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Physicochemical Properties of Water, Soil, and Morphological Characteristics of Mangrove Forests in the Island of Kamaran, Al Hodaidah, Yemen

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Abstract

Mangrove forest in Yemen is considered one of the most important components of wetlands and as an ecosystem affecting the ecological balance and biodiversity .The target of this study is to analyze the mangrove assemblages on the island of Kamaran, Featuring two species of mangrove trees black mangroves ("Crimea", *Avicennia marina*) and red mangroves ("Algendl", *Rhizophora mucronata*). This latter is the most widespread on the island. Both species grow indense forests, the study also aims to identify the most important factors contributing to growth and spreading of mangroves. This study is based on field visits, sampling, and physicochemical analysis. The results show that the trees are distinguished in terms of density, propagation, and improvement of soil properties. *Avicennia marina* has a large ability to grow in soil with varying proportions of sand and clay. Both mangrove species tolerate high salinity values. These results can be used to clarify the difference between mangroves that grow on the islands in areas protected and those that grow on the coasts. They can also contribute to the development of actions aiming to maintain the sustainability of these trees, so they can keep playing their vital role in the ecological balance.

Keywords: Mangrove; *Avicennia marina; Rhizophora mucronata;* Salinity; Thermopiles

Introduction

The mangrove forest is considered as an important ecosystem in Yemen on the Red Sea and the Gulf of Aden, due to the density of trees and presence of two species of mangroves, black mangrove (*Avicennia marina*) and red mangrove (*Rhizophora mucrunata*). This latter is a rare and endemic species of the island of Kamaran and the Red Sea coast in general. The Previous studies related on mangroves in this zone were back to the years between 1980 and 1990.

A study conducted by Aleem et al. [1], Hussain et al. [2], Clark [3] and Bala Krishna [4] confirmed the influence of physical and chemical properties and the impact of the natural properties of the coast and organic material on the spread of mangrove forests, also the extent of these shrubs adapt to the conditions of life in shallow water. This system is influenced by the surrounding environmental factors such as climate, water, and soil that affect the intensity and spread of mangrove forests [5]. The temperature plays a significant role in the growth and spread of mangroves [6,7]. Indeed, the rate of growth and spread of mangroves increases with relatively high temperatures. These trees are thermopiles, preferring high temperature, their life cycle occurs in a temperature range between (25°C-45°C) this fluctuation can't go over 5°C [8]. Soil properties affect as well the growth and development, the spread and diversity of mangrove communities [9], Where Frequently species *Rhizophra mucronata* were in areas with mud, and species *Avcennia marina* increase in the sandy soils [6,10]. Studying the growth and spread of these plants in the northeast of the island of Java Indonesian thick growth of various types of mangrove (*Avcennia marina and Rhizophora mucronata*) in soils loam, while a few bushes of mangrove scattered in calcareous soils. Annual variations in salinity and moisture of the soil affect growth and spread of mangrove [5].

In relation to the conservation of this unique ecosystem, which is the forest of mangrove Kamaran, our study mainly aims to study the ecology of mangroves on the island, studying the habitats associated with these forests and potential threats to this ecosystem, characterized by a characteristic species of the island in Yemen, *Rhizophora mucronata*, which recorded a 20% decline of its populations throughout the world, without being registered by the International union for conservation nature (IUCN) as threatened in this scale [7]. In order to achieve this objective, it was necessary to conduct a thorough study of the morphological and environmental characteristics in which the trees grow, through the study of geography and climate that affect the growth and spread of mangroves (such as the nature of the earth - heat - humidity - soil - water), and the fact that these trees are a particular ecosystem through biodiversity they contain, which makes the study of habitats associated with mangrove forests one of the objectives of this study. We aim from this study to obtain indicators that can be used in the future to compare between the mangrove forests growing on the islands, those that grow on the coast, also see the changes that occur and environmental pressures facing the mangrove forests on the island of Kamaran. This will develop designs, proposals, and measures to protect these forests against degradation. On a practical level, this study will allow us to learn some methods and means environmental assessment of mangrove forests and gain a lot of experience in the field. The Arabic version is in addition to local studies in Arabic that are rare in this area.

