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# Regression Model as a Tool for Evaluating Mangrove Degradation in Lembar Bay, West Lombok

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**ABSTRACT**

The mangrove ecosystem plays a vital role in maintaining ecological balance, supporting economic livelihoods, and sustaining socio-cultural functions. However, in Lembar Bay, West Lombok Regency, this ecosystem is increasingly threatened by human activities, particularly land conversion for aquaculture. These activities have led to significant ecological degradation, biodiversity loss, and weakened coastal protection. This study aims to analyze the key factors influencing mangrove degradation and to evaluate the effectiveness of regression models in assessing the contribution of these factors. A quantitative research approach was employed, with data collected through structured questionnaires distributed to 45 purposively selected community members considered knowledgeable about local mangrove conditions. The study also integrated field measurements and satellite imagery interpretation to assess mangrove density, biodiversity, and related environmental variables. Multiple linear regression analysis was used to examine the relationship between anthropogenic pressures such as land clearing, water quality, and rehabilitation efforts and indicators of mangrove degradation, namely biodiversity and mangrove density. Regression analysis showed a strong and significant effect of water quality on both mangrove biodiversity and density. The biodiversity regression model produced a correlation coefficient (R) of 0.820 and a determination coefficient ($R^2$) of 0.673, indicating that 67.3% of the variation in biodiversity can be explained by the analyzed factors. Similarly, the mangrove density model yielded an R of 0.800 and $R^2$ of 0.640, meaning that 64.0% of the variation in mangrove density was explained. F-test results confirmed that both models were statistically significant (p-value < 0.05). The findings indicate that aquaculture expansion and land use changes are the most critical contributors to mangrove degradation. These pressures directly impair the physical condition of the ecosystem, leading to biodiversity loss and increased vulnerability to coastal hazards. Based on community perceptions, most respondents supported stricter sanctions against mangrove destruction and agreed that mangrove conservation improves the quality of life. Therefore, this study recommends that policymakers and local governments strengthen their roles in monitoring and controlling land use changes, enforcing environmental regulations, and promoting environmental education programs. It is also essential to enhance community participation in mangrove rehabilitation through inclusive, knowledge-based initiatives and integrate scientific evidence into participatory coastal spatial planning. This study contributes to the scientific literature on mangrove conservation by demonstrating the empirical effectiveness of regression analysis in identifying and quantifying human-induced pressures affecting mangrove ecosystems.

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## A. INTRODUCTION

Mangroves serve a wide range of vital ecological and economic functions Rizal (2018). Their direct benefits include sources of firewood, charcoal, construction materials, capture fisheries products, fish and shrimp larvae, wildlife habitat, preservatives and dyes, food, medicine, livestock feed, salt, as well as opportunities for recreation, tourism, education, and research (Johari et al., 2021). As a general concept, mangrove ecosystems function as critical buffers in tropical coastal zones, particularly in Indonesia, a country rich in biodiversity (Rahmadi et al., 2023a). As valuable natural resources, mangroves contribute significantly to national development (Sukuryadi & Johari, 2022).

Mangroves are not merely trees lining the coast they play a broader and more critical role (Krauss & Osland, 2020). As a first line of defense, mangroves act as natural barriers against erosion and abrasion caused by ocean waves and climate change (Focardi & Pepi, 2023). As one of the most productive coastal ecosystems, mangroves have great potential as natural resources (Hasim, 2021). However, their existence is increasingly threatened by reductions in area, distribution, population, and species diversity (Sadath et al., 2017). These ecosystems not only support ecological, economic, and sociocultural functions but also serve as essential habitats for various flora and fauna, including rare and endangered species (Onyena & Sam, 2020). Moreover, mangroves play a crucial role in the global carbon cycle through their ability to sequester and store large amounts of carbon, helping to mitigate the impacts of climate change (Alongi, 2022).

Unfortunately, in recent decades, mangroves worldwide, including those in Indonesia, have faced serious threats from unsustainable human activities such as aquaculture expansion (Cahyaningsih et al., 2022). In the Lembar area of West Lombok, the aquaculture sector particularly shrimp and fish ponds has become a main pillar of the local economy (Ramli et al., 2022). While this sector provides considerable economic benefits, especially with growing local and international market demand Khanal & Patil (2020) it often comes at the expense of mangrove ecosystems. The conversion of mangrove forests into aquaculture ponds results in the loss of critical ecological functions, including reduced biodiversity, destruction of natural habitats, and increased risks of natural disasters such as erosion and flooding due to the loss of natural coastal protection.

Such environmental pressure has led to observable degradation, especially in the form of declining mangrove density and biodiversity in Lembar (Sukuryadi et al., 2020). Therefore, it becomes essential to identify and analyze the specific drivers contributing to this degradation in order to design appropriate conservation responses. A holistic and measurable approach is necessary to evaluate the factors influencing mangrove degradation to ensure that proposed solutions are both comprehensive and sustainable (Gong et al., 2024). One promising analytical framework is the application of regression models, which enable researchers to quantify the influence of various environmental pressures, socioeconomic drivers, and land use changes on indicators such as mangrove density and biodiversity (Hagger et al., 2022; Wei et al., 2025).

Monitoring mangrove density and biodiversity is essential to maintaining ecological balance (Damastuti et al., 2022; Rahmadi et al., 2023b). These two parameters serve as vital indicators that reflect the health of coastal ecosystems and offer a measurable means of detecting environmental disturbances (Mooney et al., 2020). By assessing the number of individual mangrove trees and the diversity of species present, researchers can evaluate the extent of ecological degradation over time. Such monitoring efforts are particularly important in areas experiencing increasing anthropogenic pressure, as they help identify the early signs of ecosystem stress. Moreover, density and biodiversity are closely linked to ecosystem services such as habitat provision, coastal protection, and carbon sequestration(Palit et al., 2022; Soto-Navarro et al., 2020). Declining ecosystem quality, often triggered by pollution, land conversion, and overexploitation, typically results in reduced abundance and diversity of the organisms that depend on mangroves for survival (Akram et al., 2023). Therefore, consistent and long-term monitoring is crucial to guide effective management interventions and ensure the sustainability of mangrove ecosystems.

