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Research Article

Comparing Mangrove Diversity and Soil Composition Along The Coast of Barangay Pamosaingan, Socorro, Surigao del Norte, Philippines

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Abstract

Mangrove ecosystems provide critical ecological services and are highly sensitive to environmental variables, particularly soil characteristics. This study explores the relationship between soil composition and mangrove species diversity along the coast of Barangay Pamosaingan, Socorro, Surigao del Norte, Philippines. A stratified random sampling design was applied, establishing twenty 10 m × 10 m quadrats across three ecological zones based on tidal influence. Mangrove species within each quadrat were identified and recorded, while soil samples were collected at a 30 cm depth for granulometric analysis using a series of standard sieves. Species diversity was assessed using Simpson's Diversity Index, and relationships between soil texture and diversity were evaluated through Pearson correlation analysis. The study identified eight mangrove species from four families, with *Rhizophora apiculata* emerging as the dominant species across the majority of quadrats. Sieve analysis revealed that fine sand constituted the majority of the substrate, with 77% of soil particles passing through the No. 10 sieve. A strong positive correlation ($r = 0.964$) was found between fine sand content and species diversity. These findings suggest that fine-grained sediments offer favorable conditions for mangrove growth and species richness. The results provide a basis for targeted conservation strategies, particularly in regions with similar coastal soil characteristics, and underscore the ecological relevance of substrate type in sustaining mangrove biodiversity.

Keywords: *Biodiversity, Mangrove, Rhizopora apiculate; Sieve Analysis; Soil Composition*

INTRODUCTION

The Philippines, an archipelagic country, possesses vast coastal and marine environments that offer essential ecological, economic, and social advantages. Nonetheless, many ecosystems, especially mangrove forests, are experiencing heightened degradation due to human activity and climate change. Research demonstrates that the nation has experienced a loss of about 50% of its mangrove coverage since the early 20th century, with ongoing challenges from deforestation, pollution, and rising sea levels (Agduma, 2024; Cuenca-Ocay, 2023). The Philippine government has enacted conservation measures, including Republic Act No. 7586 and the National Integrated Protected Areas System (NIPAS) Act of 1992, which regulates the creation and administration of protected areas. Furthermore, the Siargao Island Protected Landscape and Seascape (SIPLAS) was established by Presidential Proclamation No. 902 on October 10, 1996, to bolster mangrove conservation initiatives. SIPLAS encompasses over 278,914 acres across various municipalities in Surigao del Norte to conserve biodiversity while fostering sustainable resource management, ecotourism, and community-based conservation (Calagui et al., 2022; Baranggan et al., 2023). Despite these initiatives, mangrove degradation continues, requiring focused conservation and restoration measures that integrate ecological services and soil properties.

Mangroves function as essential blue carbon ecosystems, sequestering substantial quantities of carbon and alleviating the effects of climate change. China has acknowledged the biological importance of mangroves and has enacted the Special Action Plan for Mangrove Protection and Restoration (2020–2025), thereby augmenting regional carbon sinks through targeted conservation efforts (Feng et al., 2024). Nonetheless, extensive evaluations of mangrove-soil interactions are scarce in the Philippines, where localized research remains insufficiently developed. Recent research underscores the necessity of prioritizing conservation areas according to ecosystem functions, indicating that existing protected zones inadequately represent all mangrove species. Strategic conservation planning could preserve an additional $16.3 billion in coastal property value, safeguard 6.1 million individuals, and improve carbon sequestration (Dabala et al., 2023).

The features of mangrove soil, such as texture, pH, salinity, and organic carbon content, profoundly affect the distribution and growth of mangroves. Research on mangrove regeneration sites has revealed discrepancies in soil properties across various tidal zones, with organic carbon concentrations varying from 0.25% to 2.18% in rehabilitation areas and from 0.62% to 1.73% in non-rehabilitation zones (Dewiyanti et al., 2021). Moreover, fluctuations in salinity and nutrient accessibility influence mangrove composition and diversity. Research on the Camotes Islands identified 42 mangrove species, including two endangered species, underscoring the ecological significance of these areas (Lillo et al., 2022). Comparable results in Bengkulu City revealed 52 plants, but water quality evaluations suggested possible ecological risks from increasing nitrite levels (Soeprobowati et al., 2022).

