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Test of Land Potential Sensor Tools Based on Biomass on Measurements of Temperature, Moisture, and Soil pH and Their Relationship to the Biomass Values in Marginal Land

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Abstract. This research aims to test the accuracy of biomass-based land potential sensor devices. The indicators tested were the results of measurements of growing environmental conditions including temperature, humidity and soil pH, as well as measurements of tree biomass. The analysis technique is carried out in 2 stages, namely the comparative measurement test stage and the biomass calculation application test in the field. The research results show that the average measurement of pH = 5.7493, humidity = 88.0616% and temperature = 27.016ºC is generally not significantly different at the 95% t-confidence interval from the average of the measurement results from the 3 comparison sensor devices. In the pH measurement test, the 3 comparison devices had the lowest MSE value and the lowest standard deviation was in the pH-1 device of 0.03346, the humidity test in the RH-1 device was 0.03 and the temperature in the Temp-1 device was 0.0142. This shows that the sensor device built has quite accurate and valid measurement values with a fairly low error rate. The results of the application of sensor devices to measure tree biomass values obtained an average value of 163.878 kg/ha with a standard deviation of ± 68.878 and provided a significant difference at the 0.001 level for the 11 villages measured, as well as the relationship between biomass values and the growing environment is not linear.

1 Introduction

The country that has the second greatest diversity in the world is Indonesia [1]. Apart from that, Indonesia as a tropical region has potential resources for new species that are more than half the diversity of flora and fauna on Earth. This makes Indonesia seen as the richest source for the discovery of new types of microorganisms [2]. In recent years, Indonesia has experienced quite worrying conditions regarding land and environmental resources, characterized by the increasing expansion of critical land which has an impact on decreasing

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vegetation diversity. Generally, land criticality is characterized by fragility, vulnerability to erosion, less productivity, and difficulty managing, which results in further degradation of land quality [3]. Several things that cause the expansion of critical land are forest destruction, the expansion of agricultural areas that are not following the environmental carrying capacity, increasingly urgent population growth, and uncontrolled forest fires [4].

The success of conservancy is expected to be able to create better microclimate conditions for plants so these conditions need to be measured in plant microclimates as part of knowing the true potential of the land. Low air temperature and high air humidity under the stand are important indicators that show the quality of the microclimate, where the best quality of the microclimate is in mixed forest plantations compared to other types of land cover [5]. In constructing and applying allometric models it is preferred over the more commonly used growth factors. Because allometric models make it easier to describe variations in tree architecture and biomass compartmentalization [6]. Calculating the biomass of each tree has an important aspect in the amount of natural volatility in the data, especially for species native to tropical and subtropical areas, so it is necessary to know how large the biomass is and to what extent it is related to the growing environment.

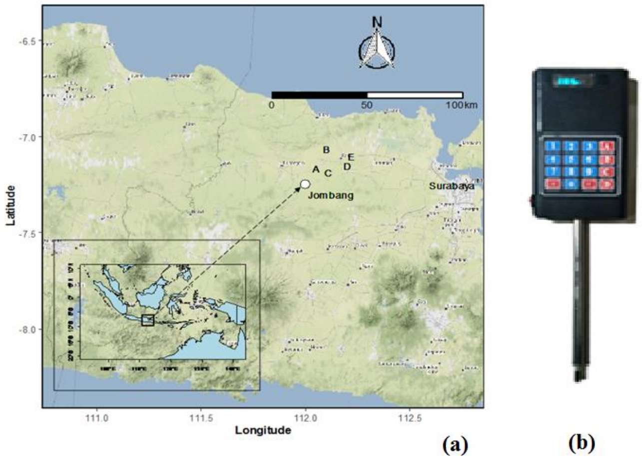
Errors are often found that occur in biomass measurement activities, mainly due to the equipment used having low accuracy or being impractical, causing operators to become tired quickly so that measurement recording becomes biased [7]. Chave added that there are four characteristics of uncertainty in the estimation of Above Ground Biomass (AGB) of tropical forests, including 1) inaccuracy of variable measurements, in the form of instrument and calibration errors; 2) allometric model error; 3) sampling uncertainty (in the form of research sample size and sampling design), and 4) low level of sampling representativeness [8]. A digital biomass measuring tool designed by Hardiansyah et al. shows that it does not indicate the level of accuracy of the distance sensor used based on angle measurements with a Gyroscope sensor to obtain the stem diameter value [9]. To meet these needs, this research carried out testing of biomass-based land potential sensor devices on 3 comparative sensor devices with different brands and specifications. The working principle of the sensor uses two distance sensors for measurements directed at the centre of the rod and one side of the rod. The diameter calculation uses the Pythagorean theorem approach so it does not require angle calculations. Next, the application of sensor devices is carried out to measure biomass and its relationship with the growing environment such as pH, temperature, and soil moisture conditions, especially in marginal soil conditions.

