

Comparative Analysis on Mangrove Leaf Sheath in Mining and Non-Mining Areas of Selected Municipalities in Caraga Region Philippines

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Abstract

This field of study was anchored on the method of using fractal dimension, geomorphic, soil and assay analysis that identified the leaf sheath of the mangrove in mining and non-mining areas of selected municipality of CARAGA, Philippines. The data revealed that *Rhizophora apiculata*, *Sonneratia alba* and *Avicenia marina* are common mangrove plants present in the area of the study. Using fractal analysis, it identified the plants by analyzing leaf complexity based on estimating their fractal dimension. The data revealed that *Rhizophora apiculata* species of mangrove in the mining area has a mean of 1.9689 while only 1.9562 fractal dimension in non-mining areas. While in *Sonneratia alba* species has an average mean of 1.9538 in mining areas while 1.9622 in non-mining areas. In *Avicenia marina* species of mangrove has a mean of 1.9474 while in non-mining areas has only 1.9463. As to soil analysis, Area Z, Area Y and Area N are more acidic in terms of soil acidity. While on the organic matter and potassium content of the soil, Area Y has a high capacity of organic matter and potassium and all sites are low in phosphorous content. In terms of magnesium content, all of the sampling sites are very high. As to leaf analysis, Area X and Area M got the highest percentage of Nitrogen acquired while Area N got the highest percentage acquired Phosphorous content, and Area Z got the highest percentage of potassium. Majority of the lowest results in mean and standard deviation of the samples are find in Area Z, therefore the leaf sizing of *Rhizophora apiculata* is smaller than the other samples.

Keywords: Analysis, Mangrove & Leaf Sheath

1. INTRODUCTION

Mangrove ecosystems are vital components of coastal environments, serving as intertidal forests that thrive in tropical and subtropical regions. These forests exist at or above sea level, experiencing tidal inundation for no more than 30% of the time. Bunting et al. (2002) highlighted that mangrove ecosystem serves as vital habitats and breeding areas for a wide range of species, such as fish, crustaceans, mollusks, and birds. And these forests deliver immense ecological and economic value by naturally protecting coastlines from storm surges, tsunamis, and erosion through their complex root networks (Alongi et al., 2008). Wherein their ability to store carbon also underscores their crucial role in mitigating the adverse effects of climate change (Friess et al., 2022).

Mangroves are very important for the environment, but they are being heavily damaged around the world because of human activities and natural pressures. These are, but not limited to clearing of forests, expanding cities, dumping industrial waste, and building carelessly along the coast which have all

identified that caused the major loss of mangrove areas (Richards and Friess, 2022). In addition, problems like poor waste disposal, cutting down trees, farm runoff, and industrial pollution have led to more sediment buildup, soil erosion, and dirty water (Alongi, 2021). The aforementioned disturb the balance of marine life, change tidal movements, and put many species at risk (Duke et al., 2022).

In the Philippines, mangrove forests are integral to coastal protection and livelihood sustainability, but mining activities have emerged as a significant environmental concern, particularly in the CARAGA Region, known as a key mining hub. The environmental impacts of mining include excessive sedimentation, heavy metal contamination, soil degradation, and water pollution, all of which pose risks to mangrove health and resilience. And these threats have been recognized, thus, Philippine environmental policies have been enacted to regulate mining operations and mitigate environmental damage. Wherein Presidential Decree 463 (Mining Act Amendment of 1936) mandates the compliance with pollution control regulations, while Presidential Decree 1198 requires the rehabilitation of mined-out areas. Furthermore, Presidential Decree 1251 imposes fines on mining-related pollution and allocating funds for environmental restoration efforts. Despite the existence of these regulatory frameworks, the effectiveness of enforcement remains a challenge, warranting further scientific evaluation of mining's ecological impact on mangrove ecosystems.