Numerous studies have been conducted to understand the dynamics of mangrove ecosystems. For example, Ariasari et al. (2024) monitored changes in mangrove vegetation density on Enggano Island using image interpretation, and Hanifa et al. (2024) utilized image interpretation and satellite imagery to monitor changes in mangrove density on Enggano Island and in Jepara. Simanullang et al. (2024) analyzed macrozoobenthos diversity in relation to mangrove density in Makassar, while Hastuti et al. (2019) studied mangrove crab biodiversity in Rembang. Sukuryadi et al. (2025) further evaluated the effectiveness of Sentinel-2B satellite imagery for mangrove mapping using vegetation indices. While these studies provide valuable insights into vegetation structure and biodiversity, they primarily emphasize technical measurements and spatial changes. They often overlook the influence of specific anthropogenic pressures such as aquaculture expansion on ecological indicators like density and biodiversity. This presents a gap in understanding the causal relationship between human-induced stressors and ecosystem health, particularly in areas such as Lembar Bay, West Lombok.

Regression analysis is a fundamental statistical approach used to investigate and quantify the relationships between multiple influencing factors and an observed environmental outcome (Tedoldi et al., 2025). This method is widely used in environmental sciences to understand the degree to which certain variables such as human activity, land use change, or pollution contribute to environmental degradation (Sannigrahi et al., 2020). In mangrove ecosystems, where complex interactions exist between natural and anthropogenic drivers, regression models provide a systematic way to identify the most critical factors and to predict their long-term impacts. This makes regression a valuable tool not only for academic research but also for supporting policy decisions in coastal ecosystem management (Olaleye et al., 2025).

In the study conducted by Pham et al. (2019); Zhu et al. (2017), the authors compared the accuracy of various regression models for mapping mangrove canopy density, demonstrating that certain regression approaches effectively predict canopy density using remote sensing data, with some models showing superior precision and reliability. This research highlights the value of regression analysis as a powerful tool for monitoring mangrove ecosystems, improving the assessment of forest structure and supporting conservation efforts. Similarly, Behera et al. (2024) developed an allometric model for estimating mangrove forest Leaf Area Index (LAI) using symbolic regression combined with structural variables and digital hemispherical photography, showcasing innovative methods to quantify mangrove structural attributes. Additionally, other studies have quantitatively assessed the effectiveness of silvofishery systems in mitigating mangrove degradation. However, these previous investigations have not specifically explored the relationship between human-induced pressures and ecological parameters such as mangrove density and biodiversity, especially in the Lembar region.

Therefore, the present study seeks to address this research gap by identifying the main factors that contribute to the degradation of mangrove ecosystems in Lembar Bay, West Lombok Regency, and assessing how effectively regression models can capture the influence of these factors. Recognizing these key drivers is vital to understanding the scale and nature of environmental pressures that pose risks to mangrove sustainability. Through the application of regression analysis, the study aims to quantify the link between human-induced activities and ecological variables such as mangrove density and biodiversity. The insights gained from this quantitative approach are expected to inform data-driven management strategies and support more precise policy formulation. In addition, a clearer understanding of the role each factor plays in ecosystem degradation will enable the design of targeted, impactful conservation measures. The study's findings are anticipated to enhance knowledge of current environmental conditions in the Lembar Bay mangrove area and serve as a scientific foundation for effective conservation planning. Ultimately, this research contributes to sustainable mangrove management by integrating empirical analysis with real-world conservation priorities.

## B. METHODS

### 1. Study Population and Sampling

The study population consisted of community members residing around the mangrove ecosystem in the Lembar area, West Lombok. A purposive sampling method was employed to select 45 respondents with adequate knowledge and experience concerning the mangrove conditions in the area. This method was chosen to ensure that participants met specific criteria related to their residency, involvement, and awareness of environmental changes. The selection criteria included: (1) residency of at least five years in the Lembar Bay area, (2) involvement in or awareness of mangrove-related activities (e.g., conservation, aquaculture, fishing), and (3) basic understanding of environmental changes. These criteria aimed to ensure data relevance and the credibility of community-based insights. The majority of respondents were male, with a considerable proportion of female participants as well. Most respondents held a bachelor's degree, reflecting a relatively high educational level. Occupations varied across the sample, with many working in the private sector or being self-employed, indicating socio-economic diversity within the community. Additionally, most respondents had lived in the area for an extended period, providing them with valuable insights into local environmental conditions.

### 2. Research Design and Data Integration

This study employed a quantitative research design integrating primary, secondary, and satellite imagery data to assess mangrove degradation in Lembar Bay, West Lombok. The data sources consisted of:

a. Primary Data Collection

   Primary data were obtained through: (1) Field surveys, conducted in selected mangrove plots to measure mangrove density and biodiversity. Mangrove density was assessed by counting tree stands per unit area, while biodiversity was calculated using species diversity indices (e.g., Shannon-Wiener Index); and (2) Structured questionnaires, administered to 45 purposively selected respondents, were used to gather information on perceptions, experiences, and participation in mangrove-related activities.

b. Secondary Data

Secondary data were sourced from local environmental agencies, NGOs, and academic institutions, including: (1) Demographic and socio-economic profiles of the population; (2) Historical records on mangrove rehabilitation programs; and (3) Data on aquaculture practices and land-use changes.

c. Satellite Imagery Analysis

Sentinel-2 imagery (2024) was used to assess spatial patterns of mangrove cover and land conversion. Image processing and vegetation index analyses (e.g., NDVI, Simple Ratio) were conducted to identify areas of degradation and regrowth. Sentinel-2 was selected for its high spatial and temporal resolution, making it suitable for detecting vegetation changes in coastal ecosystems. The NDVI and SR indices were chosen due to their wide validation and effectiveness in monitoring mangrove dynamics. This spatial analysis complemented field data and enabled geospatial validation of anthropogenic pressures.

