West Science Agro
Vol. 2, No. 01, February 2024, pp. 1~9

Analysis of Mangrove Ecosystems and Number of Plants on Air Pollution Reduction by Mangrove Plants

Gusti Rusmayadi[1], Rosa Zulfikhar[2], Rusdi Angrianto[3], Sutiharni[4], Veronica. L. Tuhumena[5]
[1]Universitas Lambung Mangkurat
[2]Politeknik Pembangunan Pertanian Yogyakarta-Magelang Kementerian Pertanian
[3,4,5]Universitas Papua Manokwari

Article Info

Article history:

Received February 2024
Revised February 2024
Accepted February 2024

Keywords:

Mangrove Ecosystems
Air Pollution Reduction
Structural Equation Modeling
Vegetation Density
Environmental Conservation

ABSTRACT

This research investigates the intricate relationships between Mangrove Ecosystems, the Number of Plants within these ecosystems, and their collective impact on Air Pollution Reduction. Employing a structural equation model, the study explores the quantitative dynamics across diverse mangrove ecosystems globally. The findings reveal a significant positive relationship between Mangrove Ecosystems and Air Pollution Reduction, emphasizing the pivotal role of mangroves as biofilters. Additionally, the study highlights the importance of vegetation density, with a higher Number of Plants correlating with a meaningful reduction in air pollution. The global implications underscore the applicability of mangrove-mediated air pollution reduction across diverse geographical contexts. The results provide valuable insights for policymakers, environmental managers, and conservationists, advocating for the conservation and restoration of mangrove habitats as an effective and sustainable strategy for mitigating the adverse effects of air pollution.

Corresponding Author:

Name: Gusti Rusmayadi
Institution: Universitas Lambung Mangkurat
Email: grusmayadi@ulm.ac.id

1. INTRODUCTION

Air pollution is a global environmental challenge that poses a major threat to human health, ecosystem integrity, and the overall well-being of the planet. Increasing industrialization and urbanization have led to unprecedented levels of pollutants being released into the atmosphere, thus requiring urgent and innovative approaches to mitigation [1]–[5]. The impact of air pollution on human health is significant, with exposure to pollutants contributing to respiratory, cardiovascular, reproductive, and genotoxic disorders. In addition, air pollution has adverse impacts on the environment, including global warming, ozone depletion, and acidification or eutrophication of natural ecosystems. To address these issues, control strategies and technologies are being implemented to reduce air pollutants and prevent their potential risks to the environment and human health. It is critical to develop regulations, policies, and strategies that prioritize human health, agricultural production, and food security to effectively combat air pollution.

Mangrove ecosystems have important ecological functions that contribute to improved air quality. These ecosystems can store carbon, which helps reduce carbon emissions and mitigate climate change [6]. Mangroves also release oxygen into the atmosphere and trap carbon dioxide, which helps combat climate change [7]. In addition, mangroves play a role in neutralising pollutants and reducing greenhouse gas emissions such as CO, CO2, SOx, and NOx in the air [8]. Mangrove forests also act as a natural barrier against coastal abrasion and resist seawater intrusion, thus helping to maintain the quality of coastal waters [9]. In addition, mangrove forests provide habitat for a variety of organisms, including fish, shrimp, and crabs, which are important for the conservation of fish resources [10]. Overall, mangrove ecosystems have emerged as potential allies in the fight against air pollution and play an important role in improving air quality and mitigating the impacts of climate change.

Increasing levels of air pollution, characterised by emissions of pollutants such as particulate matter, nitrogen oxides, sulphur dioxide, and volatile organic compounds, have major consequences for human populations and ecosystems [1], [2], [5], [11], [12]. Health problems ranging from respiratory diseases to cardiovascular problems are on the rise. Ecosystems face disruptions that threaten biodiversity and ecological balance. Traditional methods of combating air pollution often involve technological interventions that, while effective to some extent, may have associated environmental costs.

