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Analysis of Biomass Distribution in Mangrove Vegetation Using Spatial Interpolation Methods In Nusa Lembongan, Bali

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Abstract

Mangroves are coastal ecosystems that have an important role in maintaining the balance of the coastal environment and are effective carbon absorbers which have an important role in climate regulation. The effects of global warming can be reduced through the absorption of organic carbon from photosynthesis and stored in woody biomass, such as standing mangrove trees. Biomass distribution analysis in mangrove vegetation is needed to understand the condition and distribution of mangrove vegetation in more depth and to reflect the productivity and health of the ecosystem. Nusa Lembongan Bali has the potential and utilization of mangrove ecosystems which have potential flora and fauna that need to be preserved. Method spatial interpolation is an effective approach in analyzing biomass distribution because it is able to overcome the limitations of sample data in large forest areas using deterministic techniques Inverse Distance Weighted (IDW). This research aims to analyze the distribution of mangrove vegetation biomass and assess the level of accuracy of the method spatial interpolation in producing a distribution map of mangrove biomass in Nusa Lembongan, Bali. There are 4 types of mangroves found in Nusa Lembongan that are affordable for research, including: *Rhizophora apiculata, Xylocarpus granatum, Bruguiera gymnorrhiza* And *Sonneratia alba*, with 90% having a sandy mud substrate. Nusa Lembongan has good biomass distribution as shown by the mangrove vegetation biomass distribution map which shows a dominant color of green to yellow with an average biomass value of 200 Mg/ha to 300 Mg/ha. The results of the correlation calculation have a significant correlation accuracy value with a value of rCount 0.997 > rTable 0.273 which is shown through the results of correlation calculations that support the results of biomass distribution in mangrove vegetation on Nusa Lembongan Island, Bali.

Keywords: Cabon, Global warming, IDW.

1. INTRODUCTION

Indonesia is one of the regions that has the largest mangrove ecosystem in the world [1], with a total area of approximately 42,550 km² spread across 257 districts or cities [2]. Mangroves are a coastal ecosystem that has an important role in maintaining the balance of the coastal environment [3]. Apart from functioning as protection against natural disasters and mitigating coastal erosion [4], mangroves also act as breeding grounds for various types of marine biota [5], as traps for sediment originating from land [6] and effective carbon sinks [1] which have an important role in climate regulation, as an effort to balance anthropogenic emissions (CO_2) [7] in [8].

Carbon emissions are the phenomenon of carbon being released into the Earth's atmosphere [9], which has become a major concern throughout the world because of its rapid increase in the atmosphere which triggers global warming [10]. According to [10], global warming is a condition where the earth's climate becomes warmer than before due to an increase in greenhouse gases. However, the effects of global warming can be reduced through the absorption of organic carbon from photosynthesis and stored in woody biomass, such as standing mangrove trees [11]. The carbon stored in mangrove plants is known as “blue carbon” or blue carbon [12]. During photosynthesis, carbon dioxide from the atmosphere is absorbed by mangroves and converted into organic carbon in the form of biomass [13] in [12]. Biomass distribution analysis in mangrove vegetation is needed to understand the condition and distribution of mangrove vegetation in more depth and

to reflect the productivity and health of the ecosystem. According to [12], Mangrove biomass reflects the amount of available organic material, which is directly related to the ecosystem's ability to store carbon [14]. Nusa Lembongan Bali, as one of the popular tourist destinations because of its pristine natural beauty [15]. Nusa Lembongan has a mangrove forest area that is almost a third of the area of this small island. Apart from that, the mangrove ecosystem in Nusa Lembongan Bali has the use and potential of flora and fauna that need to be preserved. Where the flora and fauna in the mangrove ecosystem can result in the use of various activities, especially marine tourism [16]. The mangrove ecosystem in the coastal area of Lembongan Island, Bali, covers an area of 202 ha located on the east to north side of the island [17]. Biomass distribution analysis using the method spatial interpolation in this area it is important to provide an accurate picture of the condition of mangrove vegetation.
Method spatial interpolation is an effective approach in analyzing biomass distribution because it is able to overcome the limitations of sample data in large forest areas [18]. Thus, this research aims to analyze the distribution of mangrove vegetation biomass in Nusa Lembongan Bali, and assess the level of accuracy of the method spatial interpolation in producing a distribution map of mangrove biomass in Nusa Lembongan, Bali. The results of this research are expected to provide useful information for managing mangrove ecosystems and supporting conservation efforts and climate change mitigation through increasing carbon storage capacity.