**3. Questionnaire Design and Instrument Testing**

A structured questionnaire was administered to collect data on community perceptions, experiences, and involvement in mangrove ecosystem management. The questionnaire was developed based on variables relevant to the social and environmental conditions of the mangrove ecosystem, including mangrove density, biodiversity, logging intensity, community participation in rehabilitation efforts, water quality, and the frequency and type of rehabilitation activities. Several items were adapted and modified from existing instruments used in similar ecological and community-based studies (Friess et al., 2020), ensuring alignment with the local context. To enhance the instrument's validity, content validity was assessed by three experts in environmental science and community-based resource management. A pilot test involving 10 individuals outside the main sample was conducted to ensure item clarity and relevance. Subsequently, a reliability analysis using Cronbach's Alpha was conducted on the full dataset (N = 45). The resulting Cronbach's Alpha value of 0.756 exceeded the commonly accepted threshold of 0.70, indicating good internal consistency and reliability of the instrument.

The questionnaire consisted of several sections, including respondent demographics (age, gender, education, occupation, length of residence), knowledge and awareness of mangrove benefits, opinions on mangrove management, and perceptions of environmental conditions and rehabilitation efforts. Responses were recorded using Likert scales or frequency scales, as appropriate. The study variables included both dependent and independent variables, each measured through specific indicators as presented in the following Table 1.

**Tabel 1.** Variables and Indicators

| Variable | Variable Type | Indicator | Measurement Description |
|---|---|---|---|
| $Y_1$: Biodiversity | Dependent Variable (Y) | Biodiversity in the mangrove ecosystem | Number of species or biodiversity index within mangrove area |
| $Y_2$: Mangrove Density | Dependent Variable (Y) | Mangrove density | Number of mangrove trees per unit area |
| $X_1$: Rehabilitation Activities | Independent Variable (X) | Types of mangrove rehabilitation activities | Types and kinds of activities carried out for mangrove rehabilitation |
| $X_2$: Community Involvement in Rehabilitation | Independent Variable (X) | Level of community participation in rehabilitation | Frequency and intensity of community involvement in mangrove rehabilitation |
| $X_3$: Rehabilitation Frequency | Independent Variable (X) | Frequency of rehabilitation implementation | How often the rehabilitation activities are conducted |
| $X_4$: Mangrove Land Clearing | Independent Variable (X) | Mangrove land clearing activities | Frequency and intensity of mangrove land clearing |
| $X_5$: Water Quality | Independent Variable (X) | Water quality around mangrove area | Indicators of water quality affected by environmental conditions and human activities |

**Table 2.** Reliability Statistics

| Cronbach's Alpha | N of Items |
|---|---|
| .756 | 22 |

Table 1 presents the variables used in this study along with their respective indicators and measurement scales. The dependent variables (Y) include biodiversity and mangrove density, which represent key ecological conditions of the mangrove ecosystem. The independent variables (X) consist of rehabilitation activities, community involvement in rehabilitation, rehabilitation frequency, mangrove land clearing, and water quality, reflecting social and environmental factors expected to influence the health and sustainability of the mangrove ecosystem. This quantitative study employs a regression model to evaluate the degradation of the mangrove ecosystem in Lembar Bay, West Lombok Regency. The primary objectives are to identify the key factors that significantly influence mangrove degradation and to assess the effectiveness of the regression model in analyzing the relationships between these variables. The research was conducted in Lembar Village, within Lembar Bay, West Lombok Regency, in September 2024, as shown in Figure 1.

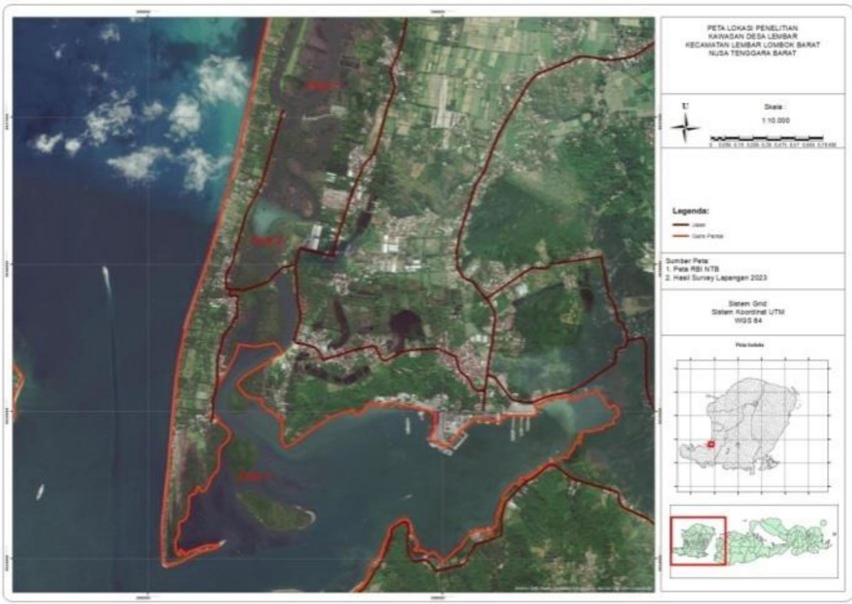


**Figure 1**. Map of the Research Location

This study utilized two types of data to support the analysis: primary and secondary data. Primary data were collected through direct field measurements of mangrove density, biodiversity, and related environmental factors within the study area. Secondary data were obtained from government agencies and previous studies, including population statistics and records of economic activities around the mangrove ecosystem. Primary data collection also involved structured questionnaires administered to community members living around the mangrove ecosystem in Lembar Village. A purposive sampling technique was employed to select 45 respondents who were deemed to have adequate knowledge and experience regarding local mangrove conditions. The respondents were predominantly male, with a significant portion of females as well. Most held a bachelor's degree, indicating a relatively high educational level. Their occupations varied, with many working in the private sector or being self-employed, reflecting socio-economic diversity. Additionally, most respondents had resided in the area for an extended period, providing them with a deep understanding of local environmental issues related to mangroves.