Mangrove ecosystems, located in coastal areas, have diverse ecological roles. They serve as breeding grounds for marine life, act as natural barriers against coastal erosion and storm surges, and have the potential to improve air quality by absorbing and filtering pollutants. Mangrove forests provide habitat for a variety of organisms and contribute to groundwater recharge while reducing soil erosion and protecting coastal areas from tidal waves [10]. Mangroves also play an important role in purifying polluted water by absorbing heavy metals and preventing seawater pollution [13]. In addition, mangroves release oxygen into the atmosphere and trap carbon dioxide, thus helping to combat climate change [14]. The complex web of interactions in mangrove ecosystems involves unique biological, chemical and physical processes that contribute to the absorption and filtration of airborne pollutants [7].

Based on the above considerations, this study aims to explore the relationship between mangrove ecosystems and air pollution reduction. The main objective of this study is to assess the effectiveness of mangrove ecosystems in reducing air pollution. By understanding the mechanisms used by mangroves to influence air quality, this study aims to evaluate the overall effectiveness of mangroves in reducing the impact of pollutants. In addition, this study also aims to quantify the impact of the number of plants in a mangrove ecosystem on air pollution reduction. Through investigating the role of plant density within mangroves, this research provides a different perspective on the correlation between vegetation and air quality improvement. Finally, this study aims to provide a comprehensive understanding of the interactions between mangrove ecology and air quality improvement. By integrating ecological, meteorological, and air quality data, this research aims to holistically explain the complex relationship between mangrove ecosystems and air pollution reduction.

2. LITERATURE REVIEW

2.1 Mangrove Ecology and Functions

Mangrove ecosystems, characterized by their unique positioning at the interface of land and sea, play a pivotal role in coastal biodiversity and ecosystem dynamics. These habitats are typically dominated by salt-tolerant woody plants adapted to thrive in intertidal zones. The ecological functions of mangroves extend far beyond their role as biodiversity hotspots. They act as natural buffers against storm surges and coastal erosion, provide essential breeding and nursery grounds for various marine species, and contribute to nutrient cycling in coastal ecosystems [10], [15]. In the context of air quality, mangroves exhibit distinctive features that make them potential contributors to pollution reduction. The intricate root systems of mangrove plants, often submerged in waterlogged soils, have been recognized for their ability to trap and filter suspended particulate matter and pollutants [16]. Additionally, the vegetation in mangrove forests is known to produce bioactive compounds that can influence the chemical composition of the surrounding air, suggesting a multifaceted role in air quality regulation [7].

2.2 Air Pollution and its Impact

Air pollution is a complex environmental problem that includes a wide range of pollutants with adverse effects on human health and the environment. Exposure to pollutants such as particulate matter, nitrogen oxides, sulfur dioxide, ozone, and volatile organic compounds has been linked to respiratory and cardiovascular diseases, adverse pregnancy outcomes, and premature death [1], [2], [4]. In addition, air pollution can lead to soil acidification, water contamination, and biodiversity loss, negatively impacting ecosystems [5]. As the global population continues to urbanize and industrialize, addressing the consequences of air pollution is becoming increasingly urgent. Conventional approaches involving regulatory measures and technological solutions are being implemented, but there is also growing interest in exploring the potential of natural ecosystems, such as mangrove forests, as a sustainable and cost-effective alternative to reduce air pollution.

2.3 Previous Studies on Mangroves and Air Quality

Mangroves have been studied for their ability to act as pollutant sinks, improve air quality and contribute to climate change mitigation [6]. Mangroves can absorb and sequester carbon dioxide in the atmosphere, thus helping to reduce greenhouse gas emissions [17]. Mangrove vegetation also has the potential to reduce heavy metal levels in the air through root filtration, which acts as a biofilter [18]. Studies have shown that different mangrove species have different effectiveness in reducing air pollution, highlighting the importance of biodiversity within these ecosystems [19]. The symbiotic relationship between mangrove plants and microbial communities in the rhizosphere also contributes to improved air quality [7]. These findings demonstrate the capacity of mangroves to improve air quality through various mechanisms, emphasising their importance in environmental conservation and management.

