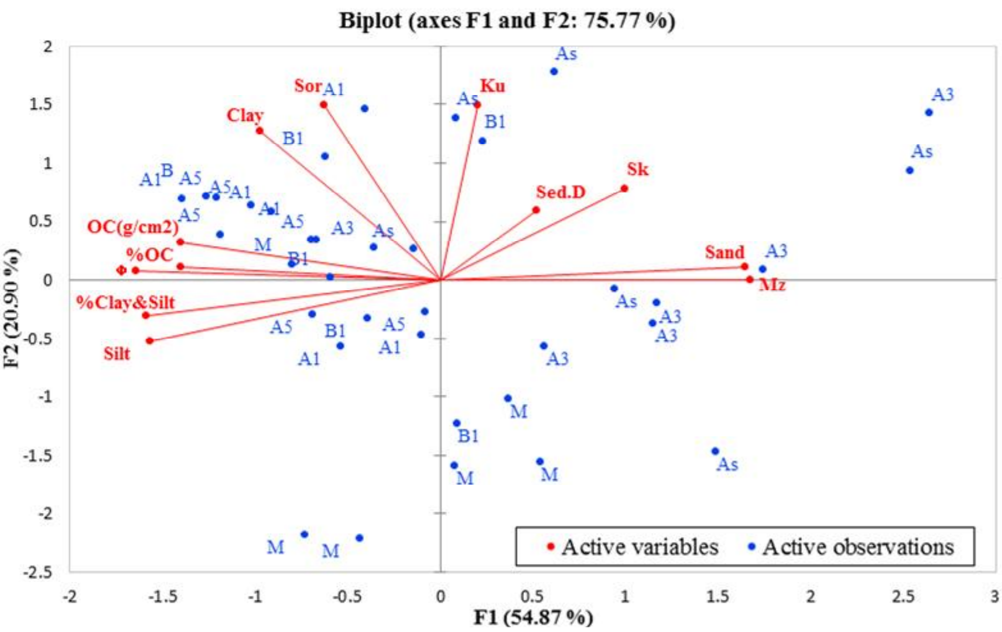

Fig. 3. PCA for sediment properties in the sediment sample from studied stations.

diameter were significantly correlated with the amount of SOC in some stations. The correlations between sediment factors and SOC values are shown in Table 2. A significant correlation was observed between SOC and several sediment factors, regarding the sampling station at each station. Also, most of the sediment parameters had a significant correlation together. For this reason, the factor analysis was performed for sediment factors and SOC content. The results of these correlations are presented in Fig. 3. Clay, Sor, and Ku were factors 2 and the rest factors are factors 1. The SOC was positively correlated to Sor, clay & silt percent, and □. All sample of stations A1 and A5 (which have more SOC content) are located in this factor. Meanwhile, the sediment density, particle size, sand percent, and Sk were negatively correlated to the SOC. Almost most of the samples are among the two factors. Factors 1 and 2 are responsible for 75.8 percent of the samples, but the samples from the control station (M) and many samples of stations as and A3 (which have less SOC content) are almost beyond the factors and other specimens.

The general relationship between SOC and clay & silt was positive (R^2=0.58, exponential). Also SOC related positively to silt (R^2=0.53, exponential), clay (R^2=0.13,