This study explores how mining activities affect mangrove forests in selected towns across the CARAGA Region. And it uses different scientific methods, including fractal analysis, geometric shape analysis, and soil testing. With a main goal to compare the physical and biological differences in mangrove leaf sheaths between areas affected by mining and those that are not.

The fractal analysis will measure how complex the leaf sheath structures are, while geometric morphometrics will analyze differences in their shapes among mangrove species. And the soil and laboratory tests will also examine the chemical and physical properties of the mangrove soil to understand nutrient levels and possible contamination.

The results of this research will help explain how mining impacts the health of mangrove ecosystems through provided data that can guide conservation and rehabilitation efforts in affected areas. And in combining advanced scientific techniques, this research seeks to fill knowledge gaps about mangrove ecosystems and support stronger policies for sustainable coastal management. As such, the findings will be valuable for local communities, environmental agencies, and policymakers in creating evidence-based programs to protect and restore mangrove forests in the CARAGA Region and other coastal areas.

2. MINING AND NON-MINING

In understanding how mining affects mangrove ecosystems, it is important to compare those areas that exposed to mining with those that are not. Such studies often use the methods like fractal analysis, soil testing and landform assessment to identify differences between damaged and untouched sites.

As example, Nguyen and Hoang (2024), studied the effects of pollution and climate change on mangrove forests in Vietnam through simulations of the Thi Vai catchment. With these, they found that environmental pollution, especially from industrial activities such as mining, affects negatively the health and productivity of mangroves. And these emphasizes the importance of using detailed and varied analytical approaches to assess mining's impact for a better management and protection measures to be developed.

The mangrove forests are vital coastal ecosystems that protect shorelines, store carbon, and serve as breeding grounds for many marine species. In the Philippines, especially in the CARAGA Region,

mangroves are essential for maintaining biodiversity and supporting local communities' livelihoods. However, increasing human activities particularly mining pose serious threats, causing habitat loss and environmental damage. Therefore, studying the specific effects of mining on mangrove features, such as leaf sheaths, is necessary to develop effective conservation and rehabilitation strategies.

2.1 Comparative Analysis in Mangrove Species

Fractal analysis is a mathematical approach used to measure complex and repeating patterns found in nature. In the mangrove research, it helps scientists to study the structural complexity of plants parts such as leaves and leaf sheaths. For instance, Pieters et al., (2022) uses fractal analysis to measure plant growth and transpiration, demonstrating how this method can reveal ways of plants responses to different environmental conditions. This approach allows researchers to quantify the plants shapes and structures, which can indicate plants ways in adapting to stress or environmental changes.

Soil properties also plays a major role in the health and distribution of mangroves forests. And in order to understand nutrient levels, salt content, and possible pollutants, detailed soil studies are needed which examines both physical and chemical characteristics. Zou et al. (2022) gives emphasis on the importance of soil structure for plant health, showing that the fractal patterns of root systems affect soil stability and water retention. Such studies are essential for identifying how external factors like mining, had a great impact on mangrove habitats and whether these environments remain suitable for growth.

In addition, the geomorphic setting of mangroves, it's shape and features of the landscape has a strong influence on their development and resilience. Factors such as sediment movement and tidal activity affects where mangroves grow, what species thrive, and how the forest structures forms. In comparing mangrove areas through geomorphic analysis helps reveal the relationship between biological and physical processes, especially in regions disturbed by mining.

2.2 Mangroves and Caraga Region

The CARAGA Region, is located in Northeastern Mindanao, Philippines, a home vast of mangrove forests which gives a vital role in fisheries and coastal protection. These mangroves have unique physical and biological features that allow them to survive in salty, intertidal environments. However, the region's abundant mineral resources have led to extensive mining activities, which pretense serious threats to these coastal ecosystems.