International studies highlight the significance of mangroves in climate resilience, carbon sequestration, and biodiversity support; nonetheless, there is a conspicuous deficiency of research examining the complex link between mangrove diversity and soil composition in the Philippines. Conservation projects are disjointed, missing thorough evaluations that incorporate mangrove ecosystem services into the administration of protected areas (Rastogi et al., 2021; Kumar et al., 2021; Sunkur et al., 2024). This study examines the correlation between mangrove species diversity and soil characteristics, offering insights into effective conservation techniques.

Comprehending these interactions is essential for optimizing conservation initiatives and bolstering mangrove resilience against environmental threats.

METHODS

Area of the Study. Figure 1. Map depicting the research location: The study was done in Barangay Pamosaingan, Socorro, Surigao del Norte, Philippines. Socorro is a coastal municipality with a land area of 131.85 km², a population of 25,942 according to the 2020 Census, and 14 barangays. Barangay Pamosaingan, the research location, is situated at 9.6495° North latitude and 125.9224° East longitude, at an elevation of 14.4 meters above mean sea level (PhilAtlas.com).

The region exhibits a tropical monsoon climate, marked by pronounced wet (November to March) and dry (April to October) seasons, with an annual precipitation of roughly 3,500 mm (PAGASA, 2023). Tidal patterns, including semi-diurnal and diurnal cycles, are essential for sediment accretion and wetland elevation responses to relative sea level rise, influencing mangrove resilience (Belliard et al., 2023). The region's soil predominantly comprises sandy loam and clay, with organic matter content varied based on distance from the sea.

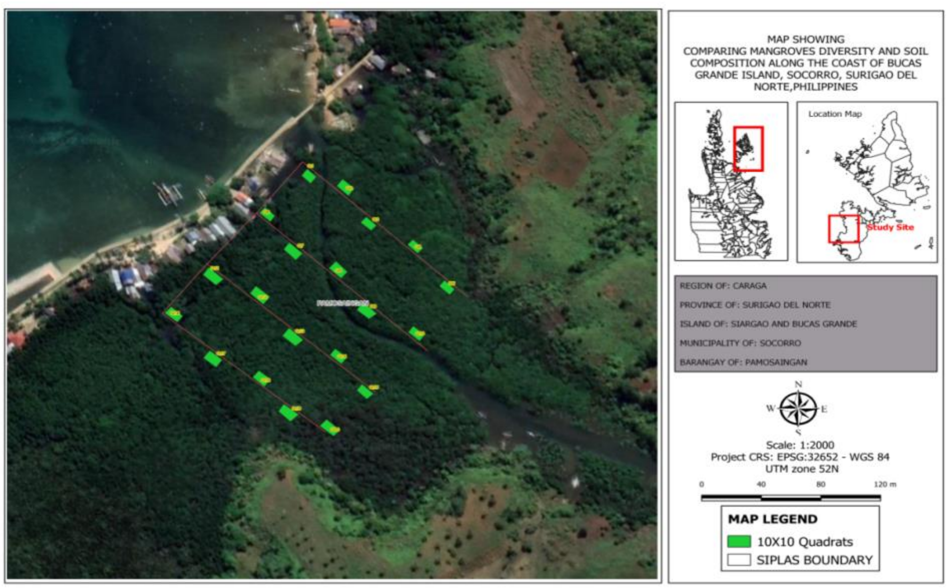

Figure 1. Map Showing the study site.

Sampling Design and Quadrats Establishment. Sampling Design and Quadrat Establishment. The research utilized a stratified random sample method, categorizing the mangrove region into three ecological zones according to their distance from the shoreline:

1. Coastal Zone (0–50 meters from beach, elevated salinity, frequent tidal inundation)
2. Intermediate Zone (50–100 meters, moderate salinity, sporadic tidal effect)
3. Inland Zone (exceeding 100 meters, minimal salinity, rare tidal influence)