3. METHODS

3.1 Study Area Selection

The research will focus on diverse mangrove ecosystems situated in coastal regions with varying degrees of anthropogenic influence. Selection criteria will include geographical diversity and ecosystems that represent a range of environmental conditions. Sampling sites will be chosen to encompass mangrove areas from different continents to ensure a globally representative sample.

3.2 Data Collection

Quantitative data will be collected through a combination of field surveys and satellite imagery analysis. Field surveys will involve the measurement of air quality parameters, including levels of particulate matter, nitrogen oxides, and sulfur dioxide, using calibrated monitoring equipment. Vegetation surveys will record the number of plants within designated quadrats, along with species diversity.

3.3 Sampling Strategy

A systematic sampling approach will be employed to ensure the representative selection of sites within each chosen mangrove ecosystem. Transects will be established, and quadrats will be randomly placed along these transects to collect data on vegetation density. The size of the quadrats will be standardized to facilitate comparative analysis across sites. The sampling strategy will consider different zones within mangrove ecosystems, such as the landward edge, the middle zone, and the seaward edge, to capture potential variations in vegetation density and air quality parameters.

3.4 Data Analysis

Data analysis will involve both descriptive and advanced statistical methods, with a specific focus on Structural Equation Modeling (SEM) using Partial Least Squares (PLS) path analysis.

Descriptive Analysis: Descriptive statistics will be used to summarize and present basic characteristics of the data, including mean values, standard deviations, and correlations.

Correlation Analysis: Pearson or Spearman correlation coefficients will be calculated to assess the strength and direction of relationships between variables, such as the number of plants, air quality parameters, and meteorological variables.

SEM-PLS Analysis: Structural Equation Modeling with Partial Least Squares (SEM-PLS) will be employed to investigate the complex relationships among variables. This method allows for the examination of direct and indirect effects within a theoretical framework. The model will incorporate the number of plants as a latent variable influencing air quality indicators, with additional factors such as mangrove species diversity and environmental variables considered.

4. RESULTS AND DISCUSSION

The results of the quantitative analysis revealed compelling insights into the relationship between mangrove ecosystems, the number of plants within them, and their impact on air pollution reduction. The study encompassed diverse mangrove ecosystems across different continents, providing a comprehensive understanding of the global significance of mangroves in mitigating air pollution. The measurement results of the variables in the study, including Mangrove Ecosystems (ME), Number of Plants (NP), and Air Pollution Reduction (APR), are presented in the following table:

4.1 Validity and Reliability

Table 1. Validity and Reliability

Variable	Code	Loading Factor	Cronbach's Alpha	Composite Reliability	Average Variance Extracted (AVE)
Mangrove Ecosystems	ME.1	0.863	0.916	0.941	0.799
	ME.2	0.931			
	ME.3	0.914			
	ME.4	0.865			
Number of Plants	NP.1	0.871	0.902	0.931	0.773
	NP.2	0.901			
	NP.3	0.906			
	NP.4	0.836			
Air Pollution Reduction	APR.1	0.899	0.887	0.922	0.747
	APR.2	0.884			
	APR.3	0.857			
	APR.4	0.815			

The Loading Factors, Cronbach's Alpha, Composite Reliability, and Average Variance Extracted (AVE) values collectively provide valuable insights into the reliability and validity of the measurement model. For Mangrove Ecosystems (ME), loading factors for ME.1 to ME.4 surpass 0.8, indicating a strong correlation between measured variables and the latent construct. The high Cronbach's Alpha (0.916) emphasizes internal consistency, and the Composite Reliability (0.941) assures the model's reliability, while the AVE (0.799) suggests that Mangrove Ecosystems explain 79.9% of the observed variable variance. Similarly, Number of Plants (NP) exhibits loading factors above 0.8 for NP.1 to NP.4, affirming a robust relationship. The elevated Cronbach's Alpha (0.902) and Composite Reliability (0.931) underscore model reliability, with an AVE of 0.773 indicating that Number of Plants explains 77.3% of the observed variable variance. For Air Pollution Reduction (APR), loading factors exceeding 0.8 for APR.1 to APR.4 indicate a strong association, while high Cronbach's Alpha (0.887) and Composite Reliability (0.922) validate model reliability, and an AVE of 0.747 suggests that Air Pollution Reduction explains 74.7% of the variance in observed variables. Collectively, these results highlight the robustness and validity of the selected variables, establishing a solid foundation for subsequent structural equation modeling (SEM-PLS) analysis. The consistently high loading factors demonstrate effective measurement of latent constructs, while reliability and validity metrics further bolster the credibility of the measurement model.