2. METHOD

2.1. Research Approach/Design

This research uses a quantitative approach which aims to measure and analyze the distribution of mangrove biomass numerically and spatially. According to [19], quantitative research is usually used to examine populations or samples, where data is collected using measuring tools or instruments which are then analyzed statistically. The collected data will be analyzed statistically and mapped using the spatial interpolation method.

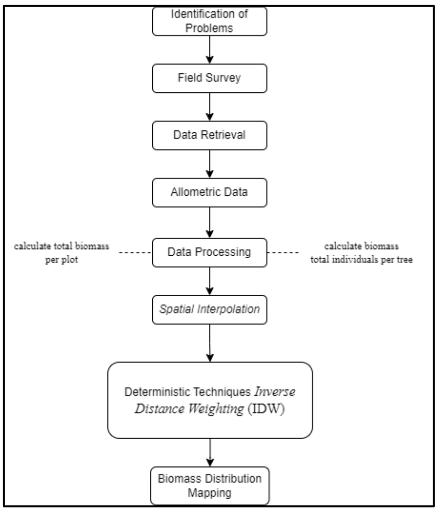

Figure 1. Research Flow
Source: Reseacher 2024.

2.2. Research methods

The research method used is Spatial Interpolation, which is a method used to estimate the value of an attribute in locations that do not have data based on values from known locations [20]. Deterministic techniques are used for Inverse Distance Weighting (IDW) spatial interpolation data which is processed using QGIS 3.34 software to produce a comprehensive biomass distribution map.

2.3. Research Techniques

2.3.1. Data Collection Techniques

Biomass data collection was carried out through direct field data collection by stretching transects measuring 10 x 10 m at a number of observation plot points along with their coordinates. The data collection stages carried out were:

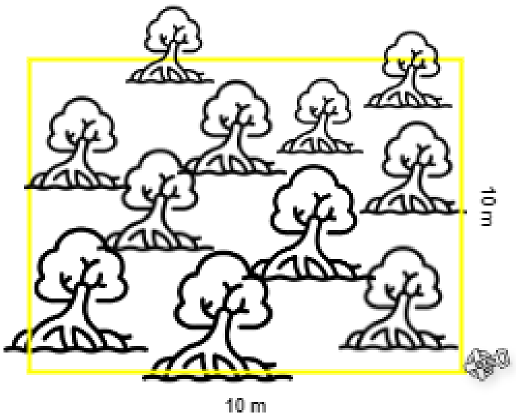

Figure 2. Illustration of Plot Determination
Source: Reseacher 2024.

1) In each measuring plot, each mangrove tree is measured at chest height or DBH (Diameter at Breast Height) with the provision of 130cm above ground level, then the diameter of the tree trunk is measured for each mangrove vegetation in the measuring plot.

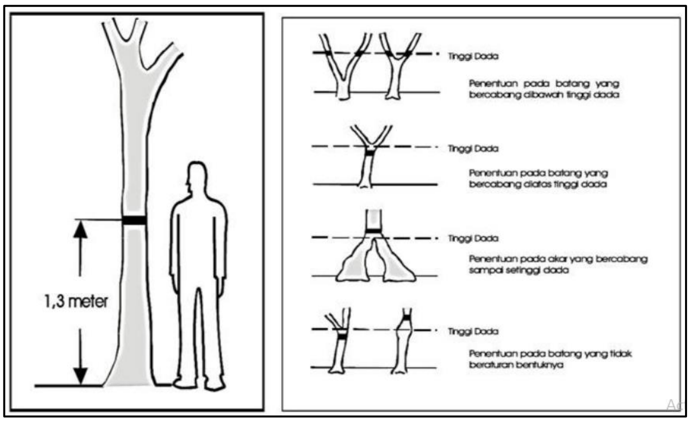

Figure 3. Data collection conditions
Source: Republic of Indonesia Minister of Environment Decree No. 201 of 2004 concerning Standard Criteria and Guidelines for Determining Mangrove Damage.