2 Materials and methods

2.1 Research location and data source

This research was conducted in the area north of the Brantas River, Jombang Regency, taking 4 sub-district locations, namely Plandaan, Kabuh, Ploso and Kudu sub-districts. Geographically, Jombang Regency is located south of the equator between 112º03′ 46″ East Longitude and 7º20′48″ South Latitude, with an area of 1,159.50 km², consisting of 21 sub-districts and 306 villages.

The time for data collection and data analysis starts from 21 to 31 August 2023. The data purposed in this research is primary data from the results of measurements from sensor devices resulting from the research design. For comparative data, three similar sensor devices were used for measuring pH, temperature, and humidity, with 45 data samples measured for each. Tree biomass measurements used locations in four sub-districts with 11 sample villages.



(a) **(b)**

Fig. 1. Research location in the northern region of Jombang Regency. (a), sensor device from the design being tested (b). Location information: A = Plandaan District, B = Kabuh District, C = Ploso District, D = Kudu District.

2.2 Analysis method

The average daily soil temperature and soil moisture are calculated using the formula [10]:

$$\overline{T} = \frac{2T_{morning} + T_{noon} + T_{afternoon}}{4} \qquad (1)$$

where, $\overline{T}$: Average daily soil temperature, T_{morning} : Soil temperature in the morning measurement, T_{noon} : Soil temperature during day time measurements, and $T_{\mathrm{afternoon}}$: Soil temperature when measured in the afternoon.

$$\overline{RH} = \frac{2RH_{morning} + RH_{noon} + RH_{afternoon}}{4} \qquad (2)$$

where $\overline{RH}$:Average daily soil moisture, RH_{morning}: Soil moisture in the morning measurement, RH_{noon}: Soil moisture during daytime measurements, and $RH_{\mathrm{afternoon}}$: Soil moisture measured in the afternoon.

Average daily temperature and soil moisture measurements were calculated at a depth of 20 cm from the ground surface. Primary data used in this research was obtained from the results of measuring tree biomass in the Jombang Regency area. The tree parameters calculated are the trunk diameter in cm at a height of 1.3 meters above ground level. This research used longan and mango trees with a sample of 250 per tree. Tree biomass is measured using the branching tree allometric formula function [11, 12]:

$$Y = 0.11.\rho.D^{2.62} \qquad (3)$$

where Y: above-ground biomass ($\mathrm{kg.tree^{-2}}$), ρ: wood density ($\mathrm{g.cm^{-2}}$), D: tree diameter (cm).

The biomass calculated is from longan and mango trees with wood densities of 0.91 and 0.58 respectively [13]. The biomass measurement process with a distance sensor uses an isosceles triangle centre of gravity approach. The working principle of the distance sensor for measuring biomass is that the sensor will measure the distance *a* and *tc* using an isosceles triangle centre of gravity approach to obtain the stem diameter value [14].

$$tc = \frac{1}{2}\sqrt{4a^2 - c^2} \qquad (4)$$

So, the value of the rod diameter (*d*) = 2*c* = 4*a* - 4*tc*. Data analysis includes descriptive statistical tests, one-sample T-tests, contour plots, and surface plot tests. The one-sample T-test is used to show whether or not the average measurement results of sensor devices have a significant difference at the α/2 level (0.025) with the average of measurement results from 3 comparative sensor devices.