Data were collected through a combination of field surveys, satellite imagery interpretation, and structured interviews using a standardized questionnaire. Field surveys assessed mangrove density and biodiversity directly in observation plots, while satellite imagery provided spatial information on mangrove cover and land-use changes. The structured interviews aimed to capture community perceptions, experiences, and involvement related to mangrove management. Questionnaire responses were coded and quantified using a Likert scale to facilitate statistical analysis. All data were compiled and processed using SPSS software. Descriptive statistics summarized the demographic characteristics of respondents and general trends in community perceptions. Furthermore, multiple linear regression analysis was conducted to examine the influence of independent variables such as logging intensity, rehabilitation efforts, and water quality on dependent variables, namely mangrove density and biodiversity. This approach allowed the researcher to determine the strength and direction of relationships between variables and to identify which factors had statistically significant effects on mangrove ecosystem conditions.

## 4. Data Source and Respondent Characteristics

The data for this study were collected through questionnaires distributed to community members living around the mangrove ecosystem in the Lembar area, West Lombok. A purposive sampling technique was applied to select 45 respondents who were considered knowledgeable and experienced regarding the condition and management of mangrove forests in the area. The characteristics of the respondents are summarized as follows:

a. Gender: The majority were male, with a significant portion of female respondents.
b. Education: Most respondents held a bachelor's degree, indicating a relatively high education level.
c. Occupation: Respondents worked mainly in the private sector or were self-employed, reflecting socio-economic diversity.
d. Length of Residence: Most respondents had lived in the area for an extended period, which contributed to their deep understanding of local environmental issues related to mangroves.

## 5. Research Procedure

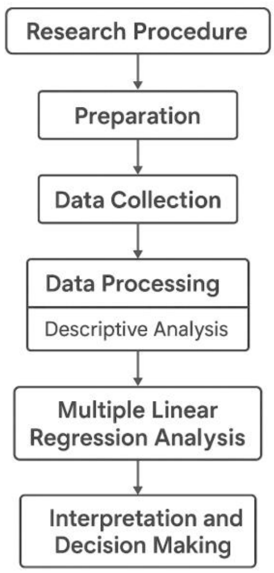


**Figure 2.** Research Procedure

The research procedure consisted of the following key steps:

a. Preparation
   Designing the questionnaire based on variables relevant to mangrove ecosystem conditions and community perceptions.
b. Data Collection
   Administering the questionnaire to 45 purposively selected respondents.
c. Data Processing
   Coding and entering questionnaire responses into a database.

d. Descriptive Analysis
   Summarizing respondent characteristics and variable distributions.
e. Multiple Linear Regression Analysis
   Modeling the relationships between independent variables (X) and dependent variables (Y).
f. Interpretation and Decision Making
   1) Evaluating regression coefficients to determine significant predictors.
   2) Formulating conclusions and recommendations based on analysis results.

## 6. Multiple Linear Regression: Decision Making and General Equation

Multiple linear regression was employed to examine the influence of several independent variables (rehabilitation activities, community involvement, rehabilitation frequency, mangrove land clearing, and water quality) on the dependent variables (biodiversity and mangrove density). The general form of the multiple linear regression equation is:

$$Y = \beta 0 + \beta 1 X 1 + \beta 2 X 2 + ... + \beta n X n + \epsilon \quad (1)$$

within this model, $X_1$, $X_2$, ..., denote the independent variables that simultaneously affect $Y$, and $\beta_1$, $\beta_2$, ..., $\beta_n$ are the coefficients quantifying the effect of each independent variable on the dependent variable.

## 7. Assumption Testing and Instrument Validity

Prior to conducting the multiple linear regression analysis, several diagnostic tests were performed to assess the validity of the model and ensure the reliability of the statistical results:

a. Multicollinearity was assessed using the Variance Inflation Factor (VIF). All independent variables yielded VIF values below 10, indicating an absence of serious multicollinearity and confirming that the predictors were sufficiently independent from one another.
b. Normality of residuals was evaluated using the Kolmogorov–Smirnov test and visually inspected through Q–Q plots. The results indicated that the residuals were approximately normally distributed, meeting one of the key assumptions of linear regression.
c. Homoscedasticity (homogeneity of variance) was verified by analyzing scatterplots of standardized residuals against predicted values. The plots exhibited no discernible pattern, supporting the assumption of constant variance across observations.
d. Linearity between the independent variables and the dependent variable was examined by plotting residuals against each predictor. The plots suggested linear relationships, justifying the use of a linear model.
e. Autocorrelation of residuals was tested using the Durbin–Watson statistic. The resulting value fell between 1.5 and 2.5, suggesting that autocorrelation was not present and that the residuals were independent.

In addition to model diagnostics, the reliability of the questionnaire instrument was tested prior to full-scale data collection. A pilot study was conducted, followed by a reliability analysis using Cronbach's Alpha. The instrument yielded an alpha value of 0.756, exceeding the commonly accepted threshold of 0.70, indicating good internal consistency and that the instrument was appropriate for the study. The results of these assumption tests confirmed that the data met the classical assumptions of multiple linear regression. Therefore, detailed outputs of these diagnostic tests are not presented in the results section, allowing the discussion to focus directly on the regression outcomes.

## C. RESULT AND DISCUSSION

### 1. Variable Influence

The research results obtained from the questionnaire data analysis will be explained in detail to understand the factors influencing the mangrove ecosystem in the Lembar area, West Lombok Regency. This analysis aims to explore aspects related to mangrove utilization, environmental pressures, current ecosystem conditions, impacts on the surrounding community, as well as the management and rehabilitation efforts that have been carried out or need improvement. The collected data include demographic aspects, community perceptions, and mangrove rehabilitation activities conducted by various stakeholders.

### 2. Questionnaire Results Analysis

This section presents the analysis of questionnaire responses collected from 45 community members living around the mangrove ecosystem in Lembar, West Lombok. The questionnaire aimed to capture demographics, perceptions, participation, and views regarding mangrove management and rehabilitation efforts.

### 3. Demographic Characteristics of Respondents

To better understand the context and background of the study participants, the demographic characteristics of the respondents were analyzed. This includes key attributes such as gender, education level, occupation, and length of residence in the area. These factors are important in assessing the respondents' potential knowledge, attitudes, and involvement in mangrove ecosystem management. Table 2 presents a summary of the demographic data collected from the 45 individuals who participated in the survey.