2) Record the type and amount of mangrove vegetation present in each measuring plot along with its substrate.

2.3.2. Data Analysis Techniques

The data that has been collected is then analyzed for mapping using the Spatial Interpolation method with the Inverse Distance Weighted (IDW) technique which is processed using QGIS 3.34 software. First, calculate the diameter of the tree trunk in centimeters (cm) for individual mangrove vegetation in each plot, using formula 1:

$$DBH = \frac{GBH}{\pi}$$

Where DBH is Diameter at Breast Height (cm) and GBH are Girth at Breast Height (cm).

After calculating the diameter for each individual, then calculate the total individual biomass per tree in kilograms (kg), with calculations using the allometric equation in formula 2 [21]:

$$Tree\ Biomass\ (kg) = \exp(-1{,}475 + 2{,}153.\ln(DBH))$$

The individual biomass of all trees in each plot is added up, to obtain information on the total biomass yield per plot. Information on total biomass yields per plot is then converted into biomass in Mg/ha units (Megagrams or tons per hectare) using formula 3:

$$Biomass\ \left(M_g\ /\ ha\right) = Biomass\ (kg\ /\ plot)\ x\ \frac{10.000m^2/_{100}m^2}{1.000kg}$$

The equation for the Inverse Distance Weighted (IDW) formula [22]:

$$Z^* = \frac{\Sigma_{i=1}^{n}\ \omega_i\,.z_i}{\Sigma_{i=1}^{n}\ \omega_i}$$

Where:

$$\omega_i = \frac{1}{d_i^p}$$

$$d_i = \sqrt{(x - x_i)^2 + (y - y_i)^2}$$

Where Z is the estimated value (x,y)*, n is the number of observation points used for estimation, , z_i is the height value of the data that will be interpolated by a number of n points, ω_i is the weight given to the value at each observation point, p is the exponent that regulates the influence of distance (p =2) and d_i is the distance from the sample point to the target location.

The final step is to carry out an accuracy test to determine the level of accuracy between the biomass field data and the processing data. The first statistical analysis of accuracy, MAE (Mean Absolute Error) with the formula [23]:

$$MAE = \frac{\Sigma_{i=1}^{n}\ |Z_{field,i} - Z_{IDW,i}|}{n}$$

Calculate the second accuracy value, RMSE (Root Mean Square Error) to calculate the squared average, with the formula [23]:

$$RMSE = \sqrt{\frac{\Sigma_{i=1}^{n}\ (Z_{field,i} - Z_{IDW,i})^2}{n}}$$

Third, calculate MAPE (Mean Absolute Percentage Error) using the formula [23]:

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{|Z_{field,i} - Z_{IDW,i}|}{Z_{field,i}}\right)x\ 100$$

Where Z_{field} is the Biomass value of field data, Z_{IDW} is the Biomass value resulting from interpolation and n is the total sample plot (n=50).

Finally, carry out a correlation test using Microsoft Excel, using the formula:

$$= CORREL\ (array1; array2)$$

Where array1 is the biomass value of field data for all observation plots and array2 is the extraction of biomass values resulting from interpolation of all observation plots.

2.4. Research Background/Settings

2.4.1. Research Time

The research was conducted in September 2024. Starting from the research preparation stages, field surveys, determining sample points to collecting field data.

2.4.2. Research Place

The research was carried out in the coastal area of Nusa Lembongan, Bali, which covers the entire mangrove area in Nusa Lembongan with sampling points distributed in a representative manner in various parts of the region, including areas with high vegetation density, transitional areas, and areas affected by human activities.