Material and Methods

Study area

The island of Kamaran is located between 42° 37'N 15° 20'E and, 7 km west of the city of Salif, and about 1.8 kilometers from the port RasIssa 72.5 km north of Al Hodaidah, 45 km south of Al Lehya. Kamaran Island has considered administratively a part of the province of Al Hodaidah. It is the largest island of the archipelago of Kamaran (third sector) and the second largest of the Yemeni islands in terms of area (106 km^2), and one of the most populated islands of the country [11]. The island of Kamaran is flat terrain with dominant altitudes does not exceed 10 m, which favored the presence of intertidal areas and marshlands which consist of sand, clay and gravel conducive to development of the mangrove. Another special feature is the geological formation of the island, which consists of reef limestone and sediments. In fact, erosion and waves led to the formation of many sea cliffs, estuaries, and straits, in addition to the formation of some interior lagoons and bays that take different forms. Therefore, these places have become protected areas from storms and waves, which created a favorable environment for the development and spread of mangroves on the island, thanks to the abundance of nutrients washed away the tides which flow in the form of low currents. In addition, the shallow water in many parts of the island led to the formation of salt marshes on which there are seagrass and algal muddy blankets, plus sandy formations of coastal sediments.

Climate

The study area has a very dry climate. The maximum temperature reached 41°C in June 2012. The risk of these high temperatures on mangroves lies in increased evaporation of tides, which are essential for the development of these trees, especially those who are at the end of the intertidal zone, slowing their growth. Rainfall is very rare. This is offset by a relatively high humidity, which can be a factor helping mangrove to withstand high temperatures and rainfall shortages. Trees also play a role in reducing the temperature of the air, contributing to their own viability. The effect of the wind on the mangroves is low for most regions, and becomes stronger in open areas, as in the site of Sabeg Arreeh. The low wind speed and direction (mostly south and west from June to September) contributed to mitigating the negative impact of the wind on mangroves on the island of Kamaran. The tide strongly influences the growth of mangroves. There is a large area of mangroves in tidal areas, especially the species Avicennia marina which is found in some places up to 50 meters.

Field sampling

Five groups of data have been identified, and include all the factors related wholly or partially to the growth and distribution of mangroves on the island. The first group included natural factors (geology, topography, and geomorphology), climatic factors (temperature, humidity, wind speed, precipitation) and the tidal range. Meteorological data of four years (2000, 2003, 2006, 2012), were used to calculate the monthly averages. The second group includes the study of morphological characteristics and production of litter and plant biomass. Three sites were selected including the full extent of the area occupied by trees of each species. Site selection was made according to the distance to the tidal zone. Thus, the first site includes trees located to the nearest point of the intertidal zone, where the floor still retains surface water reserves. The second site includes trees in the middle of the drawdown zone flooded daily by the tide. The third site is at the farthest point of the tidal zone toward the terrestrial environment.

The main reason for site choice was the existing variations in the characteristics of the trees and the need to find an explanation for these differences by analyzing samples of water and soil. This working method is identical to that used by the Regional Organism for the Conservation of the Red Sea and Gulf of Aden [12], as a part of the rapid assessment of coastal environments (CEAR), with some differences in the size of sampling squares. In this study squares of 10 m × 10 m are marked with wooden frames, ropes and tape. The operation is repeated 3 times. The length and diameter of the rod are measured at a height of 30 cm from the soil. The number of trees in 2 × 2 m^2 surfaces, as well as the number of dead or infected trees is recorded. On the other hand, an evaluation of tree density around the square is carried out. In the case of the black mangrove, the total number of aerial roots, dead and alive, in a square of 1 m^2.

The third group includes the analysis of water and soil for both mangrove species at each site. Soil samples were taken using a graduated plastic tube of 50 cm at three depths: 10 cm, 20 cm, and 30 cm [13]. In the laboratory, samples are dried and passed through a 2 mm sieve. Physical analysis of the soil allows determining the texture in each sample, using a texture triangle and to identify the proportions of clay, sand, and silt.