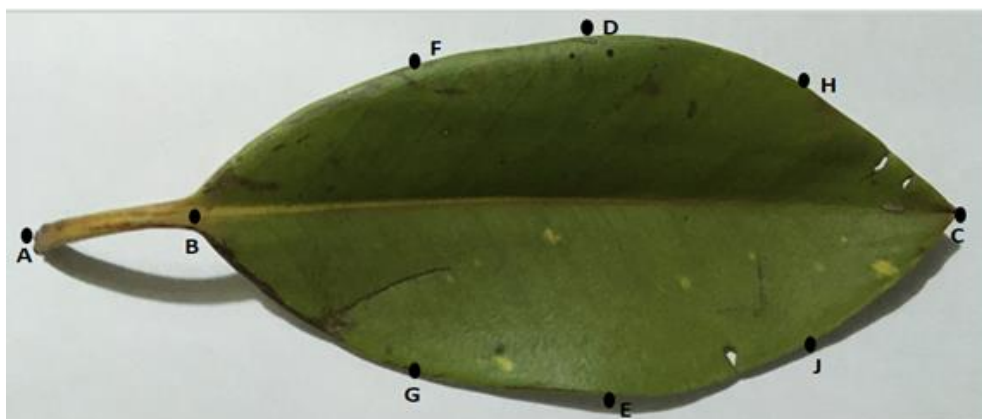


FIGURE 1. DIFFERENT MANGROVE LEAF CHARACTER

To study the different mangrove species in the area, the researchers collected leaf samples and scanned them in various orientations. The leaves were digitized using a scanner with 1200 dpi resolution to ensure

accurate measurements without size distortion. There were several leaf characteristics recorded, including Petiole Length (PL, A-B), Midrib Length (ML, B-C), Center Lamina Width (CLW, D-E), Leaf Length (LL, A-C), Left Lamina Width (LLW, F-G), and Right Lamina Width (RLW, HJ). These measurements help analyze the differences in leaf structure and provide insights into the effects of environmental stress caused by mining.

3. METHODOLOGY

3.1 Framework of the Study and Criteria

This study uses several methods such as fractal dimension, geomorphic analysis, and soil and assay testing, to examine the leaf sheaths of mangrove in both mining and non- mining areas within selected municipalities of the CARAGA Region. Fractal analysis was applied to better understand plant growth and development. For example, Ivanov et al. (2022) demonstrates how fractal analysis can be used to measure plants growth and transpiration, showing that it effectively identifies how plants respond to environmental stress, such as nutrient shortages. This approach provides deeper insights into plant physiology and helps explain how plants adapt to different habitats.

The research also used geomorphic analysis by placing primary landmarks and semi-landmarks along the leaf edges to track shape changes. This method made it possible to distinguish between different mangrove species and proved valuable for taxonomic classification.

In addition, soil testing played a key role in determining essential soil properties, such as nutrient levels, pH, and other chemical characteristics. These tests help identify nutrient deficiencies or toxic elements in the soil, allowing for more accurate recommendations to improve soil fertility, increase plant productivity, and reduce environmental damage.

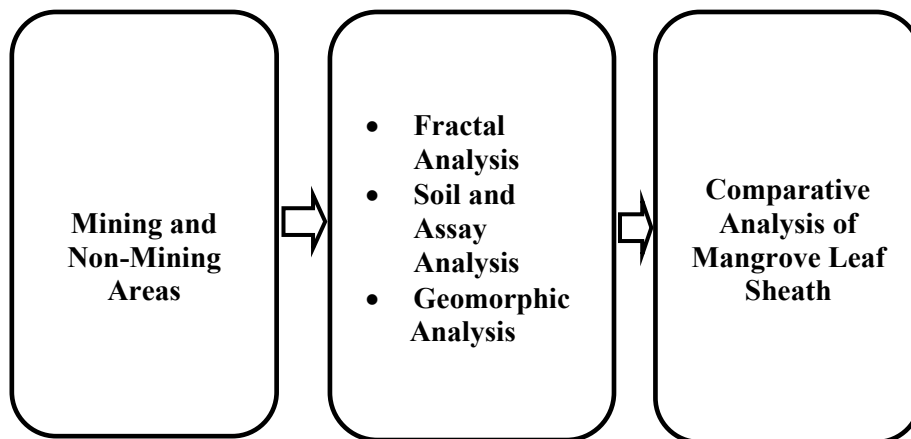


Fig. 2 Methodology of the study

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Inclusion criteria of the study:

- Only selected areas in Region Caraga is included in the study;
- Samples were taken from the sample sites 3-5 feet below the ground to avoid some organic matter or sediments;
- Only *Rhizophora apiculata* mangrove species is use for comparative analysis since this mangrove species is commonly seen in both mining and non-mining situation in the province.