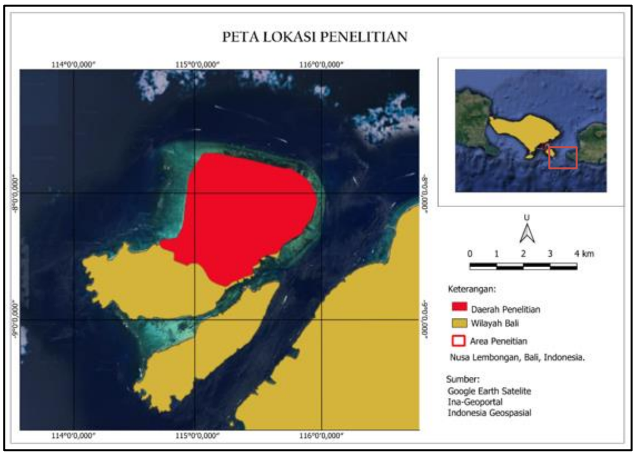

Figure 4. Map of research Locations
Source: Reseacher 2024.

Biomass data collection in the mangrove vegetation area of Nusa Lembongan Bali is represented by 50 plot points shown in Figure 5.

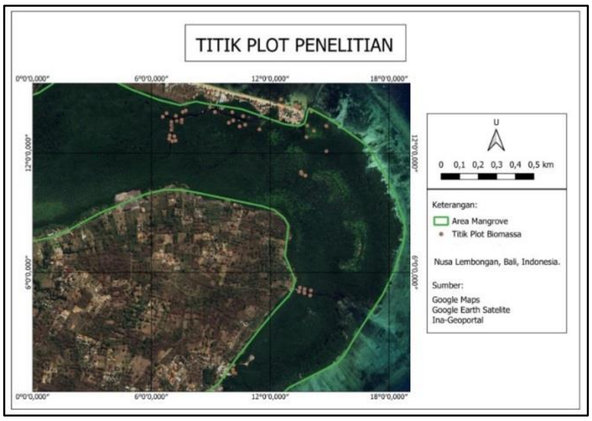

Figure 5. Research Plot Points
Source: Reseacher 2024.

3. RESULTS AND DISCUSSION

3.1. Mangrove Vegetation Findings

Based on the research that has been carried out, 50 plot points were collected for mangrove biomass data in Nusa Lembongan, Bali. In Table 1 there is data on the findings of mangrove vegetation types along with substrate, number of trees and biomass in each plot.

Table 1. Mangrove Vegetation Data for Nusa Lembongan, Bali

Plot	Coordinate		Type	Substrate	Number of Trees	Biomass / Plot (Mg/ha)
	X	Y				
1	115.4670539	-8.6668630	*Rhizophora apiculata*	Sandy Mud	26	158.55
2	115.468321	-8.667746	*Sonneratia alba*	Sandy Mud	25	189.59
3	115.4692902	-8.6672107	*Rhizophora apiculata*	Sand	16	177.97
4	115.4686820	-8.6674493	*Sonneratia alba*	Sandy Mud	19	125.43
5	115.4692882	-8.6684251	*Sonneratia alba*	Sandy Mud	20	139.71
6	115.4660182	-8.6673721	*Sonneratia alba*	Sandy Mud	19	125.11
7	115.467849	-8.666313	*Rhizophora apiculata*	Sand	11	43.97
8	115.4670804	-8.6659243	*Rhizophora apiculata*	Sand	10	50.84
9	115.4652193	-8.6667417	*Bruguiera gymnorrhiza*	Sandy Mud	35	210.22
10	115.4646882	-8.6665438	*Bruguiera gymnorrhiza*	Sandy Mud	29	176.37
11	115.4683628	-8.6671984	*Bruguiera gymnorrhiza*	Sandy Mud	27	140.53
12	115.4685596	-8.6665080	*Bruguiera gymnorrhiza*	Sandy Mud	29	160.31
13	115.4635996	-8.6663065	*Bruguiera gymnorrhiza*	Sandy Mud	35	223.17
14	115.4653165	-8.6671484	*Rhizophora apiculata*	Sandy Mud	22	161.61
15	115.4647361	-8.6669505	*Rhizophora apiculata*	Sandy Mud	22	137.25
Plot	**Coordinate**		**Type**	**Substrate**	**Number of Trees**	**Biomass / Plot (Mg/ha)**
	X	**Y**				
16	115.4650496	-8.6672332	*Rhizophora apiculata*	Sandy Mud	21	142.13
17	115.4645199	-8.6670562	*Rhizophora apiculata*	Sandy Mud	29	168.00
18	115.4638426	-8.6665392	*Rhizophora apiculata*	Sandy Mud	20	150.86
19	115.4619735	-8.6669780	*Xylocarpus granatum*	Sandy Mud	22	241.89
20	115.4619329	-8.6667268	*Xylocarpus granatum*	Sandy Mud	21	486.19
21	115.4617170	-8.6670161	*Xylocarpus granatum*	Sandy Mud	19	497.60
22	115.4622179	-8.6669170	*Xylocarpus granatum*	Sandy Mud	19	379.85
23	115.4622021	-8.6670523	*Xylocarpus granatum*	Sandy Mud	15	201.72
24	115.4622719	-8.6665339	*Xylocarpus*	Sandy Mud	17	187.21