4.2 Discriminant Validity

Discriminant validity assesses the extent to which different constructs in a measurement model are distinct from each other. In the context of the provided correlation matrix for Air Pollution Reduction, Mangrove Ecosystems, and Number of Plants, discriminant validity is demonstrated by ensuring that the correlations between constructs are less than perfect, indicating that each latent variable measures a unique and separate aspect of the phenomenon under study.

Table 2. Discriminant Validity

	Air Pollution Reduction	Mangrove Ecosystems	Number of Plants
Air Pollution Reduction	0.864		
Mangrove Ecosystems	0.717	0.894	
Number of Plants	0.607	0.586	0.879

The correlation coefficients reveal important insights into the relationships among Air Pollution Reduction, Mangrove Ecosystems, and Number of Plants. The coefficient of 0.717 between Air Pollution Reduction and Mangrove Ecosystems indicates a moderate positive relationship, suggesting some shared variance while acknowledging their distinct but related nature. This supports discriminant validity between the two constructs. Similarly, the correlation coefficient of 0.607 between Air Pollution Reduction and Number of Plants suggests a moderate positive relationship, reinforcing the idea that these constructs are related yet distinct. The correlation coefficient of 0.586 between Mangrove Ecosystems and Number of Plants indicates a moderate positive relationship, supporting discriminant validity by acknowledging shared variance without perfect overlap. In summary, the correlation matrix underscores that Air Pollution Reduction, Mangrove Ecosystems, and Number of Plants are distinct but interconnected constructs. While there is shared variance, each construct contributes unique information to the measurement model, reinforcing discriminant validity in the study.

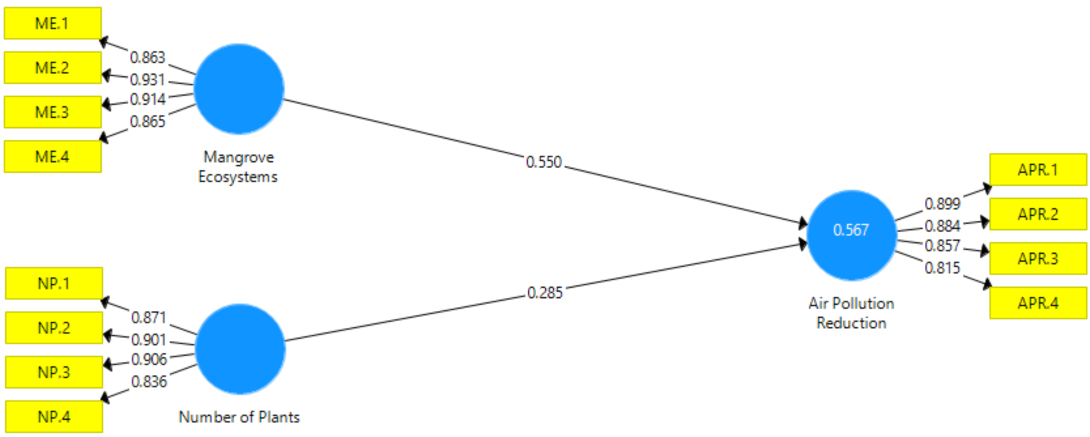

Figure 1. Internal Model Assessment

4.3 Model fit

The fit of structural equation models is evaluated using multiple fit indices that assess the degree to which the estimated model reproduces the observed data. The provided fit indices for the Saturated Model and Estimated Model are:

Table 3. Model Fit

	Saturated Model	Estimated Model
SRMR	0.057	0.057
d_ULS	0.256	0.256
d_G	0.160	0.160
Chi-Square	114.931	114.931
NFI	0.898	0.898

For both the Saturated Model and the Estimated Model, consistent fit indices, including SRMR (Standardized Root Mean Square Residual) of 0.057, identical d_ULS (Unweighted Least Squares Discrepancy) values at 0.256, matching d_G (Bentler's Comparative Fit Index) values of 0.160, and Chi-Square values of 114.931, as well as NFI (Normed Fit Index) values of 0.898, indicate robust model performance. The SRMR evaluates the average magnitude of standardized residuals, and its low value suggests a good fit. Similarly, the identical d_ULS values, representing unweighted discrepancy, support the adequacy of the estimated model. The matching d_G values indicate comparable fit improvement relative to a null model. The identical Chi-Square values imply that the estimated model reproduces the observed data as well as the perfectly fitting Saturated Model. The NFI values close to 1 for both models underscore their good fit compared to a baseline model. This consistency across all fit indices indicates that the estimated model effectively replicates the observed data, demonstrating its validity in explaining the relationships among latent constructs. Overall, the comprehensive model fit assessment suggests that the structural equation model accurately captures the underlying dynamics, supporting its credibility in interpreting the observed data.

Table 4. R Square

	R Square	R Square Adjusted
Air Pollution Reduction	0.567	0.559

The R-Square and R-Square Adjusted serve as crucial statistical metrics for gauging the extent to which a regression model, particularly within the framework of a structural equation model, explains the variance in endogenous (dependent) variables. Specifically, in the case of Air Pollution Reduction, the R-Square value of 0.567 indicates that approximately 56.7% of the variance in the variable is elucidated by the independent variables incorporated into the model, portraying a moderately robust explanatory capacity in capturing the variability within Air Pollution Reduction. The R-Square Adjusted, accounting for the number of predictors, slightly lowers to 0.559, still signifying a substantial proportion of the explained variance after adjusting for the number of predictors. This adjustment is particularly valuable in preventing potential overestimation of explanatory power, a concern often presents in models with multiple predictors. In interpretation, these metrics suggest that the structural equation model, featuring Mangrove Ecosystems and Number of Plants as predictors, effectively accounts for a noteworthy portion of the variability in Air Pollution Reduction. While acknowledging the model's significant explanatory power, it also underscores the recognition of other external factors contributing to the remaining variance beyond the model's specified scope.

4.4 Hypothesis Testing

The provided information includes the original sample values, sample mean, standard deviation, T statistics, and p-values for the hypotheses related to the relationships between Mangrove Ecosystems, Number of Plants, and Air Pollution Reduction. Let's discuss each hypothesis individually:

Table 5. Hypothesis Testing

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	P Values
Mangrove Ecosystems -> Air Pollution Reduction	0.550	0.548	0.093	5.906	0.000
Number of Plants -> Air Pollution Reduction	0.285	0.288	0.093	3.058	0.002

Both hypotheses, examining the relationships between Mangrove Ecosystems and Air Pollution Reduction, as well as the Number of Plants and Air Pollution Reduction, receive robust statistical support. For the path from Mangrove Ecosystems to Air Pollution Reduction, the original sample coefficient is 0.550, with a sample mean of 0.548 and a standard deviation of 0.093. The associated T statistics of 5.906, coupled with an extremely low p-value of 0.000, highlight a highly significant relationship, providing strong evidence to reject the null hypothesis and affirming that Mangrove Ecosystems significantly influence Air Pollution Reduction.