**Tabel 2.** Demographic Characteristics of Respondents

| Variable | Category | Frequency | Percentage (%) |
|---|---|---|---|
| Gender | Male | 25 | 56 |
| | Female | 20 | 44 |
| Education | No Schooling | 2 | 4 |
| | Elementary (SD) | 8 | 18 |
| | Junior High (SMP) | 10 | 22 |
| | Senior High (SMA) | 15 | 33 |
| | Diploma | 5 | 11 |
| | Bachelor's Degree | 5 | 11 |
| Occupation | Student | 5 | 11 |
| | Government Employee | 8 | 18 |

| Variable | Category | Frequency | Percentage (%) |
|---|---|---|---|
| | Private Sector Employee | 10 | 22 |
| | Self-employed | 12 | 27 |
| | Homemaker | 7 | 16 |
| | Others | 3 | 7 |
| Length of Stay | >5 years | 25 | 56 |
| | 3-5 years | 10 | 22 |
| | 2-3 years | 7 | 16 |
| | 0-1 year | 3 | 7 |

More than 80% of respondents agree or strongly agree that mangroves provide important benefits to coastal communities, and approximately 71% assess mangrove management as good or very good. The majority (56%) believe the government should be primarily responsible for mangrove management. While 33% report no rehabilitation activities in the last year, 67% indicate rehabilitation occurs between 1 to 4 or more times annually. Most respondents (89%) report occasional involvement in rehabilitation activities, with only 11% frequently participating. Almost all agree that mangrove clearing for land opening is taking place, and the majority believe that mangrove degradation reduces fish catch and community income. Interestingly, 100% of respondents disagree that water quality has worsened due to human activities, suggesting an area for further investigation. Most respondents support stricter sanctions for damaging the mangrove ecosystem, and the majority also agree that mangrove preservation improves the community's quality of life.

## 4. Participation in Mangrove Management Activities

The following Table 3 summarizes the level of community participation in mangrove management activities, particularly in rehabilitation and socialization efforts. It highlights how frequently respondents reported being involved in these activities, providing insights into the extent of local engagement and awareness. The data reveal that while occasional involvement in rehabilitation is relatively high, consistent or frequent participation remains limited. Similarly, participation in social outreach activities shows a wide variation, with a significant proportion of respondents never having been involved.

**Tabel 3.** Respondent Involvement in Mangrove Management Efforts

| Aspect | Category | Percentage (%) |
|---|---|---|
| Rehabilitation Participation | Never | 0 |
| | Occasionally | 89 |
| | Often | 11 |
| Socialization/Social Outreach | Never | 56 |
| | Occasionally | 16 |
| | Often | 7 |
| | Sometimes | 22 |

## 5. Analysis of Relationships Between Variables

This section presents the results of a multiple linear regression analysis conducted to examine the influence of various independent variables (X) on the condition of the mangrove ecosystem, which is measured by two dependent variables (Y), namely biodiversity ($Y_1$) and mangrove density ($Y_2$). The dependent variables are defined as follows:

a. $Y_1$: Biodiversity, measured by the number of species or biodiversity index in the mangrove ecosystem.
b. $Y_2$: Mangrove Density, measured by the number of mangrove trees per unit area.

The independent variables ($X$) included in the analysis are:

a. $X_1$: Rehabilitation Activities, types and characteristics of mangrove rehabilitation efforts carried out in the study area.
b. $X_2$: Community Involvement in Mangrove Rehabilitation, frequency and intensity of local community participation in rehabilitation activities.
c. $X_3$: Rehabilitation Frequency, how often rehabilitation activities are performed within given time frames.
d. $X_4$: Mangrove Land Clearing, incidence and scale of mangrove clearing for land use changes
e. $X_5$: Water Quality. indicators of water quality conditions around mangrove areas affected by human activities.

The regression model aims to evaluate how each of these independent variables affects the ecological conditions of mangroves. Mathematically, the relationship is modeled using the multiple linear regression equation:

$$Y = \beta_0 + \sum_{i=1}^{5} \sum_{j=1}^{4} \beta_{i,j} \, . \, X(i,j) + \varepsilon \tag{2}$$

where:

Y : represents either biodiversity ($Y_1$) or mangrove density ($Y_2$),
$\beta_0$ : Intercept
$\beta_{I,j}$ : are regression coefficients corresponding to each sub-variable $X(i,j)$
$\epsilon$ : Error term

This mathematical model enables the quantification of the strength and direction of the relationships between specific factors namely rehabilitation activities, community involvement, rehabilitation frequency, mangrove land clearing, and water quality and the ecological conditions of the mangrove ecosystem, represented by biodiversity ($Y_1$) and mangrove density ($Y_2$). By assessing the statistical significance of each coefficient (typically at $\alpha = 0.05$), the analysis identifies the most influential variables affecting these dependent outcomes. This rigorous approach provides a solid foundation for pinpointing key drivers of mangrove ecosystem health and informs the development of targeted, evidence-based conservation and management strategies.

## 6. Mangrove Density and Biodiversity

This section presents the detailed assessment of mangrove density and biodiversity across different stations. The data include the number of species, biodiversity indices (Pi), relative density, and Importance Value Index (INP) for various mangrove types and their growth stages (trees, stakes, seedlings). These metrics provide essential insights into the structure and ecological status of the mangrove ecosystem, which are critical for evaluating the health and sustainability of these coastal habitats. The following Table 2 summarizes the species composition and quantitative indicators collected from multiple sampling stations.