3 Result and discussion

Environmental factors that influence growth change constantly throughout plant growth. These factors include soil moisture, quantity and solubility of mineral nutrients, soil acidity level, disease, insecticides, air and soil temperature, and photoperiod [15]. Fluctuations in microclimate elements, in the form of temperature and soil moisture at different soil depths, are influenced by temperature and relative air humidity in the area.

3.1 Sensor device test

Based on the results of measurements of pH, temperature, and soil moisture from the sensor devices that have been designed, as well as the results of measurements from 3 comparative sensor devices. The measurement results of the average pH value of the designed sensor device were 5.7493. The results of the pH hypothesis analysis show that the p-value > significance coefficient, α/2, (0.025), which means that the average value of the 3 comparison sensor devices does not provide a significant difference. This shows that the average pH value of the sensor device has the same measurement value as the 3 comparative pH sensor devices, meaning that this sensor device has accuracy and reliability.

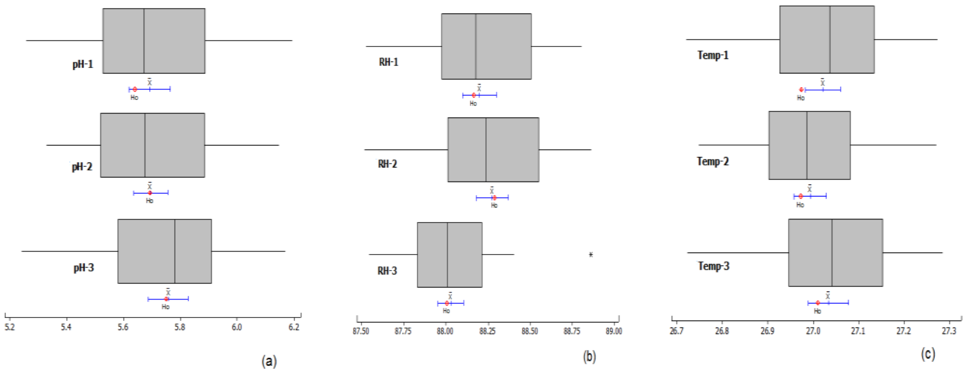
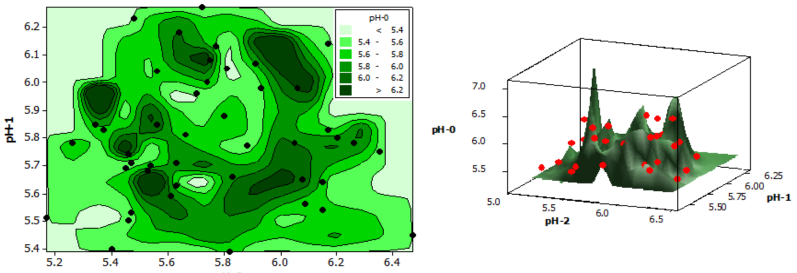


Fig. 2. Boxplot display, which shows the average value of pH (pH Ho = 5.7493), humidity (RH Ho = 88.04%) and temperature (Temp-0 Ho. = 27.016ºC)) is in the range of average values pH (a), humidity (b), and temperature (c) which shows that the value of the sensor device is not significantly different at the level (α/2) of 0.025 to the pH value of the 3 comparison devices.