Similarly, for the hypothesis involving the Number of Plants and Air Pollution Reduction, the original sample coefficient is 0.285, with a sample mean of 0.288 and a standard deviation of 0.093. The T statistics of 3.058, combined with a p-value of 0.002, signify a statistically significant relationship, reinforcing the rejection of the null hypothesis and supporting the assertion that the Number of Plants significantly impacts Air Pollution Reduction. The consistently low p-values in both cases indicate that the observed relationships are unlikely to be attributed to random chance, strengthening the reliability of the findings. Collectively, these results contribute to a comprehensive understanding of the studied relationships within the structural equation model, emphasizing the significant influences of Mangrove Ecosystems and Number of Plants on Air Pollution Reduction.

DISCUSSION

The highly significant relationship between Mangrove Ecosystems and Air Pollution Reduction underscores the crucial role of mangrove ecosystems as effective air quality regulators. The positive coefficient suggests that an increase in the extent and health of mangrove ecosystems is associated with a substantial reduction in air pollution. This aligns with the well-documented ability of mangroves to act as biofilters, contributing to the improvement of air quality.

The significant relationship between the Number of Plants and Air Pollution Reduction highlights the importance of vegetation density within mangrove ecosystems. A higher number of plants, reflecting a denser vegetation cover, is linked to a meaningful reduction in air pollution. This finding emphasizes the potential of mangrove restoration and conservation efforts in mitigating the adverse effects of air pollution.

Practical Implications

The study's results have practical implications for environmental management and conservation policies. Emphasizing the conservation and restoration of mangrove ecosystems can be considered a sustainable strategy for improving air quality in coastal regions. Policymakers may use these findings to prioritize mangrove protection as part of broader efforts to address environmental challenges.

Global Significance

The global significance of the relationships observed in this study suggests that the benefits of mangrove-mediated air pollution reduction are applicable across diverse geographical contexts. This underscores the importance of international collaboration in mangrove conservation efforts, recognizing the broader impact on global air quality.

Research Limitations and Future Directions

Acknowledging the robustness of the findings, it is essential to consider potential limitations. Factors such as variations in mangrove species, local environmental conditions, and human activities may contribute to nuanced effects. Future research could delve into these nuances, employing finer-scale analyses and considering additional variables for a more comprehensive understanding.

5. CONCLUSION

In conclusion, this research contributes to our understanding of the quantifiable impact of mangrove ecosystems on air pollution reduction. The robust statistical analysis supports the hypotheses that both Mangrove Ecosystems and a higher Number of Plants within these ecosystems significantly influence the reduction of air pollution. The findings have practical implications for environmental management and conservation policies, emphasizing the need to prioritize mangrove protection as part of broader efforts to address environmental challenges. The global significance of the observed relationships underscores the importance of collaborative international efforts in mangrove conservation. As we navigate the challenges of environmental sustainability, this study advocates for the incorporation of mangrove ecosystems into comprehensive strategies aimed at improving air quality and fostering a healthier planet.

REFERENCES

[1] S. Maji, S. Ahmed, M. Kaur-Sidhu, S. Mor, and K. Ravindra, “Health Risks of Major Air Pollutants, their Drivers and Mitigation Strategies: A Review,” *Air, Soil Water Res.*, vol. 16, p. 11786221231154660, 2023.

[2] S. Agarwal, B. Rupini, and D. K. Saxena, “Holistic Management of Air Pollution Using Modern Technology,” in *Environmental Studies and Climate Change*, CRC Press, 2022, pp. 529–558.

[3] C. Martins, “Air pollution and health–the importance of air monitoring and burden of disease for attaining SDGs,” *Eur. J. Public Health*, vol. 32, no. Supplement_3, pp. ckac129-018, 2022.

[4] A. Gandhimathi, R. Manju, K. Ramadevi, S. Rajalakshmi, and I. Mayilvahanan, “A study of environmental impact of air pollution on human health: PM deposition modelling,” 2023.

[5] A. Singh, R. Eram, M. Agrawal, and S. Agrawal, “Air Pollution: Sources and its Effects on Humans and Plants,” *Int. J. PLANT Environ.*, vol. 8, pp. 10–24, Sep. 2022, doi: 10.18811/ijpen.v8i01.02.