3.2 Dimensions and Indicators Selection

Selection of Mangroove species were collected through Global Positioning System (GPS), an electronic satellite based system that detects a particular samples sites to calculate the user's exact location which is displayed on the units' map. Global Positioning System (GPS) is a method of tracing the location of each mangrove species. Samples were collected from the mangrove forests identified sample distribution municipalities within the mining and non-mining areas of the selected areas of Caraga Region, namely: Area M and Area N as mining sites and Area X, Area Y, and Area Z as non-mining sites.

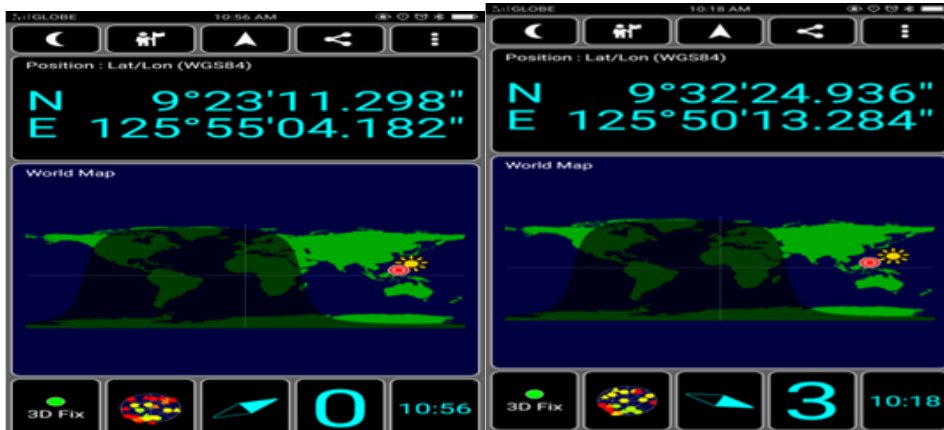


Image 1.1. (GPS) of Area M Image 1.2. (GPS) of Area N

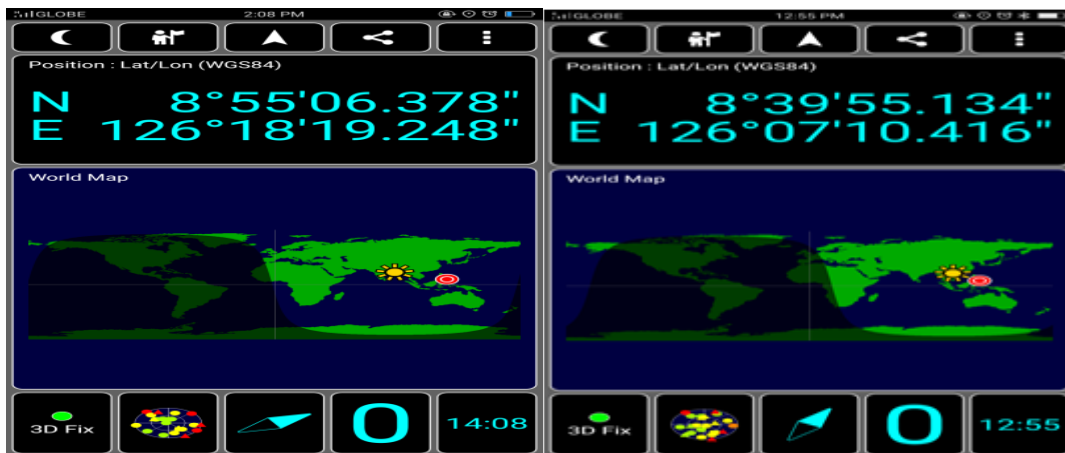


Image 1.3. (GPS) of Area X

Image 1.4. (GPS) of Area Y

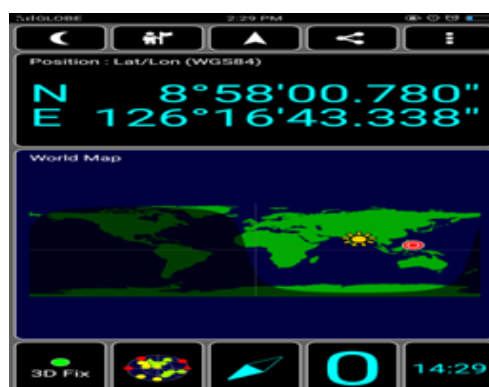


Image 1.5. (GPS) of Area Z

3.2. Normalisation

Data calculated or obtained from quantitative analysis methods for the data gathering from the research environment concerning the comparative analysis on mangrove leaf sheath in both the mining and non-mining areas of the selected municipality of