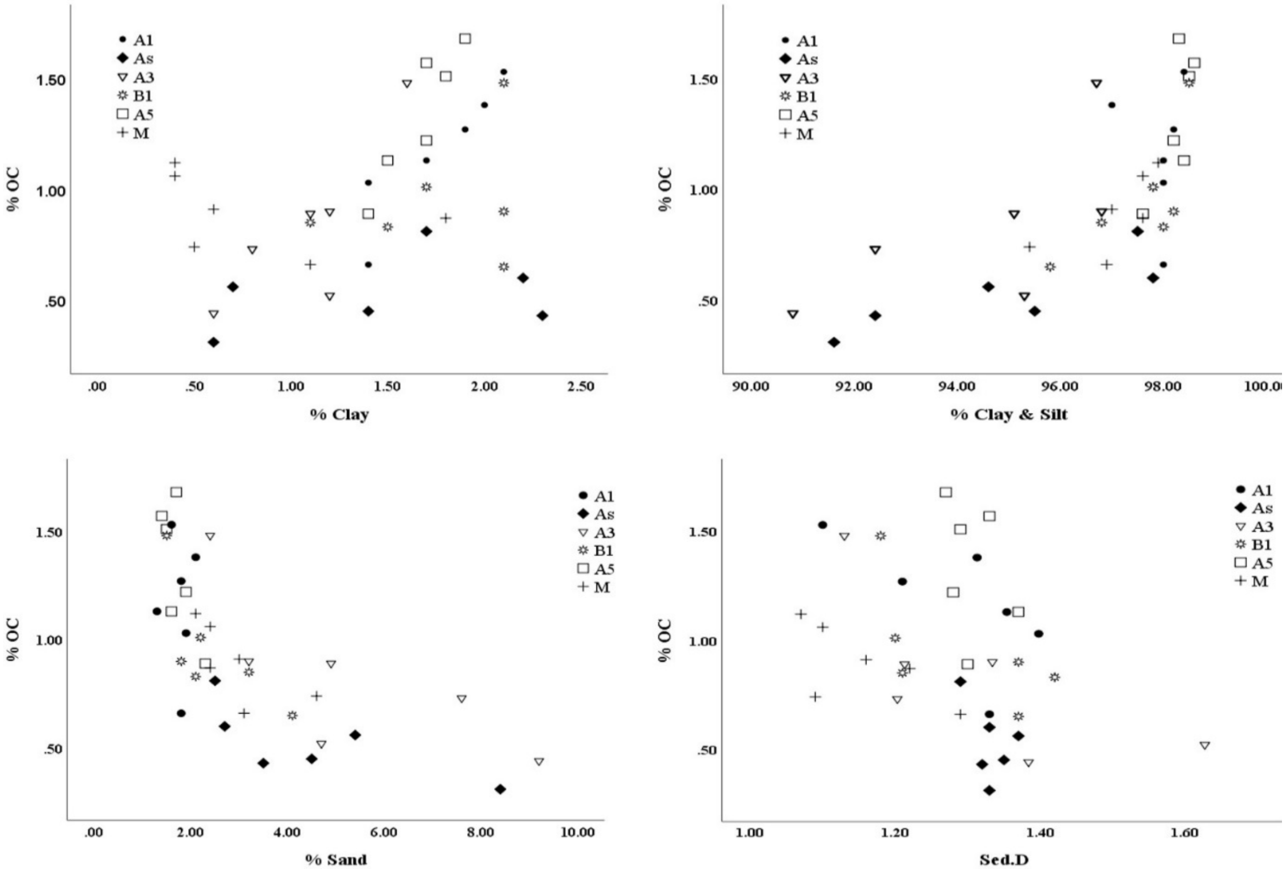

Fig. 4. Correlation between SOC percent and sediment texture and sediment density (P<0.01).