**Tabel 2.** Mangrove Density and Biodiversity

| Station | Mangrove type | Number of Speciess | Species | Biodiversity (Pi) | Relative Density | INP |
|---|---|---|---|---|---|---|
| I | Avicennia marina | 14 | Tree | 0,156 | 15,556 | 67,243 |
| | Rhizophora stylosa | 28 | Tree | 0,311 | 31,111 | 80,391 |
| | Rhizophora mucronata | 13 | Tree | 0,144 | 14,444 | 63,725 |
| | Rhizophora apiculata | 20 | Tree | 0,222 | 22,222 | 71,975 |
| | Sonneratia alba | 15 | Tree | 0,167 | 16,667 | 16,667 |
| | Avicennia marina | 19 | Stake | 0,413 | 41,304 | 91,949 |
| | Rhizophora stylosa | 12 | Stake | 0,261 | 26,087 | 69,022 |
| | Rhizophora mucronata | 5 | Stake | 0,109 | 10,87 | 66,279 |
| | Rhizophora apiculata | 3 | Stake | 0,065 | 6,522 | 57,532 |
| | Sonneratia alba | 7 | Stake | 0,152 | 15,217 | 15,217 |
| | Avicennia marina | 10 | Seedling | 0,323 | 32,258 | 48,925 |
| | Rhizophora stylosa | 9 | Seedling | 0,29 | 29,032 | 79,032 |
| | Rhizophora mucronata | 2 | Seedling | 0,065 | 0 | 0 |
| | Rhizophora apiculata | 4 | Seedling | 0,129 | 12,903 | 46,237 |
| | Sonneratia alba | 6 | Seedling | 0,194 | 19,355 | 19,355 |
| II | Avicennia marina | 10 | Tree | 0,11 | 10,989 | 62,676 |
| | Rhizophora stylosa | 24 | Tree | 0,264 | 26,374 | 75,654 |
| | Rhizophora mucronata | 15 | Tree | 0,165 | 16,484 | 65,764 |
| | Rhizophora apiculata | 22 | Tree | 0,242 | 24,176 | 73,929 |
| | Sonneratia alba | 20 | Tree | 0,22 | 21,978 | 44,2 |
| | Avicennia marina | 18 | Stake | 0,367 | 36,735 | 87,38 |
| | Rhizophora stylosa | 10 | Stake | 0,204 | 20,408 | 63,344 |
| | Rhizophora mucronata | 7 | Stake | 0,143 | 14,286 | 69,695 |
| | Rhizophora apiculata | 4 | Stake | 0,082 | 8,163 | 59,174 |
| | Sonneratia alba | 10 | Stake | 0,204 | 20,408 | 31,519 |
| | Avicennia marina | 8 | Seedling | 0,308 | 30,769 | 47,436 |
| | Rhizophora stylosa | 7 | Seedling | 0,269 | 26,923 | 76,923 |
| | Rhizophora mucronata | 1 | Seedling | 0,038 | 0 | 0 |
| | Rhizophora apiculata | 3 | Seedling | 0,115 | 11,538 | 44,872 |
| | Sonneratia alba | 7 | Seedling | 0,269 | 26,923 | 49,145 |
| III | Avicennia marina | 4 | Tree | 0,16 | 16 | 67,687 |
| | Rhizophora stylosa | 5 | Tree | 0,2 | 20 | 69,28 |
| | Rhizophora mucronata | 6 | Tree | 0,24 | 24 | 73,28 |
| | Rhizophora apiculata | 6 | Tree | 0,24 | 24 | 73,753 |

| Station | Mangrove type | Number of Speciess | Species | Biodiversity (Pi) | Relative Density | INP |
|---|---|---|---|---|---|---|
| | Sonneratia alba | 4 | Tree | 0,16 | 16 | 16 |
| | Avicennia marina | 4 | Stake | 0,182 | 18,182 | 68,827 |
| | Rhizophora stylosa | 9 | Stake | 0,409 | 40,909 | 83,844 |
| | Rhizophora mucronata | 3 | Stake | 0,136 | 13,636 | 69,046 |
| | Rhizophora apiculata | 3 | Stake | 0,136 | 13,636 | 64,647 |
| | Sonneratia alba | 3 | Stake | 0,136 | 13,636 | 13,636 |
| | Avicennia marina | 4 | Seedling | 0,286 | 28,571 | 45,238 |
| | Rhizophora stylosa | 3 | Seedling | 0,214 | 21,429 | 71,429 |
| | Rhizophora mucronata | 1 | Seedling | 0,071 | 0 | 0 |
| | Rhizophora apiculata | 4 | Seedling | 0,286 | 28,571 | 61,905 |

a. Dependent Variables:
   1) Mangrove Density: Measures the number of individual mangrove trees at each observation station.
   2) Mangrove Biodiversity: Measures the species variation of mangroves in the area using the Shannon-Wiener Index.

$$H' = \sum_{i=1}^{S} Pi \ \ ln \ \ Pi \tag{3}$$

Where:
- H′ = Diversity index
- S= Total number of species in the community
- $Pi$ = Proportion of the iii-th species individuals relative to the total individuals (i.e., pi=$\frac{ni}{N}$, where $ni$ is the number of individuals of species i, and N is the total number of individuals of all species)
- In = Natural logarithm

b. Independent Variables:
   1) Socioeconomic and Demographic Factors:
      a) Occupation: Type of occupation (private sector, self-employed, etc.)
      b) Education: Level of education (High school, Bachelor's degree, etc.)
      c) Length of Residency: Duration of stay in the coastal area.

   2) Environmental and Human Impact Factors:
      a) Mangrove Deforestation: Cutting down mangrove trees for agriculture or settlement.
      b) Community Involvement in Mangrove Rehabilitation.
      c) Water Quality: Condition of water quality around the mangrove ecosystem.
      d) Rehabilitation Activities: Community participation in mangrove rehabilitation.

   3) Ecosystem Condition:
      a) Reduction in Mangrove Area: The extent of mangrove area that has been degraded.
      b) Water Quality Degradation: Deterioration of water quality due to human activities.

4) Effects on Community and Environment:
   a) Decline in Marine Products: Reduction in fish and shellfish catch.
   b) Decline in Income: Reduction in income for communities dependent on the mangrove ecosystem.

5) Management and Response Actions:
   a) Mangrove Rehabilitation Activities: Presence of mangrove rehabilitation efforts.
   b) Level of Community Participation in Mangrove Management.