In Fig. 2(a), the boxplot display shows that for all the comparison sensor devices, the average pH value is not significantly different from the average value of the sensor device designed by researchers, which is shown in Ho to be within the range of average values. This can strengthen the reliability of the sensor device; the pH measurement results are quite valid. In Fig. 2(b) the box plot shows that for all the comparison sensor devices the average humidity value is not significantly different from the average value of the sensor devices designed by researchers, especially for sensor devices ((RH-1), (RH-2), and (RH-3), where Ho is in the range average value. However, on sensor device (c) outlier data was found. In Fig. 2(c) the box plot shows that for all the comparison sensor devices the average temperature value is not significantly different from the average value of the sensor devices designed by researchers for sensor devices (Temp-1), (Temp-2), and (Temp-3).

Furthermore, the characteristics of the relationship between the average pH value of the designed sensor device and the comparison sensor device are shown in Fig. 3.

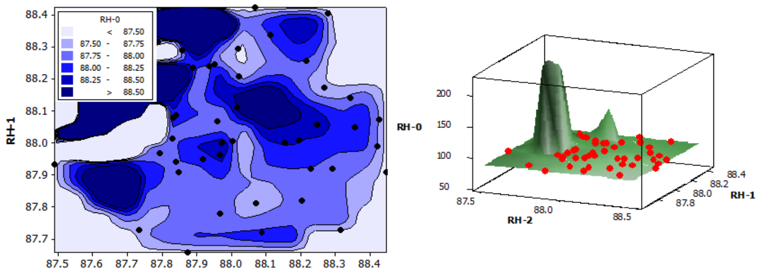


(a) (b)

Fig. 3. 3-dimensional display of the characteristics of the relationship between the average pH value of the sensor device (pH-0) and the comparison sensor device (pH-1 and pH-2. (a) Contour Plot graphic display, (b) Surface plot graphic display.

Fig. 3 shows that even though the pH value results from a comparison of existing devices, it still provides various characteristics and is the basis for distinguishing characteristics between devices. This variation in pH values is shown by the circular contour appearance of the pH value levels (Fig. 3(a)) and more than one peak point (Fig. 3(b)), meaning that there are other factors that influence the differences in pH values. The results of the humidity hypothesis analysis show that the p-value > significance coefficient, $\alpha/2$, (0.025) on the comparative humidity sensor device does not provide a significant difference. In general, the sensor device has the same measurement values as the two comparative pH sensor devices, meaning that this sensor device still has accuracy and reliability.

The characteristics of the relationship between the average humidity value of the designed sensor device and the comparison sensor device are shown in Fig. 4.



(a) (b)

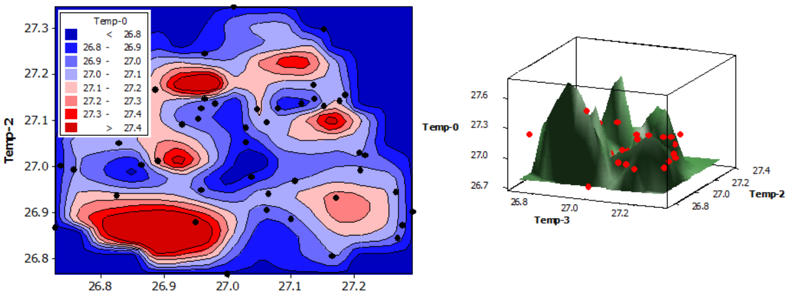
Fig. 4. 3-dimensional display of the characteristics of the relationship between the average humidity value of the sensor device and the comparison sensor device. (a) Contour Plot display, (b) Surface plot display.

Fig. 4 shows that even though the humidity value is produced from a comparison of existing devices, it still provides various characteristics and is the basis for distinguishing characteristics between devices. This variation in humidity values is shown by the circular contour appearance of the humidity value levels (Fig. 4(a)) and more than one peak point

(Fig. 4(b)), meaning that there are other factors that influence the differences in humidity values.

The measurement results of the average temperature value of the designed sensor device were 27.016ºC. The results of the temperature hypothesis analysis show that the p-value > significance coefficient, α/2, (0.025) on the comparative temperature sensor devices does not provide a significant difference. This shows that the sensor device has the same measurement value as the three comparative temperature sensor devices, meaning that the sensor device resulting from this design still has accuracy and reliability.