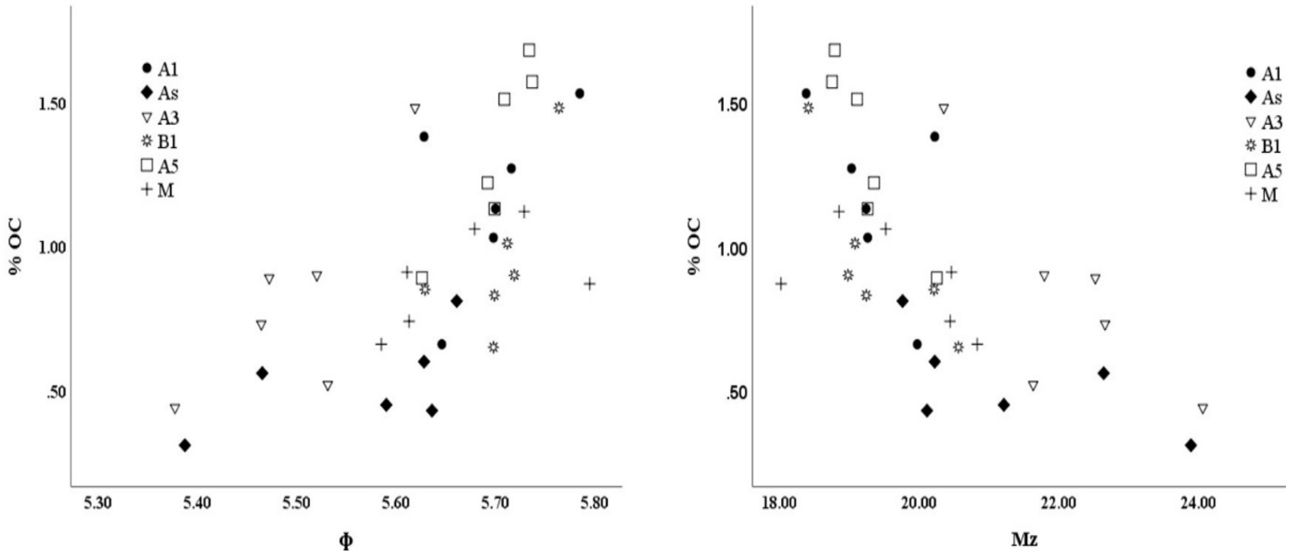

Fig. 5. Correlation between SOC percent and particle size (P<0.01).

linear) and □ (R^2=0.45, exponential), while the general relationship between SOC and mean particle (Mz) was negative (R^2=0.50, exponential), as well as SOC related negatively to sediment density (R^2=0.63, power), (Fig. 4 and 5).

4. Discussion

The results of factor analysis indicated that clay percent, Sor, and Ku are factors 2 and the other ones are factors 1. Also, the density, particle size, Sk, and sand percent were

Table 3. Guidance values for determining the amount of skewness, kurtosis, and sorting of sediment particles.

Kurtosis		Skewness		Sorting	
Very Platykurtic	<0.67	Very fine	0.3 to 1.0	Very well	<0.35
Platykurtic	0.67-0.90	Fine	0.1 to 0.3	Well	0.35-0.50
Mesokurtic	0.90-1.11	Symmetrical	-0.1 to 0.1	Moderately well	0.50-0.70
Leptokurtic	1.11-1.50	Coarse	-0.3 to -0.1	Moderately	0.70-1.00
Very leptokurtic	1.50-3	Very coarse	-1.0 to -0.3	Poorly	1.00-2.00
Extreme leptokurtic	>3.00			Very poorly	2.00-4.00
				Extreme poorly	>4.00

Table 4. Sediment properties in the study area.

	Station A1	Station As	Station A3	Station A5	Station B1	Station M
Mean(ϕ)	5.70±0.06	5.56±0.11	5.50±0.08	5.70±0.04	5.70±0.04	5.67±0.08
grain type	19.35±0.66 Coarse Silt	21.31±1.64 Coarse Silt	22.17±1.24 Coarse Silt	19.25±0.55 Coarse Silt	19.41±0.81 Coarse Silt	19.69±1.09 Coarse Silt
sorting sorting type	1.43±0.04 Poorly	1.41±0.07 Poorly	1.37±0.05 Poorly	1.42±0.03 Poorly	1.44±0.05 Poorly	1.35±0.05 Poorly
skewness skewness type	0.22±0.06 Fine	0.30±003 Fine	0.31±0.04 Fine	0.21±0.03 Fine	0.18±0.02 Fine	0.12±0.06 Fine
kurtosis kurtosis type	0.59±0.04 Very Platykurtic	0.59±0.04 Very Platykurtic	0.59±0.06 Very Platykurtic	0.59±0.02 Very Platykurtic	0.58±0.04 Very Platykurtic	0.55±0.03 Very Platykurtic