**7. Multiple Linear Regression Model for Biodiversity**

This section presents the results of the multiple linear regression analysis examining the influence of multiple ecological and socio-environmental factors on mangrove biodiversity ($Y_1$). The regression model includes five independent variables with a total of 20 indicators:

$$Y_1 = \beta_0 + \sum_{i=1}^{5} \sum_{j=1}^{4} \beta_{i,j} \, . X(i,j) + \varepsilon \quad (4)$$

where:

$Y_1$ : Biodiversity index of the mangrove ecosystem
$X_{1,j}$ : Rehabilitation Activitie
$X_{2,j}$ : Community Involvement in Mangrove Rehabilitation
$X_{3,j}$ : Rehabilitation Frequency
$X_{4,j}$ : Mangrove Land Clearing
$X_{5,j}$ : Water Quality
$\beta_0$ : Intercept
$\beta_{I,j}$ : Regression coefficients for each indicator
$\epsilon$ : Error term

The regression analysis results, obtained through SPSS, are summarized in Table 3, Table 4 and Table 5 below:

**Table 3.** Model Summary Biodiversity

| Model Summary | | | | |
|---|---|---|---|---|
| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
| 1 | ,820[a] | ,673 | ,665 | ,05206 |

a. Predictors: (Constant), X5_4

Based on the Model Summary Table 3, the correlation coefficient (R) is 0.820, indicating a very strong relationship between the variable X5_4 (perception of water quality) and mangrove biodiversity. The R Square value of 0.673 suggests that 67.3% of the variation in biodiversity can be explained by the X5_4 variable, while the remaining 32.7% is influenced by other factors outside the model. The Adjusted R Square value, which is close to the R Square at 0.665, indicates that the model is fairly stable and does not suffer from overfitting. The low Standard Error of the Estimate (0.05206) reflects a small prediction error.

The selection of X5_4 as the sole independent variable in this model is based on the results of a previously conducted multiple regression analysis. Although the initial model included all indicators, the analysis revealed that only X5_4 had a statistically significant contribution to biodiversity. Therefore, the model was simplified to include only X5_4, in order to focus on the most influential factor consistent with the principle of a parsimonious model and taking into account the ecological validity of the research findings.

**Table 4.** Anova Regression Biodiversity

**ANOVA**[a]

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | .240 | 1 | .240 | 88.483 | <,001b |
| | Residual | .117 | 43 | .003 | | |
| | Total | .356 | 44 | | | |

a. Dependent Variable: Biodiversity

b. Predictors: (Constant), X5_4

Based on the ANOVA table for the biodiversity variable, the calculated F-value is 88.483 with a significance level (Sig.) of less than 0.001. This indicates that the regression model is statistically significant, meaning that the predictor variable X5_4 (perception of water quality) has a significant effect on mangrove biodiversity. The Sum of Squares for regression is 0.240, which is much larger than the residual value of 0.117, suggesting that most of the variation in the data can be explained by the model. With degrees of freedom (df) of 1 for regression and 43 for residual, and Mean Square values of 0.240 for regression and 0.003 for residual, these results confirm that the explained variation is far greater than the unexplained variation, indicating that the predictive quality of the model is very strong.

**Tabel 5.** Coefficients Table – Multivariate Linear Regression Output Biodiversity

**Coefficients**[a]

| Model | | Unstandardized Coefficients | | Standardized Coefficients | | |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | t | Sig. |
| 1 | (Constant) | .129 | .011 | | 11.848 | <,001 |
| | X5_4 | .146 | .016 | .820 | 9.407 | <,001 |

a. Dependent Variable: Biodiversity

Based on Table 5, which presents the Coefficients output from the linear regression analysis on the biodiversity variable, the resulting regression equation is:

$$\text{Biodiversity} = 0.129 + 0.146 \times X5\_4 \tag{4}$$

The constant value of 0.129 indicates that when the perceived water quality (X5_4) is zero, the predicted biodiversity score is 0.129. The regression coefficient of 0.146 means that for each one-unit increase in perceived water quality, the biodiversity score increases by 0.146 units, assuming other variables remain constant. The standardized coefficient (Beta) of 0.820

demonstrates that X5_4 is a very strong predictor of biodiversity. A t-value of 9.407 and a significance level of < 0.001 confirm that this effect is highly statistically significant. Although the initial model included all indicators from variables X1 to X5, the regression results revealed that only X5_4 had a significant effect. Therefore, to ensure a more parsimonious and focused model, the regression was simplified to emphasize the most influential factor. These findings underscore the ecological importance of water quality in sustaining mangrove biodiversity.

**8. Multiple Linear Regression Model for Density**

This section presents the results of the multiple linear regression analysis aimed at examining the effect of several factors on mangrove density ($Y_2$). The model includes the same five independent variables as in the biodiversity model, each with multiple indicators:

$$Y_2 = \beta_0 + \sum_{i=1}^{5} \sum_{j=1}^{4} \beta_{i,j} \cdot X(i,j) + \varepsilon \quad (5)$$

where:

$Y_1$ : Mangrove density (number of trees per unit area)
$X_{1,j}$ : Rehabilitation Activitie
$X_{2,j}$ : Community Involvement in Mangrove Rehabilitation
$X_{3,j}$ : Rehabilitation Frequency
$X_{4,j}$ : Mangrove Land Clearing
$X_{5,j}$ : Water Quality
$\beta_0$ : Intercept
$\beta_{I,j}$ : Regression coefficients for each indicator
$\epsilon$ : Error term

The regression analysis results, obtained through SPSS, are summarized in Table 6, Table 7 and Table 8 below:

**Table 6.** Model Summary Mangrove Density

| Model Summary | | | | |
|---|---|---|---|---|
| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
| 1 | ,800[a] | ,640 | ,632 | 5.88969 |
| a. Predictors: (Constant), X5_4 | | | | |

Based on the Model Summary Table 6, the correlation coefficient (R) is 0.800, indicating a very strong relationship between the variable X5_4 (perceived water quality) and mangrove density. The R Square value of 0.640 suggests that 64.0% of the variation in mangrove density can be explained by X5_4, while the remaining 36.0% is attributed to other factors outside the model. The Adjusted R Square of 0.632 indicates that the model remains fairly stable even after adjusting for the number of predictors. Meanwhile, the Standard Error of the Estimate of 5.88969 represents the average prediction error of the model compared to the actual values. Although this value seems relatively high, its significance depends on the unit and context of the data. This finding reinforces the role of perceived water quality (X5_4) as a strong predictor in explaining mangrove density at the study site.