Caraga Region, Philippines. Data were analyzed thoroughly through fractal and geometric morphometric analyses. Laboratory activities such as soil and assay both for nutrient contents analyses were conducted for they are contributory factors in mangrove leaf sheath differentiation.

3.4 Comparison of different mangrove species found in Caraga Region

The mangrove flora is consisting of 47 true mangroves and associated species that belongs to 26 families. The true mangroves grow in the mangrove environment while associated species may grow on other habitat types such as beach, forest and lowland areas. However, the focus of the study are Area M and Area N as mining site and Area X, Area Y, and Area Z as non-mining site, and these are the mangrove species present in the location: *Rhizophora apiculata*, *Sonneratia alba* and *Avicenia marina*.



Image 2.1. *Sonneratia alba*



Image 2.2. *Rhizophora apiculata*



Image 2.3. *Avicenia marina*

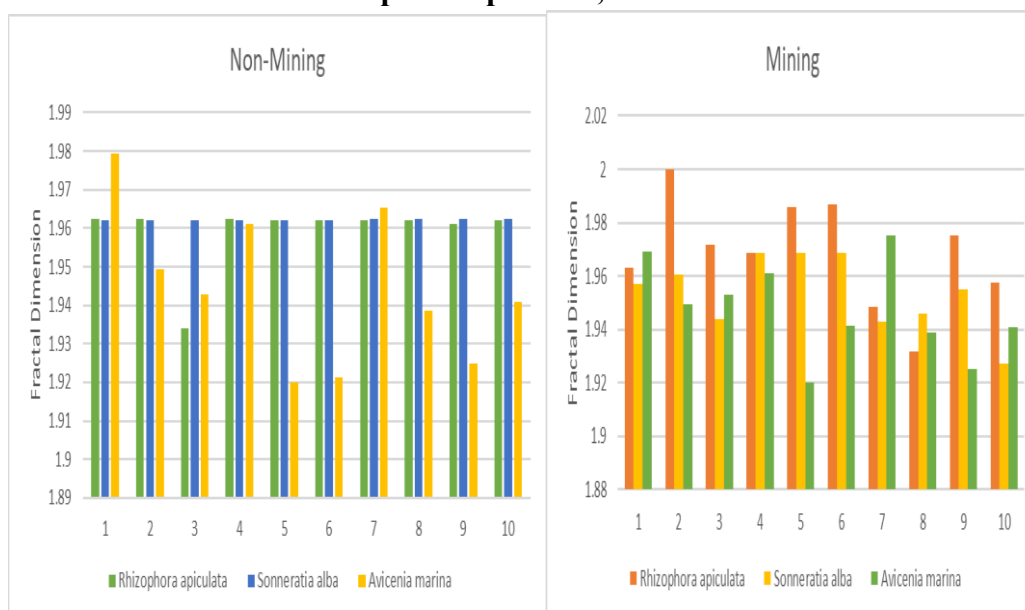
4. RESULTS AND DISCUSSION

4.1 Differences between mangrove leaf sheath in mining and non-mining areas.

Table 1 Fractal Dimension of Rhizophora apiculata, Sonneratia alba & Avicenia marina.