Plot	Coordinate X	Coordinate Y	Type	Substrate	Number of Trees	Biomass / Plot (Mg/ha)
			granatum			
25	115.4624184	-8.6664716	*Xylocarpus granatum*	Sandy Mud	25	182.30
26	115.4617133	-8.6671782	*Xylocarpus granatum*	Sandy Mud	24	304.23
27	115.4617505	-8.6672975	*Xylocarpus granatum*	Sandy Mud	11	296.74
28	115.4617170	-8.6674000	*Xylocarpus granatum*	Sandy Mud	16	320.35
29	115.4616328	-8.6676711	*Bruguiera gymnorrhiza*	Sandy Mud	21	197.52
30	115.4616094	-8.6678305	*Bruguiera gymnorrhiza*	Sandy Mud	19	126.59
31	115.4617586	-8.6679339	*Bruguiera gymnorrhiza*	Sandy Mud	24	231.19
32	115.4619182	-8.6679137	*Bruguiera gymnorrhiza*	Sandy Mud	16	115.69
33	115.4618511	-8.6677115	*Bruguiera gymnorrhiza*	Sandy Mud	21	363.45
34	115.4612905	-8.6667632	*Rhizophora apiculata*	Sandy Mud	26	277.88
35	115.4614776	-8.6665998	*Rhizophora apiculata*	Sandy Mud	26	232.22
36	115.4679984	-8.6749980	*Sonneratia alba*	Sandy Mud	23	285.92
37	115.4682307	-8.6750626	*Sonneratia alba*	Sandy Mud	20	272.49
38	115.4685375	-8.6751329	*Sonneratia alba*	Sandy Mud	27	220.85
39	115.4685030	-8.6753698	*Sonneratia alba*	Sandy Mud	23	347.17
40	115.4682240	-8.6752615	*Sonneratia alba*	Sandy Mud	23	431.48
41	115.4679578	-8.6751823	*Bruguiera gymnorrhiza*	Sandy Mud	25	303.94
42	115.4647563	-8.6787257	*Bruguiera gymnorrhiza*	Sandy Mud	24	270.92
43	115.4647204	-8.6789384	*Bruguiera gymnorrhiza*	Sandy Mud	27	271.31
44	115.4647502	-8.6790740	*Bruguiera gymnorrhiza*	Sandy Mud	27	238.46
45	115.4648495	-8.6791303	*Bruguiera gymnorrhiza*	Sandy Mud	25	216.08
Plot	**Coordinate X**	**Coordinate Y**	**Type**	**Substrate**	**Number of Trees**	**Biomass / Plot (Mg/ha)**
46	115.4679706	-8.6662777	*Rhizophora apiculata*	Sand	18	157.99
47	115.4680889	-8.6695136	*Sonneratia alba*	Sandy Mud	25	224.74
48	115.4680554	-8.6694228	*Sonneratia alba*	Sandy Mud	28	242.26
49	115.4677992	-8.6661975	*Rhizophora apiculata*	Sand	18	140.18
50	115.4682683	-8.6695964	*Sonneratia alba*	Sandy Mud	26	268.22

Based on the data in Table 1. There are 4 types of mangroves found in Nusa Lembongan, including *Rhizophora apiculata, Xylocarpus granatum, Bruguiera gymnorrhiza* And *Sonneratia alba,* with 90% having a sandy mud substrate.