We also recorded certain physical properties of the soil for the Electric conductivity (EC), and (pH). For chemical analyses, we measured a number of dissolved salts (TDS), primary macronutrients (Nitrogen, Phosphorus, Potassium), and secondary macro elements (Calcium, Magnesium). We also measured the sodium adsorption ratio (SAR) and the amount of organic matter in the soil. All analyses were consistent with the criteria and methods accredited by the International Centre for Agricultural Research in the Dry Areas. The fourth group of this work has been devoted to the study of biodiversity associated with mangrove forests, such as endemic and migratory birds, fish, algae, crustaceans, molluscs and coral reefs. The fifth group concerns the environmental pressures experienced by mangroves on the island of Kamaran, and we have also tried to understand the causes of these pressures and to propose solutions to ensure the sustainability of these trees and their biodiversity [14].

Results and Discussion

Physical parameters of water

Analysis of the samples of water and soil in the six studied sites has yielded several physical and chemical characteristics of the environment where mangrove growth. Physical water measures including the temperature did not differ from that of the air starting at the end of March. Temperatures ranged between 28.5°C and 30.8°C in all stations. The increase of temperature in some stations may be due to the difference in sampling time between the morning and the afternoon. Values of pH ranged between 7.54 and 7.69 and showed that these waters are slightly alkaline. Conductivity as a measure of the degree of salinity, showed an increase in the salinity of mangrove water relative to that of seawater, confirming the ability of mangrove to tolerate high salt levels, especially *Avicennia marina* (Figure 1).

Chemical parameters of water

We obtained similar values for dissolved salts between the two species, between 46400 and 48000 ppm. In addition, the results showed high levels of chemical elements such as calcium, magnesium, sodium, and potassium. The sodium adsorption ratios (SAR) were important for both species. We have seen an increase in the values of sodium adsorption ratio in sites where water remains stagnant for a long time (Table 1). These values decrease in sites flooded during the rise of the tide. In general, the sodium adsorption ratio increases when going terrestrial, which may be due to the increase in salt leaching in areas close to the sea (Table 2).

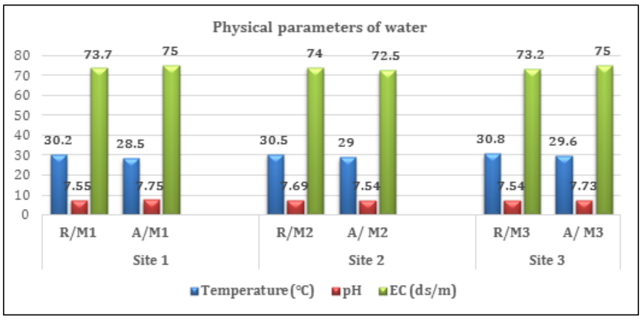

Figure 1: Results of physical parameters of water for *Avicennia marina* (AM) and *Rhizophora mucronata* (RM).

	Site 1		Site 2		Site 3	
	R/M1	A/M1	R/M2	A/ M2	R/M3	A/ M3
TDS (ppm)	47168	48000	47360	46400	46848	48000
Ca (Mq)	22	20	25	22,7	21	22
Mg (Mq)	127	120	128	119	117	132
Na (Mq)						
K ((Mq)						
SAR (%)						

Table 1: Results of chemical parameters of water for *Avicennia marina* (AM) and Rhizophora mucronata (RM).

Physical parameters of the soil

The result of soil analyses showed important differences in physical properties. Indeed, the pH slightly increased compared to that of water and varied between 7.43 and 8.12, indicating a sharp increase in the alkalinity of the soil due to the increase in salt and abundance of the ions of sodium, magnesium, and calcium. There was also an increase in salinity (EC) on the ground of *Avicennia marina* compared to *Rhizophora mucronata* (Figure 2). The results showed an important difference of salinity between selected sites for sampling water, especially those of *Avicennia marina*. This salinity is closely linked to the tide. Indeed, tidal waters reach the first site, located closer to the sea and continuously for a long period, allowing the leaching of salts, which is important because of the permeability of the soil on this site. For the second site, in the middle of the intertidal zone, the salinity of soil value recorded for *Avicennia marina* was close to the salinity of the soil in the second site of *Rhizophora mucronata*, because of the similarity of soil properties between both sites. The third site, the closest to the continental area, is characterized by stagnant water for a short time. It can be inferred that there are two main factors influencing soil salinity, the first one is the removal of the tidal zone, and the second is the nature and properties of the soil (Figure 3).