negatively related to the SOC deposits. Almost most of the samples are among the factors. Factors 1 and 2 are responsible for 75.8 samples, but samples from station M are almost outside of the factors and outside of the other samples. It seems that the SOC content of the Malegonzeh sediment is affected by a pattern other than the parameters that affected the SOC sequestration of the Nayband sediment. Stations A5, A1, and B1 are located between both factors (1 and 2) in PCA, respectively. Concluded that these stations have suitable sediment for mangrove growth. The amount of SOC in most stations significantly correlated with clay percent, silt percent, and clay & silt percent. Many studies have shown that the smaller the sediment particles are, the greater the amount of SOC deposition in the sediment is (Azlan et al., 2012; Dinakaran and Krishnayya, 2011; Yang et al., 2014). While SOC values were negatively correlated with mean particle size and sand percent. The amount of SOC in the sand fraction is usually much lower than the other fractions of sediment (Guang-Lu and Xiao-Ming, 2014). Regarding Figs. 4 and 5, the amount of SOC decreases with increasing the particle size, and the more accumulation of fine particulates caused more SOC sedimentation, which is consistent with the results of the most studies.

4.1. Sediment properties affecting SOC sequestration

Particle type was determined based on the particle diameter followed by Wentworth (1922), and the values of Ku, Sk, and Sor of the sediment particle size were performed followed by the Folk and ward method, 1975 (Table 3). According to the results of the present study (Table 4), the Sk was positive in most of the samples and the sequence of the curves was towards fine particles. Fine and positive Sk indicates an environment with slow sedimentation conditions (Mousavi Harami, 1996). According to the results of particle grain analysis, in all samples, the Kurtosis was very Platykurtic and sorting was poor. Sorting is the result of selective particle deposition under the influence of different velocities in sediment transport (Maghsoudi et al., 2011). Sorting indicates variations in kinetic energy; therefore, differences in the sorting of specimens indicate differences in the amount of energy during deposition. Good sorting indicates a high-energy environment. When most specimens are moderate to poorly sorted and a few are well sorted, it indicates a low-energy to the rarely energetic environment. Also, relatively good to moderate sorting is related to large particles (Memarian et al., 2005).

Poor sorting is a feature of fluvial origin sediments (Feyznia, 2008). In the two studied bays, the Gavbandi River with a basin area of 116600 ha has a decisive role in the survival and sediment properties of the two bays, especially the Basatin bay which is connected to it from the east. The bay is a semi-closed environment in terms of water energy and is relatively calm compared to normal beaches; therefore, the results are consistent with the hydrological conditions of the bay. Less energy than other beaches and its slow filling and emptying provide the bay opportunity for settling fine sediments. Besides, the roots of mangrove trees and shrubs are an important factor for slowing water and trapping fine particles and SOC attached to these particles.

In the most samples of the present study, the highest percent of particles was silt. The relationship between SOC and silt percent had a higher R^2 and its effect on SOC sequestration was much greater than that of the clay percent. The correlation between sorting and SOC was observed only at stations A1 and A5. It appears that the high density of trees and their roots in these two stations (based on field observation of the authors) and accordingly, the high SOC content in the sediments of these two stations cause this correlation. The percent of SOC significantly and negatively is correlated to the density. Denser sediment has less moisture and porosity, less sorting, and therefore, has less SOC content. In other words, increasing SOC and organic matter reduces sediment density (Avnimelech et al., 2001). Organic carbon significantly and negatively correlated to skewness only at Malegonzeh station. In Malegonzeh, some samples had symmetrical skewness, while in other stations all samples had positive skewness towards fine particles. Also in PCA observed M samples are almost out of agents and out of other samples. It seems that the SOC of the Malegonzeh station is formed from a pattern that differs from the parameters effective on SOC sequestration in Nayband forests.

All sediment properties and those effects on SOC in the three studied forests in the present study can be beneficial for the local management and development of these mangrove forests in the future.

5. Conclusion

The SOC percent is significantly correlated with many sediment factors such as particle size, clay, silt, sand, and density. Generally, by decreasing the size of the sediment particles, the amount of SOC content of the sediment was increased. According to the results of the present study, fine size, moderate sedimentation environment, and constant energy conditions during sedimentation have a positive influence on SOC content in the studied mangrove forests. While the high density of sediments, large particle size, and an unstable sedimentation environment with variable energy affected negatively SOC content. According to the result of factor analyses, stations A5, A1, B1, and as are suitable for developing and planting mangroves in future mangrove management and decisions. Besides the sediment properties, investigating hydrological and physicochemical factors of water can be suggested in the future studies.

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