Twenty quadrats, each measuring 10m x 10m, were formed inside these zones, with a spacing of 30 meters between quadrats to reduce spatial autocorrelation while ensuring enough coverage. The sample size was established by analogous studies (Pototan et al., 2021; Natividad et al., 2014; Jumawan, 2015) and power analysis, hence assuring statistical rigor. In each quadrat, 1m x 1m subplots were allocated to evaluate seedlings (Bersamo et al., 2023). Mangrove species were identified utilizing field guides and taxonomic keys (Goloran et al., 2020; Melana & Gonzales, 2000; Primavera et al., 2004), with only species found inside quadrats incorporated into the final inventory. The subsequent instruments were employed for precise data collection:

Transect tape – for accurate quadrat arrangement
- Rope and stakes – for defining sampling areas
- Digital camera — for documentation and species authentication

Mangrove Diversity Analysis

Mangrove species diversity was examined using Paleontological Statistics (PAST) software (Puzon et al., 2022; Hammer et al., 2001), generating important diversity indices, including Simpson's Index, Shannon-Wiener Index, and species richness. A Spearman's rho correlation study was performed to investigate the association between mangrove diversity and soil composition, as preliminary tests revealed a non-normal data distribution. The choice of Spearman's rho instead of Pearson's correlation was warranted due to the ordinal characteristics of soil composition variables. Soil sampling analysis. Soil samples were obtained from the sampling quadrats. A minimum of 2,000 grams of quadrate samples will be collected at a depth of 30 cm for sieve size and sieve analysis. The samples were thoroughly mixed and permitted to air-dry for approximately one week in the room settings. The dried soil samples were measured at 2,056g, utilizing a solution beam balance for granulometric soil analysis, adhering to the methodologies established by Kauffman and Donato (2012) and Donato et al. (2011).

RESULT AND DISCUSSIONS

Table 1 shows that the sieve analysis performed on the soil samples provided critical information regarding the particle size distribution and composition of the samples. The sample underwent processing through a succession of sieves with differing mesh sizes, and the outcomes were meticulously documented. The sieve analysis presented in Table 1 indicates the particle size distribution of the soil sample as follows: No. 10 sieve: 77% passing; No. 40 sieve: 6% passing; No. 200 sieve: 2% passing.

Table 1. Sieve Size and Sieve Analysis

Sieve size mm (in.)	Wt retained	% retained	Cumulative			Governing	Remarks
			Wt Passing	% Passing	% retained	Spec's passing	
75.00 (3")	0	0	2010	0	100	100	Passed
63.00 (2 1/2)	0	0	2010	0	100	0	-
50.00 (2")	0	0	2010	0	100	0	-

37.50 (1 1/2”)	0	0	2010	0	100	0	-
25.00 (1’’)	0	0	2010	0	100	0	-
19.00 (3/4’)	11	00	1999	0	99	0	-
12.50 (1/2”)	3	0	1996	0	99	0	-
9.50 (3/8”)	16	0	1980	0	99	0	-
6.30	0	0		0	0	0	-
4.75 (No.4)	66	0	1914	0	95	0	-
2.36 (No.8)	0	0		0	0	0	-
2.00 (No.10)	361	0	1553	0	77	0	-
1.18 (No.16)	0	0	0	0	0	0	-
0.60 (No.30)	0	0	0	0	0	0	-
0.425 (No.40)	1424	0	129	0	6	0	-
0.300 (No.50)	0	0	0	0	0	0	-
0.250	0	0	0	0	0	0	-
0.150 (No.100)	0	0	0	0	0	0	-
0.075 (No.200)	98	0	31	0	2	0-15	Passed
PAN	5	0	0	0	0	0	-
Washing No. 0.075	0	0	26	0	1	0	-
Total	1984						

Figure 2. Actual images of Soil particles view during Sieve Size and Sieve Analysis
(A) 19mm,3/4”; (B) 12.50mm,1/2”; (C) 4.75mm,4”; (D)2.00mm,10”; (E)0.425mm,40”; (F)0.075mm,200”; (G) Pan

The results indicate that most soil samples comprise fine sand, as reflected by the elevated percentage passing through the No. 10 sieve. The particle distribution is distinctly refined, exhibiting a gradual decrease in particle size with an increase in sieve number, signifying a prevalence of smaller particles in the sample. The soil's fine texture is corroborated by the minimal percentages kept on the smaller sieves, especially the No. 200 sieve, which retained merely 2% of the material.