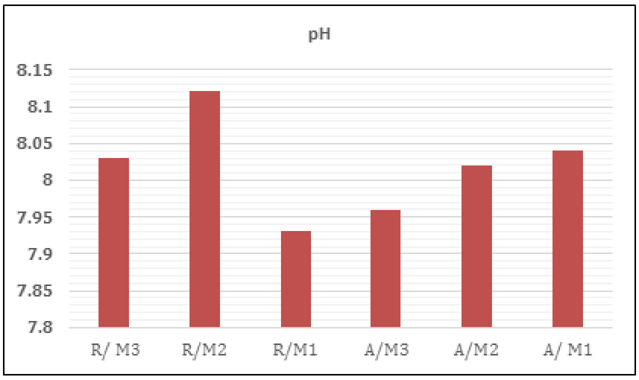

Figure 2: pH for sampling *Avicennia marina* (AM) and *Rhizophora mucronata*(RM).

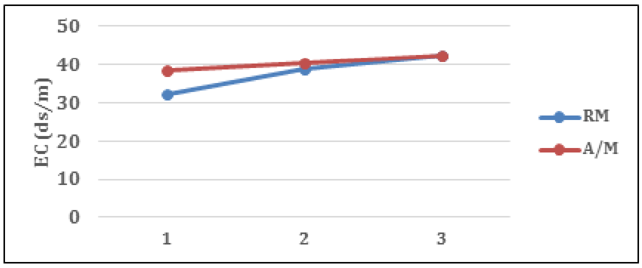

Figure 3: Salinity variations at mangroves soil for *Avicennia marina* (AM) and *Rhizophora mucronata* (RM).

Analysis of soil texture showed that soils with *Avicennia marina* are sandy soils where the sand proportion is between 70-80%, followed by silt and clay. In the case of Rhizophora mucronata, the results showed that the soil is loamy and sandy loam, where the sand percentage is between 50-60% followed by silt and clay, whose percentages are higher than those recorded in the ground. These rates indicate the ability of Avicennia marina to grow in clay soils. Nevertheless, the growth of this species in these types of soil is low in the presence of the competing species Rhizophora mucronata (Table 2).

Chemical properties of soil

Soil analysis showed high contents of dissolved salts, magnesium, sodium, and calcium, respectively, in the samples of Avicennia marina. The high content of magnesium in water and the soil with mangroves is due to the loss of large amounts of calcium during the formation of gypsum, leading to its reaction with magnesium sulfite, forming the dolomite CaMg (CO^3) [14]. The rate of sodium adsorption in the soil were less than its rates water. Larger proportions of nitrogen, phosphorus, and organic matter were recorded in soils with Avicennia marina, versus those of Rhizophora mucronata, excepting sample number 2 (Table 3). The increase in the proportion of organic matter is due to the weakening of bacterial oxidation in soils which remain flooded for long periods, and where the performance of anaerobic bacteria in the degradation of organic matter is reduced. The location sites from the sea and soil type affect the chemical parameters content in soils with mangrove trees in Kamaran Island.

Sampling	R/M3	R/ M2	R/ M1	A/ M3	A / M2	A/ M1
Sable (%)	46	61	50	79	59	68
Limon (%)	38	31	31	16	25	25
Clay (%)	16	8	19	5	16	7
Texture (%)	loam y	Sandy loamy	Loam y	Sandy loamy	loamy	Sandy loamy

Table 2: Results of soil texture analysis for two species: *Avicennia marina* (AM) and *Rhizophora mucronata*(RM).