Samples	Mining			Non-Mining		
	Rhizophora apiculata	Sonneratia alba	Avicenia marina	Rhizophora apiculata	Sonneratia alba	Avicenia marina
Leaf 1	1.9633	1.9569	1.9692	1.9624	1.9620	1.9792
Leaf 2	2.0000	1.9607	1.9494	1.9624	1.9620	1.9494
Leaf 3	1.9716	1.9436	1.9529	1.9340	1.9620	1.9429
Leaf 4	1.9685	1.9688	1.9612	1.9624	1.9620	1.9612
Leaf 5	1.986	1.9688	1.9201	1.9620	1.9620	1.9201
Leaf 6	1.9869	1.9688	1.9413	1.9620	1.9620	1.9213
Leaf 7	1.9483	1.9427	1.9752	1.9620	1.9624	1.9652
Leaf 8	1.9317	1.946	1.9386	1.9620	1.9624	1.9386
Leaf 9	1.9754	1.955	1.9249	1.9610	1.9624	1.9249
Leaf 10	1.9575	1.927	1.9408	1.9620	1.9624	1.9408
Mean	1.9689	1.9538	1.9474	1.9562	1.9622	1.9463

Fig. 1 Fractal Dimension of Rhizophora apiculata, Sonneratia alba and Avicenia marina



The data revealed that *Rhizophora apiculata* species of mangrove in mining area has a mean of 1.9689 with the highest fractal dimension of 2.0000 Leaf 2 has a highest fractal dimension among other sample while leaf 8 has the lowest fractal dimension with only 1.9317. *Sonneratia alba* species that leaf 4,5 and 6 has the highest fractal dimension of 1.9688 while leaf 10 has the lowest fractal dimension with only 1.927. Sample 2 also has an average mean of 1.9538. The *Avicenia marina* species of mangrove has a mean of 1.9474. Leaf 7 is the highest fractal dimension of 1.9752 among other sample while leaf 5 has the lowest fractal dimension with only 1.9201.

While the data revealed in non-mining areas that *Rhizophora apiculata* species of mangrove in mining area has a mean of 1.9562 with the highest fractal dimension of 1.9624 Leaf 1,2 &4 has a highest fractal dimension among other sample while leaf 3 has the lowest fractal dimension with only 1.9340. *Sonneratia alba* species that leaf 7, 8, 9 and 10 has the highest fractal dimension of 1.9624 while leaf 1-6 has the lowest fractal dimension with only 1.9620. Sample 2 also has an average mean of 1.9622. While the *Avicenia marina* species of mangrove has a mean of 1.9463. Leaf 1 is the highest fractal dimension of 1.9792 among other sample while leaf 6 has the lowest fractal dimension with only 1.9213. Moreover, the data showed that majority of *Rhizophora apiculata* species has a fractal dimension of 1.994 and a mean of 1.994. It implies that *Rhizophora apiculata* specie has the same fractal dimension compared to other mangrove specie.

4.2 Soil Analysis of the Mangrove Leaf Sheath to determine nutrient content and other chemical characteristics.

Table 2 Soil Analysis of Mangrove Leaf Sheath

Leaf Analysis			
Field	Special Assay Analysis		
	N	P	K
	%		
Non Mining			
Area Z	1.03	0.21	0.9
Area X	1.32	1.14	0.5
Area Y	1.18	0.18	0.7
Mining			
Area M	1.33	0.15	0.8
Area N	1.03	0.23	0.8

Data revealed that Area X and Area M got the highest percentage of nitrogen acquired with a percentage of 1.33%, followed by Area Y with 1.18% while Area Z and Area N got only 1.03 %.