The sieve analysis results reveal a different particle size distribution pattern, with significant implications for both environmental and technical applications. The examination commenced with the largest sieve sizes (75.00 mm and smaller) (Image A), revealing no material retention, which signifies the lack of coarse particles in the sample. Thus, the entirety of the soil traversed these sieves, verifying that the soil composition is primarily fine-grained. This observation is consistent with prior research on mangrove soil textures, which indicate analogous fine sediment compositions (Nguyen et al., 2013).

A comprehensive analysis of filter diameters of 12.50 mm and smaller reveals a gradual shift in particle retention. At 12.50 mm, 3 grams of material were preserved, representing approximately 1% of the original sample. This indicates that a small proportion of bigger particles, presumably detritus or mineral pieces, exists in the soil. However, a more dramatic shift occurred at the 4.75 mm (No. 4 sieve), where 66 grams of material were held, reducing the cumulative weight to 95%. This underscores the shift from coarser to finer fractions within the sample, signifying a heterogeneous soil composition in this spectrum.

Further sifting through increasingly lower diameters (2.00 mm, 0.425 mm, and 0.075 mm) demonstrates a strong pattern of decreasing particle retention. At 0.075 mm (No. 200 sieve), merely 2% of the material was retained, indicating the preponderance of fine sand and silt fractions. This conclusion is noteworthy, as it indicates that the soil's texture corresponds with established classifications for fine-grained sediments, which are recognized to affect soil permeability and water retention capacity. This observation is corroborated by research on mangrove soil structures, which demonstrates that smaller particles are essential for nutrient retention and hydrodynamic processes in these environments (Thura et al., 2023).

The concluding sieving procedures for the "PAN" (pan part) and "Washing No. 0.075" produced supplementary material, 5 grams, and 26 grams, respectively. This slight retention further substantiates the conclusion that the soil primarily comprises fine particles, confirming its classification within the fine sand to silt group. Comparative analyses of mangrove ecosystems underscore analogous particle size patterns, emphasizing the ecological importance of fine-grained sediments. Kamal et al 2017 assert that mangrove soils are predominantly composed of fine particles, which enhance sediment stability and support mangrove root systems. The complex aerial root structures of mangroves trap fine sediment particles, reducing water velocity and promoting sediment deposition. This process contributes to the stability of the sediment and supports the mangrove root systems. The outcomes of this study corroborate existing research, thereby reinforcing the essential function of fine sand in preserving the ecological integrity of mangrove ecosystems.

Furthermore, the ramifications of these findings pertain to engineering and environmental applications. The soil's fine texture indicates its potential suitability for agricultural and ecological restoration initiatives, especially regarding water retention and nutrient cycling. Tiny particles also prompt questions regarding soil erosion potential and sediment transport dynamics in coastal habitats.

Recent research has examined the particle size distribution in mangrove soils, indicating a predominance of tiny particles. For instance, research reveals that soil particle sizes ranging between 0.074 and 0.5 mm form around 75–95% of the soil sample weight in particular mangrove environments (Nguyen et al., 2013). Another study indicated that mangrove soils had a greater proportion of fine particles than neighboring mudflats, with soil texture growing finer over time following mangrove restoration (Thura et al., 2023). Furthermore, research on the effects of microplastics on mangrove soils indicates that most microplastic particles are smaller than 700 μm, with substantial proportions ranging from 158 to 355 μm (Hu et al., 2022). These findings highlight the essential significance of fine-grained sediments in maintaining mangrove ecosystems' structural integrity and ecological activities.

The sieve study results offer a thorough evaluation of soil particle size distribution, indicating dominance of fine sand and silt fractions. The gradual reduction of residual material across sieves substantiates the fine-grained characteristics of the sample, consistent with prior studies on mangrove soil compositions. These findings possess considerable ramifications for environmental sustainability and technical applications, especially in comprehending soil stability, nutrient retention, and ecological restoration. Future research should investigate the hydrodynamic characteristics of these soils to improve conservation techniques and land-use planning in mangrove ecosystems. Table 2 shows the species composition of mangroves at Pamosaingan, Socorro, and Surigao del Norte. Eight (8) mangrove species from four (4) families were identified, with the most common being *R. apiculata*, observed across thirteen (13) quadrats. These results provide insight into how soil types influence mangrove species diversity in the study area.