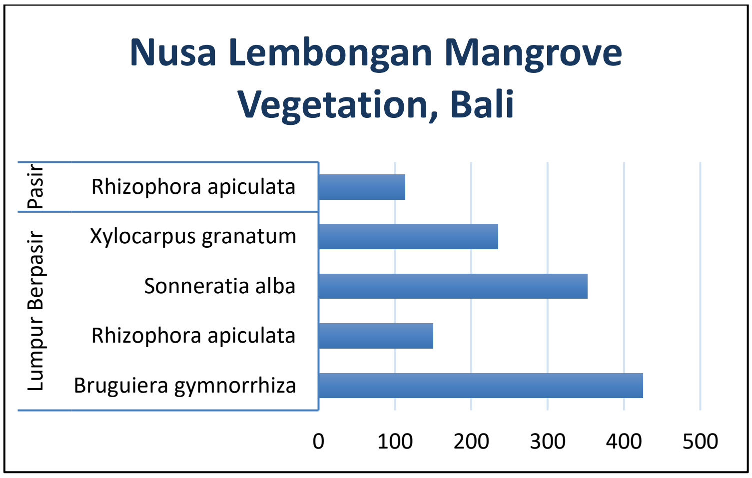

Figure 6. Findings of Mangrove Vegetation on Nusa Lembongan, Bali
Source: Researcher 2024.

The mangrove vegetation shown in Figure 6 can be seen as the type of mangrove vegetation *Bruguiera gymnorrhiza* being the most dominant vegetation compared to the other 3 types of mangroves. Apart from that, the sandy mud substrate is the substrate that grows on all types of mangrove vegetation found on Nusa Lembongan. The situation is different with the sand substrate which only grows with 1 type of mangrove, namely *Rhizophora apiculata*. This is due to the type of vegetation *Rhizophora apiculata* has a unique adaptation to survive in dynamic environments because it has strong supporting roots that extend in various directions which can provide stability in less dense substrates such as sand [24].

3.2. Mangrove Vegetation Biomass Distribution

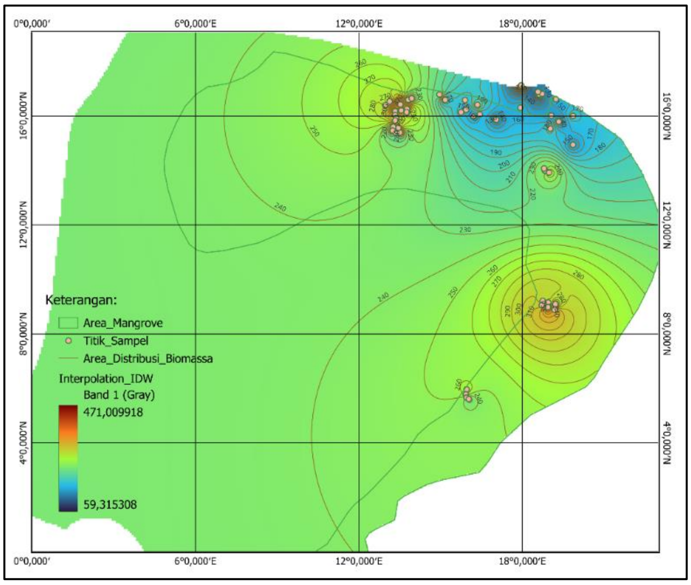

Figure 7. Biomass Distribution Layout
Source: Researcher 2024.

The biomass distribution seen in Figure 7 shows the results of processing using the technique Inverse Distance Weighted (IDW) mangrove vegetation on Nusa Lembongan Island, Bali through interval colors. In addition, the area for distribution of mangrove vegetation biomass is shown through contours which provide an estimate of the biomass distribution value in the surrounding mangrove area which has no value. The interpolation area is basically influenced by proximal points and minimally by distant points. The interpolation point is the weighted rate of the nearest points, the weight given to each nearest point decreases as the distance from the interpolation point to the neighboring points increases [25].
The results show that the lowest biomass value has a value of 59.315308 Mg/ha, which is indicated by the

lower the value, the darker the color of the indicator, with the distribution value increasing as you move away from the observation point. Meanwhile, the highest biomass value with a value of 471.009918 Mg/ha is marked with a darker red color which indicates that the area has a higher biomass, with a distribution value that decreases as you move away from the observation point.