While in Phosphorous content, Area N got the highest percentage acquired with a percentage of 0.23%, followed by Area Z with 0.21%, Area Y with 0.18%, Area M with 0.15% and Area X with 0.14%. In terms of Potassium content acquired, Area Z got the highest percentage of 0.9%, followed by Area M and N with 0.8%, and Area Y with 0.7% while Area X has the lowest percentage of 0.5%.

According to Yates, et.,Al. (2002) An understanding of nutritional requirements is important for both management and restoration of mangrove areas. Interaction effects, particularly between N, P and K, were apparent. Leaf expansion was also affected by N, P and K and their interaction with salinity.

Also, Osman, & Abohassan, (2010) stated that, despite a growing knowledge of nutrient limitation of mangrove species and how mangroves adapt to low nutrients, there is limited information about the

relative importance of NPK fertilizer application on the carrying out of mangroves in terrestrial environments. Application of phosphorus alone had meaningfully increased plant height, number of leaves and number of branches/plant, especially at later stages of plant growth. Application of K considerably increased the number of branches/plant in the later stages, whereas that of N had negatively reduced plant height in the early stages of growth, but it increased the number of branches in the late stages of growth. Application of phosphorus alone had expressively increased culms, leaves and total dry weights/plant, whereas that of N that significantly increased leaves' weight.

These studies prove how important the NPK, phosphorus increased plant height, number of leaves and number of branches/plant, while K increased number of branches/plant. N helps the growth of plants and significantly increased leaves' weight.

Leaf Characters	Non-mining			Mining	
	Area X	Area Y	Area Z	Area M	Area N
N	100	100	100	100	100
Petiole Length(PL)	40.08 ± 9.7	40.76 ± 10.6	26.4 ± 5.3	38.3 ± 10.6	31.8 ± 11.03
Midrib Length (ML)	153.8 ± 16.6	159.3 ± 17.05	124.9 ± 22.02	155.4 ± 17.1	117.3 ± 49.6
Center Lamina Width (CLW)	60.5 ± 7.09	64.4 ± 6.02	39.98 ± 14.7	59.9 ± 7.01	73.28 ± 44.1
Leaf Length (LL)	193.4 ± 24.6	201.7 ± 24.6	149.5 ± 29.6	193.8 ± 25.9	190.6 ± 39.6
Left Lamina Width (LLW)	44.5 ± 6.4	44.1 ± 7.2	51 ± 10.9	43 ± 5.4	49.6 ± 9.9
Right Lamina Width (RLW)	49.2 ± 6.8	49.2 ± 5.9	36.5 ± 8.2	47.5 ± 6.8	44.3 ± 8.7

Table 3 The morphometric variation (mean and standard deviation) of the leaf characters of the mangrove *Rhizophora apiculata* specie collected in different sites of Caraga.

The data revealed that the lowest mean and standard deviation of petiole length (PL) is the sample from the Area Z with 26.4 & ± 5.3, while the rest of the mean and standard deviation value are almost the same. And the lowest mean and standard deviation of midrib length (ML) is 117.3 and ± 49.6 of the sample from the Area N and the other places are most likely the same. The lowest mean & standard deviation of center lamina width (CWL) is 39.98 ± 14.7 from the Area Z while the highest is 73.28 ± 44.1 from the Area N and the remaining sites had almost the same value. On the leaf length (LL), the Area that had the highest value of mean and standard deviation is Area Y with 201.7 ± 24.6 while the lowest mean and standard deviation of 149.5 ± 26.6 is from the Area Z and the remaining value of mean and standard deviation are mostly likely the same. The Area that has a highest value of 51 ± 10.9 for left lamina width (LLW) is Area Z, and the next highest value of the mean and standard deviation is 49.6 ± 9.9 from the Area N while the remaining value are almost the same. And the municipality with the lowest value of 36.5 ± 8.2 for the leaf characters of right lamina width (RLW) is Area Z while the remaining mean and standard deviation value are very close. The result entails that majority of the lowest result in mean and standard deviations are from the Area Z, therefore the leaf sizes of *Rhizophora apiculata* specie is smaller than the other samples.