Table 2. Species composition of mangrove at Pamosaingan, Socorro, Surigao del Norte.

Family	Species	Common Name
Acanthaceae	*Avicennia officinalis*	Api-api
Combretaceae	*Lumnitzera littorea*	Tangal
Lythraceae	*Sonneratia alba*	Pagatpat
Rhizophoraceae	*Bruguiera cylindrical*	Pototan
	Bruguiera gymnorrhiza	Busain
	Rhizophora apiculata	Bakhaw Lalaki
	Rhizophora mucronata	Bakhaw Babae
	Rhizophora stylosa	Bakhaw Bato

Table 2 defines the species makeup of mangroves at Pamosaingan, Socorro, Surigao del Norte, identifying eight (8) mangrove species across four (4) families. Rhizophora apiculata demonstrated the greatest dominance, occurring in thirteen (13) quadrats. This dominance indicates a pronounced biological preference for environmental circumstances, such as tidal inundation frequency, soil composition, and salinity levels. The ubiquity of R. apiculata can be ascribed to its adaptation to wet environments and its capacity to develop robust root systems in fine-grained, organic-rich substrates. The soil analysis results (Table 1) reveal that fine sand is the primary substrate at the study location, potentially facilitating optimal circumstances for R. apiculata, hence enhancing root aeration and nutrient uptake. These features facilitate the species' extensive dispersal across many quadrats.

Other species, including Sonneratia alba and Avicennia officinalis, were encountered less often, potentially attributable to their varying sensitivities to soil and salinity. S. alba typically flourishes in regions with increased freshwater influx and finer silt, but A. officinalis is frequently located in habitats with variable salinity levels. The infrequent presence of these species in the study area indicates that fluctuations in hydrological conditions and sediment composition substantially affect mangrove community structure. Statistical analysis should enhance the understanding of the relationship between species distribution and soil composition. Correlation and regression analysis can ascertain how soil texture, organic matter concentration, and salinity influence species occurrence and dominance. A more profound statistical analysis would yield significant insights into the resilience of mangrove species to environmental alterations, informing conservation initiatives and habitat restoration techniques. This research emphasizes the ecological importance of mangrove species diversity and habitat selections. It also emphasizes the significance of site-specific conservation strategies that take into account environmental factors affecting species distribution. Future studies must use comprehensive soil physicochemical investigation and multivariate statistical techniques to enhance the comprehension of mangrove-soil interactions.

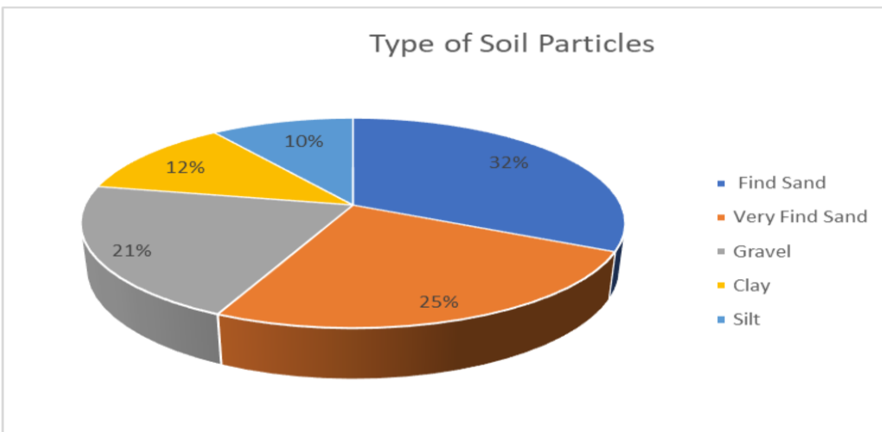

Figure 3. Soil Composition and Dominant Substrates in the Mangrove Area.

Figure 3 illustrates that the soil composition of the study region was predominantly comprised of fine sand (32%), followed by very fine sand (25%) and coarse sand (21%). Larger particles were generally more abundant in the soil than smaller particles, such as clay (12%) and silt (10%). Fine sand's prevalence was uniform over most of the quadrats, especially in quadrats 1, 4, 5, 7, and 15. The composition of these bigger particles indicates that the soil's physical structure in this region favors the establishment of mangrove species, especially those suited to well-drained soils.