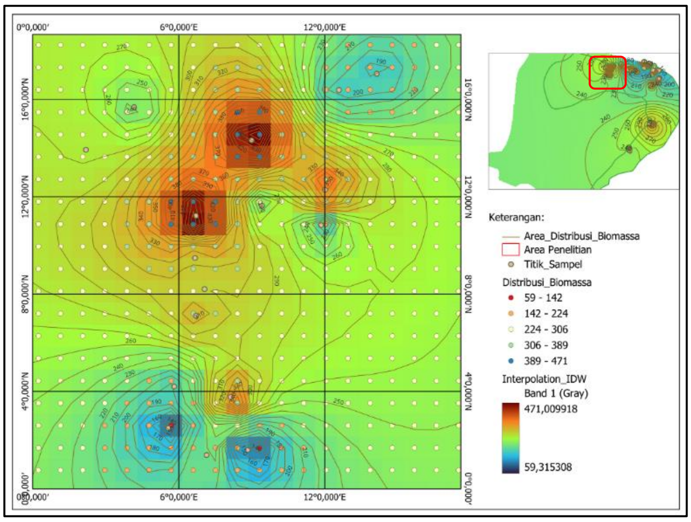

Figure 8. Height Distribution Observation Area
Source: Researcher 2024.

The processing results show that the area with the highest biomass value is in the deeper coastal area which has a sandy mud substrate, because sandy mud substrate has a higher content of organic matter and nutrients compared to pure sand. This content provides a source of essential nutrients that support the growth and development of mangroves [26]. This is shown by the indicator color becoming increasingly dark red in Figure 8, where the results are comparable to the color shown by the biomass distribution points which are relatively white to dark blue with values of 224 Mg/ha to 471 Mg/ha.

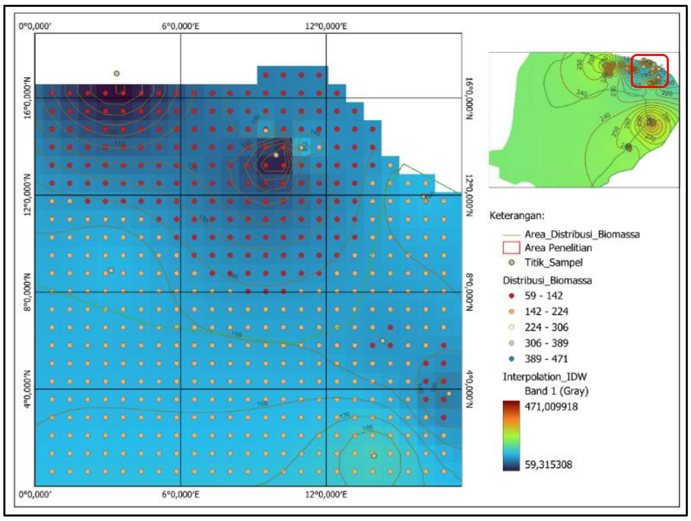

Figure 9. Low Distribution Observation Area
Source: Researcher 2024.

The results in Figure 9 show that the area with the lowest biomass is located in the area closest to the beach with a sand substrate, because the sand substrate generally has a lower organic material content compared to the sandy mud substrate, where organic material has an important role as a source of nutrients for mangrove growth [26]. This is indicated by the indicator color becoming increasingly dark blue, with lower biomass distribution as indicated by the red biomass distribution points with values of 224 Mg/ha to 59 Mg/ha.

3.3. Biomass Value Accuracy

Based on the calculation results between Biomass field data and processing data using the method spatial Interpolation deterministic techniques Inverse Distance Weighted (IDW), obtained the value of the results of statistical analysis of accuracy using analysis Mean Absolute Error (MAE), Root Mean Square Error (RMSE), Mean Absolute Percentage Error (MAPE) and Determination Coefficient (R^2) which can be seen in Table 2.