Parameter	R. M3	R. M2	R. M1	A. M3	A . M2	A . M1
TDS (ppm)	27136	24960	20736	27008	25856	24704
N(%)	0.007	0.01	0.013	0.017	0.005	0.018
P (ppm)	0.61	1.13	1.23	1.55	0.52	1.7
Ca (Mq)	10	26	32	12	35	12.4
Mg Ca (Mq)	230	184	128	92	185	76.5
Na Ca (Mq)	50.8	49.4	71.71	24.6	38	52.28
K Ca (Mq)	6.8	6.1	5.8	9.7	8.57	7.77
O.M	1.2	2.1	2.6	3.1	1.1	3.2
SAR	4.61	4.9	8.3	3.4	3.6	8.2

Table 3: Chemical analysis results for two soils species: *Avicennia marina* (AM) and *Rhizophora mucronata* (RM).

Analysis of Mangrove Vegetation

Results of the analysis of morphological characters showed an important contrast in measured traits such as height, thickness of the log and number of trees in a square of 10 m^2, as well as the number of aerial roots in 1 m^2. The results showed differences between mangrove species on the island and between individuals of the same species, in the six studied sites. These differences are due to the influence of proximity to tidal waters, protection of the areas and of flooding (Table 4).

Avicennia marina sites

The first site is located at the closest point to the sea southeast of Sabeg Arreeh. Mangroves showed an excellent development where tree height could reach up to five meters. The thickness of the log was between 33 and 80 cm, and many aerial roots were noted. There were three trees in a 10 × 10 m square. This does not mean a negative indicator because mangroves develop large horizontal branches after leaving the ground, and a tree can form a circle up to 8 meters in diameter. We also recorded a single tree that has been logged and was parasitized. We have not registered dead trees or trees affected by grazing.

Site N°	Site location	GPS	GPS
		N	E
1	SouthwestsabegArreeh	15 26 03 21	42 37 20 54
2	North of khorTowis	15 24 57 50	42 36 31 79
3	NortheastsabegArreeh	15 26 20 10	42 38 09 88
4	Big basin	15 25 01 66	42 36 09 52
5	Small basin	15 24 44 60	42 35 34 00
6	Small basin	15 24 74 65	24 36 37 60

Table 4: The name and geographic coordinates of sites studies.

The second site is located in the intertidal zone, in a protected area north of Khour Tweis. The waters flooded the area during high tide and recede during low tide. This area is considered among the places where Rhizophora mucronata is abundant. Trees showed good development since the height varied from 2.80 to 3.50 m and thickness between 58 and 100 cm. The number of aerial roots reached 115 per m^2. We recorded 4 trees in the sampling square without finding dead infected trees or trees affected by grazing or logging, because of the difficulty in accessing these places.

The third site is located in the northeast of Sabeg Arreeh, at the end of the intertidal zone toward the land. It is characterized by stagnant water which is renewed only with the highest tides. Trees were of medium height, 1.20 to 1.70 m; and the thickness varied from 11 to 25 cm. There were 6 trees per sampling square, and we observed trees affected by grazing, without noticing the presence of infected, dead or fallen trees. We also saw important leaf yellowing of a major part of the trees, which may be due to the deficiency of certain nutrients such as sulphur, iron or zinc. Effectively, stagnant waters in this area result in an increase of alkalinity of the soil and the osmotic pressure outside, making plants unable to capture these elements. The reasons of leaf yellowing certainly require a more precise study of trace elements.

The results obtained in the sites of Avicennia marina show that the trees of this species are characterized by a good development and good morphological traits (Tables 5 and 6). The abundance of trees is due to the large area occupied by the species in the intertidal zone and open coasts as well as in protected area (especially in sandy soils). The study also revealed a relationship between the location of trees in the intertidal zone and the morphological traits such as height which increase in destination to the field.

N° site	Species	Number of Tress 2 × 2 m	Tress Thickness (cm)			Mean	the Trees Height (m)			Mean
1	A.M	1	38	57	53	80	-	-	4.45	4.45
2	A.M	3	65	78.33	70	100	2.8	3.5	3	3.1

3	A.M	3	11	17.33	16	25	1.6	1.25	1.7	1.5
Mean	-					68.3				3

Table 5: The trees height, thickness, trunk and the mean for the sites *Avicennia marina*.