**Tabel 7**. Anova Density

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 2768,082 | 2652.914 | 1 | 2652.914 | 76.478 |
| | Residual | 1376,436 | 1491.605 | 43 | 34.688 | |
| | Total | 4144,518 | 4144.518 | 44 | | |

ANOVA[a]

a. Dependent Variable: Density

Based on the ANOVA table for the mangrove density variable, the F-value of 76.478 with a significance level less than 0.001 indicates that the regression model is statistically significant. This means that the predictor variable X5_4 (perceived water quality) has a significant effect on mangrove density. The Sum of Squares for regression is 2768.082, which is substantially higher than the residual sum of 1376.436, suggesting that most of the variation in the data is explained by the model. The degrees of freedom (df) are 1 for regression and 43 for residuals, resulting in Mean Square values of 2652.914 for regression and 34.688 for residual. Overall, these results indicate that the regression model is effective in explaining the variation in mangrove density based on perceived water quality.

**Table 8.** Coefficients Multivariate Linear Regression Output Density

| Model | | Unstandardized Coefficients | | Standardized Coefficients | | |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | t | Sig. |
| 1 | (Constant) | 12.103 | 1.228 | | 9.855 | <,001 |
| | X5_4 | 15.360 | 1.756 | .800 | 8.745 | <,001 |

Coefficients[a]

a. Dependent Variable: Density

The intercept value of 12.103 indicates that when the value of X5_4 (perceived water quality) is zero, the predicted mangrove density is 12.103 units. The regression coefficient of 15.360 means that for every one-unit increase in X5_4, the mangrove density increases by 15.360 units, assuming other variables are held constant. The standardized Beta coefficient of 0.800 shows that X5_4 is a strong predictor of density. The t-value of 8.745 and the significance level less than 0.001 confirm that the effect of X5_4 on mangrove density is highly statistically significant. Thus, the resulting regression equation is:

$$\text{Density} = 12.103 + 15.360 \times X5\_4 \tag{5}$$

The results of the regression analysis indicate that among the five groups of factors examined, the perception of water quality (X5_4) emerged as the most statistically significant predictor for both mangrove biodiversity and density. This finding underscores the ecological importance of water quality as a limiting factor for mangrove ecosystem health. Specifically, better perceived water quality was positively associated with higher biodiversity and tree density, which aligns with the ecological understanding that mangrove species are highly sensitive to changes in salinity, pollution, and waterborne contaminants. From an ecological perspective, these results emphasize that water quality not only affects mangrove physiology but also the composition and structure of the associated biotic communities. Poor water conditions can limit seedling survival, inhibit root respiration, and disrupt nutrient cycling ultimately reducing both density and species richness. Therefore, maintaining or improving water quality should be seen as a central strategy in mangrove conservation and rehabilitation programs.

This study aligns with and extends previous research on mangrove degradation, such as those conducted by Bandyopadhyay & Maiti (2019); Kim et al. (2019); Pan et al. (2016) confirming that ecological degradation is closely related to human activities, rehabilitation efforts, and water quality conditions. However, this study advances the discussion by quantitatively examining the relationships between these variables through a regression model, offering more measurable insights into their individual contributions. Based on community perceptions, the findings underscore the importance of strengthening the role of local governments and policymakers in monitoring mangrove conditions, educating the public about mangrove benefits, and supporting rehabilitation programs through inclusive and continuous engagement. The scientific contribution of this study lies in its integration of ecological indicators with community-based variables to evaluate mangrove degradation, providing a replicable model for other coastal regions.

Moreover, the regression results reflect the significance of community-based perceptions in evaluating environmental quality. As the indicators were derived from structured questionnaires, the findings validate the role of local knowledge in identifying real ecological stressors. This supports the idea that community engagement is not only vital for implementation but also for diagnostics and monitoring. In practical terms, the results highlight the need for stronger involvement of local governments and policymakers in addressing water-related issues near mangrove areas. Policies that focus on reducing industrial runoff, regulating aquaculture waste, and enhancing wastewater treatment systems could have direct positive effects on mangrove restoration outcomes. Furthermore, public education about the benefits of healthy mangrove ecosystems and the importance of clean water can further reinforce conservation behavior. Scientifically, this study contributes to the growing body of literature that integrates ecological indicators with community-based socio-environmental data. By demonstrating a replicable regression model that effectively captures the interaction between human perception and ecosystem variables, this study offers a methodological contribution for future mangrove assessments in other coastal regions.

## D. CONCLUSION AND SUGGESTIONS

Based on the analysis, this study concludes that the perception of water quality (X5_4) plays a critical role in influencing both mangrove biodiversity and density, with regression analysis showing that this single variable explains 67.3% of the variation in biodiversity and 64.0% in density. This highlights the ecological importance of water conditions in maintaining mangrove ecosystem health. In terms of community perception, more than 80% of respondents acknowledged the benefits of mangroves for coastal livelihoods, and around 71% rated mangrove management as good or very good. A majority (56%) assigned primary responsibility for mangrove management to the government, while 89% of respondents participated occasionally in rehabilitation activities. Notably, all respondents perceived ongoing mangrove clearing for development purposes, and most agreed that degradation negatively impacts fish catches and local income.

Interestingly, all respondents disagreed with the statement that water quality has worsened due to human activities indicating a gap between public perception and ecological findings, and suggesting a key area for future investigation. This divergence underlines the importance of increasing environmental awareness and improving the accuracy of community knowledge regarding ecological stressors. Policy implications of this study include the need for more robust and inclusive mangrove management strategies, particularly those led by local governments with active community participation. Strengthening environmental education, enforcing stricter regulations on mangrove destruction, and addressing industrial and aquaculture-related water pollution should be prioritized to ensure effective conservation outcomes. Limitations of this study include its reliance on self-reported community perceptions, which may not fully capture actual ecological conditions. Further research is recommended to combine perception data with empirical environmental monitoring, especially in examining discrepancies around water quality. Future studies could also expand the regression model by reintroducing other variables initially tested (such as knowledge, participation, and institutional roles) to evaluate their interactive effects under more complex modeling approaches.

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