Table 2. Analysis of Accuracy Levels

ACCURACY STATISTICAL ANALYSIS	
MAE	5,62
RMSE	11,48
MAPE	5%
Correlation Test	0,997088

Results on calculations Mean Absolute Error (MAE) produces a value of 5.62 and Root Mean Square Error (RMSE) with a value of 11.48, where this value shows accurate results with lower error values for 50 sample data plots with a data range of 44 Mg/ha to 486 Mg/ha [23]. As for value Mean Absolute Percentage Error (MAPE) produces an error of 5%, where the result is less than 10%, which means the calculation results are said to be very accurate [23]. Apart from that, the results of the correlation test were obtained with a value of 0.997088, where this result was greater than the calculated value of rTable with a significance level of 5% = 0.278 for 50 sample data plots. This shows that the high correlation reflects a very significant relationship between field data and the results of processing using the method Spatial Interpolation with deterministic techniques Inverse Distance Weighted (IDW) [27].

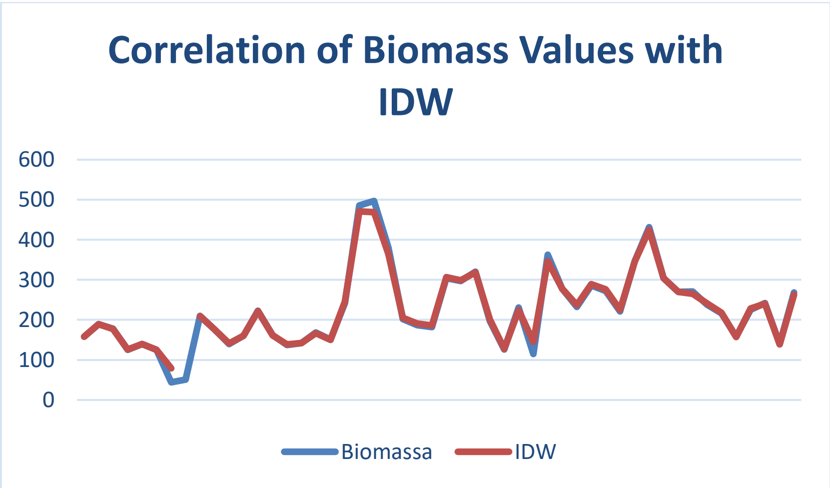

Figure 10. Correlation of Biomass Values with IDW
Source: Researcher 2024.

Representation of data accuracy between biomass field data and processing data using the method Spatial Interpolation with deterministic techniques Inverse Distance Weighted (IDW) can be seen in Figure 10. This significant relationship indicates that the method used is able to represent data distribution patterns very well, so that it can be used as an accurate basis for further analysis and decision making related to resource management or similar research [27].

3.4 Policy Recommendations

Research on the distribution of mangrove vegetation using spatial interpolation methods shows very accurate results, which provides a strong basis for developing data-based policies [28]. The data from this research can be used in the sustainable management and monitoring of mangrove ecosystems, including in the implementation of geographic information systems (GIS) to monitor changes in vegetation periodically [29]. In addition, this data supports mangrove rehabilitation programs by determining priority locations that require restoration, as well as measuring the effectiveness of the program over time.

The research results can also be used to develop mangrove protection policies, such as establishing conservation areas and preventing land conversion. In the context of regional planning, mangrove distribution data can be integrated into environmentally based spatial planning to ensure development that is in harmony with the sustainability of coastal ecosystems [30]. Community education and empowerment based on data from this research can also increase awareness of the importance of mangroves, as well as involve the community in mangrove rehabilitation and management efforts [31]. By supporting the development of spatial data-based monitoring technology and encouraging collaboration between stakeholders, this research provides strategic direction for the protection and optimal use of mangrove ecosystems.

4. CONCLUSION

Nusa Lembongan Island, Bali, has good biomass distribution as shown by the mangrove vegetation biomass distribution map which shows a dominant color of green to yellow with an average biomass value of 200 Mg/ha to 300 Mg/ha. Apart from that, the accuracy calculation results have a significant relationship with the MAE value of 5.62 < 10% of the average data on the number of samples, RMSE 11.48 < 10% of the data range on the data of the number of samples, MAPE 5% and Accuracy Test rCalculated 0.997 > rTable 0.278. Demonstrated through the results of statistical analysis calculations, accuracy and correlation tests, where these results support the distribution of biomass in mangrove vegetation on Nusa Lembongan Island using the method spatial Interpolation with deterministic techniques Inverse Distance Weighted (IDW) has accurate results.

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