Table 3 presents a comprehensive overview of the soil composition for all quadrats. It demonstrates that very fine sand and clay were also substantial components in the soil structure of some quadrats, contributing to the overall variance in substrate types. The prevalence of fine sand underscores the significance of sandy bottoms in sustaining mangrove ecosystems. Larger soil particles, such as fine sand, provide for improved drainage and root penetration, which are required to grow mangrove species. Moreover, soil composition affects plant dispersal by influencing nutrient availability and water retention. Soil quality is characterized by its capacity to support the production of plants and animals, enhance water and air quality, and promote ecosystem resilience.

Table 3.Overview of Soil Substrate, Key Mangrove Species, and Diversity Indicators Across 20 Quadrants

PN	*Substrate*	*DS*	*SR*	*AB*	*SD*
Q1	FS	*Rhizopora apiculata*	7	40	0.857143
Q2	VFS	*Lumnitzera littorea*	3	7	0.666667
Q3	GVL	*Rhizophora stylosa*	2	4	0.5
Q4	FS	*Rhizopora apiculata*	6	51	0.833333
Q5	FS	*Rhizopora apiculata*	7	46	0.857143
Q6	VFS	*Sonneratia alba*	4	6	0.75
Q7	FS	*Rhizopora apiculata*	6	37	0.833333
Q8	FS	*Rhizophora mucronata*	3	21	0.666667
Q9	VFS	*Avicennia officinalis*	3	8	0.666667
Q10	CLY	*Avicennia officinalis*	3	5	0.666667
Q11	SLT	*Bruguiera gymnorrhiza*	4	4	0.75
Q12	VFS	*Bruguiera gymnorrhiza*	3	7	0.666667
Q13	CLY	*Bruguiera cylindrica*	2	4	0.5
Q14	CLY	*Bruguiera cylindrica*	2	2	0.5
Q15	FS	*Rhizopora apiculata*	9	91	0.888889
Q16	CLY	*Bruguiera cylindrica*	4	4	0.75
Q17	GVL	*Rhizopora apiculata*	5	17	0.8
Q18	SLT	*Rhizophora mucronata*	3	25	0.666667
Q19	GVL	*Rhizophora mucronata*	4	16	0.75
Q20	SLT	*Bruguiera cylindrica*	4	3	0.75

Plot Number (PN); Dominant Species (DS); Species Richness (SR); Abundance (AB); Simpson Diversity (SD).

Table 4 illustrates that the diversity of mangrove species in the study was evaluated using the Simpson Diversity Index, a commonly employed metric that accounts for both species richness and evenness. The findings indicated that Rhizophora apiculata was the predominant species, with the greatest abundance recorded in Quadrat 15, which housed 91 mangrove plants. This quadrat also demonstrated the highest species richness and Simpson Diversity Index (0.888), indicating that it provided the ideal conditions for mangrove growth. Furthermore, fine sand constituted the predominant substrate in Quadrats 7 and 15, where R. apiculata was also prevalent. This indicates a robust correlation between fine sand and the successful proliferation of R. apiculata, reinforcing the concept that soil substrate type substantially affects mangrove species distribution and diversity. These findings corroborate the research conducted by Manual et al. (2022), which identified Rhizophora apiculata as the predominant species, with a significance value index of 144.41%.

Table 4. The Pearson correlation indicates a positive relationship between substrates and Simpson diversity.

	FS	*VFS*	*CLY*	*SLT*	*GVL*
Simpson	0.964	0.933	0.928	0.833	0.928

Legend: FS- Fine Sand; VFS-Very Fine Sand; CLY-Clay; SLT-Silt; GVL- Gravel

The Pearson correlation study revealed a robust positive association between soil substrates and Simpson diversity. Fine sand (0.964) exhibited the strongest link with species diversity, succeeded by very fine sand (0.933), clay (0.928), and gravel (0.928). The findings indicate that soil abundant in fine sand and clay significantly promotes mangrove biodiversity by supplying vital resources, including nutrients, water retention, and stability for mangrove root systems. The association between fine sand and species diversity was the most robust, underscoring that sandy foundations are ideal for sustaining a diverse mangrove community.