N° site	Species	Number of dead roots	Number of living roots	Number of aerial roots
1	A.M	69	35	1 × 1 m
2	A.M	96	27	104
3	A.M	50	20	123
Total		215	82	297

Table 6: The total number of aerial, living and dead roots in the sites of *Avicennia marina*.

Rhizophora Mucronata Sites

The first site (Great Basin) is difficult to access during high tide, but also during low tide when the water depth is less than 10 cm. Even the small boats cannot sail in these shallow waters. The number of trees in the 10 × 10 m square was 12 trees. This is the highest number recorded in the studied sites of red mangrove. Tree height ranged from 6 to 9 m [11] and the thickness of the log reached 60-72 cm. We do not have noted dead threes, infected or affected by grazing. We observed a number of trees with a low height of the species *Avicennia marina*, forming a belt around trees of *Rhizophora mucronata*, because of the competition.

The second site (Little Basin), is one of the best sites for these mangrove species. It is characterized by the abundance of alluvium with saturated water. The water depth is 1 m and the number of trees was 8 in the square of 10 × 10 m and 3 trees in a square of 2 × 2 m. The height reached 7-10 m and thickness varied from 50 to 128 cm (Table 7). We observed a dense network of adventitious roots, rooted in the ground in the form of a dome. There were faint traces of logging, but no dead, infected or tree affected by grazing were observed.

In the third site, called Khour-Toweis, the water depth exceeds 1.50 m. The trees were spaced and adventitious roots were more abundant. The number of trees was 6 in a square of 10 × 10 m and 3 trees on a 4 m^2 surface. Tree height ranged from 6 to 7 m. We have not registered dead, infected or trees affected by grazing. Based on the analysis of the results of the studied sites of Rhizophora mucronata, it is clear that these trees were mainly distributed in protected areas, such as bays and lakes, and were more widely distributed in clay soils and sandy-clay. This species is also characterized by the growth of vertical branching. The influence of the distance from the tidal zone was less important for this species. This is evident from the figures that were recorded in the red mangrove sites (Table 7).

N° site	Species	Trees affected by pasture	Trees down	Trees infected	Trees dead	Trees living	Number of Tress 10 × 10 m
1	R.M	-	1	-	-	11	11
2	R.M	-	1	-	-	8	8
3	R.M	1	-	-	-	6	6
Total	-	1	2	-	-	25	25

Table 7: Number of trees (living, dead, infected and affected) for sites of *Rhizophora mucronata*.

Conclusion

The results of the study of mangroves on Kamaran Island have shown the existence of two species: the black mangrove (Avicennia marina) and the Red Mangrove (Rhizophora mucronata). Both exist under the form of a dense forest covering more than 7 km. Theseresults also showed a strong ability for growth and proliferation of black mangrove on soils with different physical and chemical characteristics: sandy soils, sandy-clay soils, and clay soils. However, the most widespread growth of black mangrove on the island is in sandy soils. The growth of this species in clay soils is lesser, limited by the presence of the second species of mangrove Rhizophora mucronata, which grows exclusively on this type of soil. The results also showed that mangroves of the island tolerate changes in salinity levels and a relatively high percentage of sodium, influencing soil permeability and the absorption of nutrients existing in water. In fact, natural factors either geographical or climatic play an important role in the growth and spread of mangroves on the island of Kamaran. Mangroves in protected areas are more widespread and stronger than those growing in open coastal areas. Effectively, these open areas are more vulnerable to recent climate change, pollution, grazing, human activities and other factors that affect the growth of mangroves. Despite the scarcity of rain, young seedlings, especially those of Avicennia marina areas not reached by the tide, prove that they are resistant to drought.

Mangrove forests of the island of Kamaran are of paramount importance, not only by the trees of these two species but also due to the associated biodiversity therein, namely migratory and endemic birds, algae, sea herbs, fish or mammals. This element promotes to redouble the efforts, in order to maintain and ensure their sustainability. The present study showed the success of the efforts made by the authorities in the protection of mangrove communities on the island of Kamaran, reducing environmental pressures by declaring it as a natural reserve.

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