Table 4 Principal component analysis (PCA) of leaf morphometric characters of *Rhizophora apiculata* in different sampling sites.

Characters	Area X	Area M	Area Y	Area N	Area Z
Petiole Length(PL)	-0.81	-0.27	-0.88	-0.35	-1.60
Midrib Length (ML)	0.90	-1.58	-0.35	0.77	0.35
Center Lamina Width (CLW)	-0.42	1.21	-0.52	1.41	0.52
Leaf Length (LL)	1.60	0.96	0.20	-0.70	-0.41
Left Lamina Width (LLW)	-0.62	-0.21	1.91	0.18	-0.23
Right Lamina Width (RLW)	-0.65	-0.10	-0.37	-1.32	1.36
Total variance explained					
% of variance	45.62	58.22	63	48.11	62.11
Cumulative variance	45.62	58.22	63	48.11	62.11

Table 3 The morphometric variation (mean and standard deviation) of the leaf characters of the mangrove *Rhizophora apiculata* specie collected in different sites of Caraga Region. It entails the principal component analysis (PCA) of leaf morphometric characters of *Rhizophora apiculata* specie in different sampling sites. Shell morphometry in Area X is significantly determined by a uni-dimensional component of six (6) correlated leaf characters explained by a total variance of 45.62%. Moreover, Area X had highest loading for LL and ML with a factor loading of 1.60 and 0.90 respectively; that is LL and ML primarily determines leaf shape in Area X. The second site is Area M where LL is determined in a factor loading of 0.96 with a total variance of 58.22. While in Area Y, the LL also had a highest loading by factor of 1.91 and with a variety of 63 a highest variance. In Area N, CWL with a factor 0.77 and LL with a factor of 1.41 determine the leaf shape and a total variance of 48.11. Lastly, Area Z RLW had highest loading by a factor of 1.36 and a variance of 62.11. It implies that Area X significantly determined ML and LL while Area M is LL, Area Y LLW and Area N LL and CWL while Area Z RLW.

5. Conclusion

This study gives meaningful insights to the characteristics of mangrove species and soil conditions across various coastal locations in the region. The results showed that *Rhizophora apiculata*, *Sonneratia alba*, and *Avicennia marina* were the dominant mangrove species in the study areas, which all exhibits nearly on the same fractal dimensions. This means that despite of differences in environmental factors, these species maintain a similar level of structural complexity, reflecting their strong adaptability to coastal environments.

In terms of soil conditions, Areas Z, Y, and N were found to be more acidic soils¹⁰, which may influence nutrient absorption and mangrove growth. The nutrient analysis also revealed that Area Y had a higher level of organic matter and potassium, which suggest better soil fertility. And magnesium content was consistently high in all locations, indicating an abundant presence of this essential nutrient that supports photosynthesis and enzyme functions. However, phosphorus levels were generally low across most sites, which could limit plant growth and productivity.

When looking at specific nutrient variations, Area X and M had the highest nitrogen levels, while Area N recorded with the highest phosphorous content, and Area Z had the highest potassium concentration. These differences show that nutrient distribution varies greatly from one area to another, which potentially affects

mangrove health and development. Notably, Area Z had the lowest overall nutrient levels, which was reflected in the smaller leaf sizes of *Rhizophora apiculata* found in the area. This suggests a possible connection between soil fertility and mangrove leaf structure, emphasizing the importance of nutrients for healthy growth.

Overall, this study highlights the complex relationship between mangrove species, soil composition, and nutrient distribution which provide essential baseline information. As such, future research is encouraged to further investigate how environmental changes and variations in soil nutrients affect the long term health and sustainability of mangrove forests.

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