The characteristics of the relationship and variation between the average temperature value of the designed sensor device and the comparison sensor device are shown in Fig. 5.



(a) (b)

Fig. 5. 3-dimensional display of the characteristics of the relationship between the average temperature value of the sensor device and the comparison sensor device. (a) Contour Plot graphic display, (b) Surface plot graphic display.

Fig. 5 shows that even though the temperature values are produced from a comparison of existing devices, they still provide various characteristics and serve as a basis for distinguishing characteristics between devices. This diversity of temperature values is shown by the circular contour display of the temperature value levels (Fig. 5(a)) and more than one peak point (Fig. 5(b)), meaning that there are other factors that influence the differences in temperature values. The colour display of the lowest temperature is shown in dark blue and the highest temperature is shown in red so that the colour variations are formed from the level of difference in temperature values in contour plot, Fig. 5(a). Variations in temperature values can also be shown in the display of more than one graphic peak on surface plot 5(b).

3.2 Tree biomass measurement

Tree biomass measurements were carried out on critical land, especially in the four sub-district areas that were the research samples. Based on the results of biomass measurements from 11 sample villages. The results of the analysis of variance show that there are significant differences in diversity from the 11 villages studied with an average of 163,836 kg/ha with a standard deviation of ±68.878. The highest biomass was shown in Gebang Bunder village at 306.059 kg/ha. and the lowest was in Randuwatang village at 62.098 kg/ha. This shows that there are differences in the soil fertility conditions of the 11 villages, which influences the differences in biomass content in each land.

The relationship with environmental conditions for plant growth, such as pH value, temperature, and soil moisture, can be seen in Fig. 6, where there is a non-linear relationship between biomass and environmental conditions. This relationship can be described in the condition that the pH, temperature, and humidity vector lines do not form a line perpendicular to the contour lines. In the picture, it can be seen that the contour lines form a curved and varied line pattern so it can be indicated that the relationship is not linear and is indicated by a fairly low r^2 value, less than or equal to 0.50.

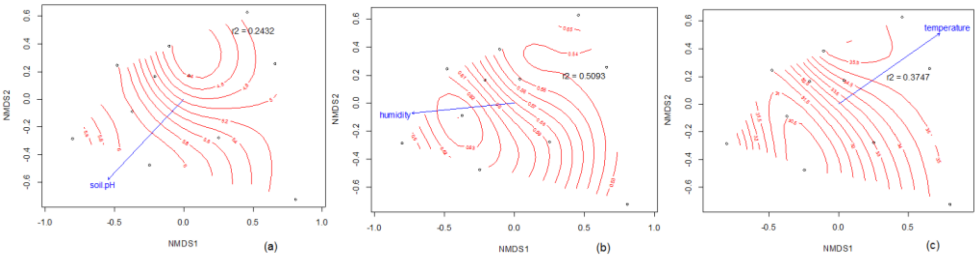


Fig. 6. The relationship between variations in tree biomass and growing environmental conditions is not linear with low r^2 values, namely, (a) $r^2 = 0.2432$ (pH), (b) $r^2 = 0.5093$ (humidity) and (c) $r^2 = 0.3747$ (temperature) at 11 villages from the four sub-districts studied.

The relationship between tree biomass and the growing environment, such as pH, humidity, and soil temperature, generally shows a non-linear relationship. This means that there are many factors that influence the condition of tree biomass whereas there are other factors that influence it. Although pH, humidity, and temperature conditions have a significant influence on tree biomass, they are not determining factors.