Sandy soils enhance mangrove diversity by promoting nutrient absorption and root growth. The weak connection of gravel and silt with Simpson diversity (0.833 for both) implies that while these substrates also support mangrove growth, their influence on species diversity is less significant than that of fine sand and clay. These findings hold considerable significance for the conservation and restoration of mangroves. The significant link between fine sand and mangrove species diversity highlights the significance of soil composition in sustaining healthy and diverse mangrove ecosystems. Regions characterized by fine sand as the primary substrate are expected to sustain a greater diversity of mangrove species, enhancing ecosystem services, including coastal protection, carbon sequestration, and biodiversity conservation. The originality of this research rests in its detailed analysis of the relationship between soil composition and mangrove diversity, employing Pearson's correlation to measure the strength of the relationship between specific soil substrates and Simpson diversity. This work offers a comprehensive statistical analysis of how various soil substrates affect species richness and abundance in mangrove ecosystems, building on prior research emphasizing soil type's significance.

CONCLUSION

This study shows the essential influence of soil composition on mangrove species diversity, particularly the significant impact of fine sand on species dispersion. The sieve analysis revealed that fine sand represented most of the soil sample, with 77% passing through the No. 10 sieve. This discovery corroborates other studies demonstrating that fine-grained sediments enhance sediment stability and nutrient retention, both crucial for mangrove ecosystems. The statistical link between soil substrate composition and Simpson diversity index values (0.833 to 0.964) reinforces the robust relationship between soil texture and mangrove species richness, especially for Rhizophora apiculata. To augment the dependability of this finding, subsequent research should include more comprehensive quantitative validation by regression modeling and controlled field studies.

The study adds to mangrove conservation by proving that fine sand-dominated surfaces encourage the growth of R. apiculata, which displayed the highest dominance across quadrats. This understanding has practical consequences for ecosystem management, especially in formulating conservation strategies emphasizing habitat restoration in regions with analogous soil conditions. Nonetheless, although the study combines sieve analysis with Pearson’s correlation to evaluate mangrove-soil interactions, it does not significantly distinguish itself from established approaches. Future research should explore novel analytical tools, such as geospatial mapping and improved soil physicochemical assessments, to provide a more thorough understanding of mangrove habitat appropriateness.

Numerous methodological constraints must be recognized. The study was limited to a singular mangrove zone, thus introducing sampling biases that may not reflect wider regional differences. This study did not consider seasonal variations in soil composition that may affect mangrove dispersal. Additionally, while Pearson's correlation was applied to analyze soil-mangrove connections, more robust statistical techniques, such as multivariate regression, could provide deeper insights into the interplay between environmental conditions and species distribution. Mitigating these constraints in forthcoming research would enhance the relevance of findings in mangrove conservation and management.

Future studies should broaden the analytical scope by integrating seasonal variability in soil properties and evaluating supplementary environmental data, such as salinity and organic matter content, to enhance the comprehension of mangrove-soil interactions. Moreover, incorporating ecological modeling techniques could improve predictive efficacy for mangrove conservation strategies. By focussing on these areas, subsequent studies might enhance the findings of this research to formulate more precise and effective conservation policies.

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AUTHORS CONTIBUTIONS

In this study, Jhondel P. Baranggan, as the corresponding author, designed the research framework, led field data collection including soil and mangrove sampling, coordinated institutional permits and logistics, conducted sieve and correlation analyses, drafted the initial manuscript, and finalized the submitted version. Aldwin Y. Sarmen contributed to mangrove species identification and taxonomic classification, assisted in soil sample preparation and drying, participated in fieldwork design and documentation, and supported the interpretation of statistical analyses. Manny P. Eviota, Ph.D., provided scientific supervision throughout the research process, critically reviewed the manuscript to ensure alignment with international academic standards, and contributed to data interpretation and the formulation of ecological implications. Archie D. Cawaling gathered supporting literature and conducted the literature review, helped organize the manuscript structure, and contributed to content revision and formatting consistency.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest related to the design, implementation, analysis, or publication of this research. All procedures were conducted independently, and no financial or personal relationships have influenced the outcomes presented in this article.

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