[6] M. Xu, C. Sun, Y. Zhan, and Y. Liu, “Impact and prediction of pollutant on mangrove and carbon stocks: A machine learning study based on urban remote sensing data,” *Geosci. Front.*, p. 101665, 2023.

[7] S. Cadena and J. Ochoa-Gómez, “MANGROVES:‘SUPERHERO’ ECOSYSTEMS”.

[8] E. H. Saragih, W. O. B. Barat, and W. Naibaho, “Sosialisasi Peran Mangrove terhadap Kelimpahan Ikan di daerah Pelabuhan Belawan,” *ABDI SABHA (Jurnal Pengabdi. Kpd. Masyarakat)*, vol. 3, no. 1, pp. 187–191, 2022.

[9] H. Zeng *et al.*, “Monitoring the light pollution changes of China’s mangrove forests from 1992-2020 using nighttime light data,” *Front. Mar. Sci.*, vol. 10, p. 1187702, 2023.

[10] A. H. P. Hamzah, M. Marzuki, N. Nurhasanah, and S. Nurmawati, “ENVIRONMENTAL RISK ANALYSIS IN MAGROVE AND CRAB CONSERVATION AREAS IN PAMUSIAN VILLAGE DUE TO LAND USE CHANGE IN TARAKAN CITY,” *J. Ilm. Glob. Educ.*, vol. 4, no. 2, pp. 980–995, 2023.

[11] M. Hormati *et al.*, “Consequences and health effects of toxic air pollutants emission by industries,” *J. Air Pollut. Heal.*, vol. 7, no. 1, pp. 95–108, 2022.

[12] A. Singh and K. K. Singh, “An Overview of the Environmental and Health Consequences of Air Pollution,” *Iran. J.*

Energy Environ., vol. 13, no. 3, pp. 231–237, 2022.
[13] G. V Limmon, E. Waardenburg, W. Lengkeek, P. Vodegel, and Y. A. Noya, "RESTORASI EKOSISTEM MANGROVE PADA MEDIA BIODEGRADABLE DI PESISIR DESA WAAI: Restoration Of Mangrove Ecosystem On Biodegradable Media On The Coast Of Waai Village," *MESTAKA J. Pengabdi. Kpd. Masy.*, vol. 2, no. 2, pp. 99–103, 2023.
[14] E. S. Bindiya, P. M. Sreekanth, and S. G. Bhat, "Conservation and Management of Mangrove Ecosystem in Diverse Perspectives," in *Conservation and Sustainable Utilization of Bioresources*, Springer, 2023, pp. 323–352.
[15] A. A. A. Rizqi, A. W. Ningtias, R. Nadhifah, D. E. Aquarista, and H. Nurpratiwi, "Penanaman Mangrove Guna Mengurangi Resiko Banjir Di Sine Kecamatan Kalidawir Tulungagung," *J. Creat. Student Res.*, vol. 1, no. 3, pp. 21–35, 2023.
[16] R. Aprilina and R. Hastijanti, "Penerapan Konsep Solid Nature pada Penataan Ekowisata Mangrove di Gunung Anyar Surabaya," *Selasar*, vol. 19, no. 2, pp. 61–70, 2023, doi: 10.30996/selasar.v19i2.8535.
[17] B. J. Wainwright *et al.*, "The core mangrove microbiome reveals shared taxa potentially involved in nutrient cycling and promoting host survival," *Environ. microbiome*, vol. 18, no. 1, p. 47, 2023.
[18] J. M. Booth, M. Fusi, R. Marasco, and D. Daffonchio, "The microbial landscape in bioturbated mangrove sediment: A resource for promoting nature-based solutions for mangroves," *Microb. Biotechnol.*, 2023.
[19] J. Ye *et al.*, "Insights into the phylogenetic diversity, biological activities, and biosynthetic potential of mangrove rhizosphere Actinobacteria from Hainan Island," *Front. Microbiol.*, vol. 14, p. 1157601, 2023.