3.3 Discussion

Based on the results of biomass measurements from 11 sample villages, the following analysis results were obtained are an important factor in supporting plant growth and development. Low air temperature and high air humidity under the stand are important indicators indicating the quality of the microclimate. The research results show that land revegetation can improve pH, temperature, and soil moisture conditions. Measuring tools as a medium for knowing the pH content, reliable temperature and humidity are very helpful in knowing the exact environmental conditions of plant growth. In previous research, it was seen that biomass prediction has complex parameters in the environment when the mapping between land surface parameters and SAR images is always very complex due to strong nonlinearity. Apart from that, the regression model used based on real data measurements does not provide a clear enough relationship. The traditional allometric method in the form of the Schumacher-Hall equation provides deficient accurate biomass approximates, whereas the logarithmic transformation has the shortcoming of not being able to increase the validity of the estimates [16] so it needs to be strengthened by designing tools that can increase the validation of biomass calculations that are integrated with pH, temperature and humidity measurements.

Kim et al 2016 explained that MSE with a low value for validation of regression models is highly recommended in addition to standard methods. Another advantage of the high-level kernel estimator is that the method stages are shorter because they do not need classical requirements such as parametric regression. Based on the condition of the soil, the moisture in the soil texture, the lower the soil pH will be and the opposite applies [17]. Therefore, measuring soil pH is very necessary to maintain the quality of the soil. Errors in the calibration and data collection process can result in quite large error values. This can be caused by several factors, one of which is that the sensor used is not cleaned properly so the probe on the sensor experiences errors and the data obtained is less accurate. Apart from that, errors in this tool are also influenced by the specifications of the sensor used. If the sensor has a pH reading range specification of 3.5 – 8, it does not rule out the possibility that an error will occur at each level of the measured pH value. This happened because the factorymade soil pH sensor system used was different where the results of testing the pH sensor device were five repetitions, producing the same data in each repetition [18]. The accuracy value obtained was 97.60% with an error of 2.40%, which means that the approach to the sensor output value of the digital pH meter is said to be quite good.

Arnold stated that soil moisture has an important function as information for the government to determine the potential for surface flow and flood control, soil erosion failure and slope, water resource management, as well as geotechnical and water quality [19]. Soil moisture factors include rainfall, soil type, and evapotranspiration rate. Soil moisture will determine the availability of water in the soil for plant growth [20]. From the results of the soil moisture prototype, it was concluded that overall this tool worked well. Mahdi & Dian stated that the deficiency in humidity sensor measurements is that the sensor value exceeds the sensor value that has been set when the soil is dry and moist [21]. So the water pump, which should turn on when the ground is dry, turns off. Likewise, the output that should not be on when the ground is damp turns on [21].

Soil temperature is closely related to atmospheric temperature but its fluctuations do not always follow atmospheric temperature fluctuations. An important factor controlling this turmoil is the act of covering land [6]. The test results of sensor devices for measuring soil temperature, although in general do not show significant differences in values with comparison sensor devices, still show differences in values as shown in the contour display and surface response. This is in line with the opinion of Alif that when testing the accuracy of the LM35, DHT11, and DS18B20 temperature sensors that were made, the value reading results were different due to differences in the characteristics and active properties of the sensors in responding when connected to a DC source [22].

4 Conclusion

Testing of a prototype biomass-based land potential sensor device that uses pH, temperature, and humidity sensors integrated with a distance sensor for measuring tree biomass against 3 comparative sensor devices shows that the measured values have an average that is not significantly different at 95% t-confidence intervals. The average measurement results were pH = 5.7493, humidity = 88.0616%, and temperature = 27.016ºC. Based on the MSE value obtained in general, it has a fairly low value, the lowest is on the pH-1 device at 0.03346, the humidity test on the RH-1 device is 0.03 and the temperature on the Temp-1 device is 0.0142. This shows that the sensor device built has quite accurate and valid measurement values with a fairly low error rate. The results of the application of sensor devices to measure tree biomass values obtained an average value of 163.878 kg/ha with a standard deviation of ± 68.878 and provided a significant difference at the 0.001 level for the 11 villages measured. The relationship between biomass values and the growing environment is not linear, as shown by the low r^2 values, namely $r^2 = 0.2432$ (pH), $r^2 = 0.5093$ (humidity), and $r^2 = 0.3747$ (temperature).

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