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Geostatistical Approach and Drone Image Analysis of the Spatial Distribution of Bacterial Leaf Blight in Rice Plants

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ABSTRACT

Bacterial leaf blight caused by the bacterium Xanthomonas oryzae is an important disease because it can cause severe damage and can infect the vegetative and generative phases of rice plants. This research was carried out to determine the spatial distribution of leaf blight using a geospatial approach and drone imagery. The results of this research indicate that the distribution of bacterial leaf blight disease on land at the research location tends to be higher in the northern part compared to the southern part of the land. The attack rate value at the end of the observation ranged between 20-68%. The distribution of leaf blight on land can be described through simulations using a geostatistical approach and confirmed by aerial imagery. Aerial imagery, especially binary imagery and kriging imagery, mutually confirm (crosscheck) the occurrence of leaf blight on land. Aerial images that are processed into binary images have the potential to be a remote sensing method that can make it easier to observe the distribution of diseases on land, especially leaf blight.

1. INTRODUCTION

Rice plants are a very important main food source, producing rice. Demand for rice continues to increase as the population increases. According to the Sidoarjo Regency BPS report (2020), rice production in East Java decreased in 2019 to 5.50 million tonnes, from 5.86 million tonnes in 2018. This production is not sufficient for national food needs. One of the obstacles in rice cultivation is bacterial leaf blight (BLB) disease caused by the bacteria *Xanthomonas oryzae*. The disease is greatly destructive especially for rice-producing countries in tropical areas such Indonesia, Philippine, Thailand, India, Bangladesh, Mali, and Japan (Teja *et al*., 2025). The BLB disease was reported to decrease rice yield up to 50%, not only for wetland rice but also upland rice (Suryadi *et al*., 2011). A filed assessment in three provinces in Indonesia (South Sulawesi, North Sumatra, and South Sumatra) reported that incidence of BLB disease was in range of 25% to 100% with severity on rice of 5.5% to 72.91% (Suryadi *et al*. (2016). Initial step for management of this disease can be done by monitoring directly on the land as a preventive control measure to realize the concept of Integrated Pest and Disease Management (IPM).

Currently, monitoring is still often carried out conventionally by observing the presence of pathogens as well as attacks and symptoms on plants in the field directly. This method is time consuming and expensive, especially if carried out over a large area, thereby reducing the accuracy of monitoring data (Nasution *et al*., 2023). Now, monitoring can be carried out more effectively and efficiently using drones which produce aerial photography images, which can quickly show symptoms of damage to rice plant leaves. Therefore, it is necessary to conduct research on geospatial monitoring using drones and geostatistical approaches to determine disease incidence, disease distribution patterns, and the influence of abiotic environmental factors on the development and spread of bacterial leaf blight in rice plants. The aim of research on the distribution of bacterial leaf blight using a geospatial approach is to determine the distribution pattern of bacterial leaf blight through monitoring using drones and geostatistical methods.

2. MATERIALS AND METHODS

2.1. Sampling

Sampling in the research was carried out in April – May 2020 on rice fields owned by farmers in the Sadang Village, Taman District, Sidoarjo Regency at -7.3 to -7.5° Latitude and 112.5-112.9° Longitude (Figure 1). Taman District has an area of 31.54 km² at an altitude of 9 m asl. The average rainfall over the last five years was 150.33 mm (BPS, 2020).

2.2. Making a Map of Sampling Locations

Making a map of sampling locations using ArcGIS 10.7 software from the Indonesian Earth Map (RBI) of Sidoarjo Regency which was downloaded from the official website of the Geospatial Information Agency via the page https://tanahair.indonesia.go.id/portal-web. The rice fields attacked by bacterial leaf blight were located in Sadang Village, Taman District, Sidoarjo Regency.

2.3. Preliminary Survey

An initial survey was carried out to identify locations of rice fields showing symptoms of bacterial leaf blight in Sidoarjo Regency. Observations and interviews with farmers were carried out to obtain information about the presence of this disease on the land. The land surveyed was in Sadang Village, Taman District, Sidoarjo Regency.

2.4. Identify the Bacteria that cause Bacterial Leaf Blight

The bacterial isolation process was carried out using the method adopted by Herwati (2016). Bacteria are isolated from the leaves of plants that are suspected of being infected and showing signs of disease. Leaves are cut at the boundary between the symptomatic and healthy parts, then washed with sterile water. The leaf pieces were then crushed with a mortar and 1 ml of sterile water was added. The crushed leaf extract was put into a test tube containing 9 ml of sterile water for gradual dilution up to four times (10-4) using a vortex so that the suspension was homogeneous.

A bacterial suspension of 0.1 ml from each dilution tube was taken with a micropipette and grown in a petri dish containing NA (Nutrient Agar) media. The bacterial suspension on the surface of the media is spread evenly with a spatula. The bacterial culture is incubated for 2-3 days and the colonies that appear are observed and selected. The bacteria suspected to be the pathogen *Xanthomonas oryzae* were re-grown on NA media by scratching the bacterial colony with a loop needle and then the bacteria were incubated for 2-3 days. Bacterial purification was carried out by growing single colonies on NA media.

2.5. Bacterial Morphology Test

Morphological testing is to determine the characteristics of bacteria that have been grown, such as colony color, colony shape, and the shape of the bacteria observed using a microscope.

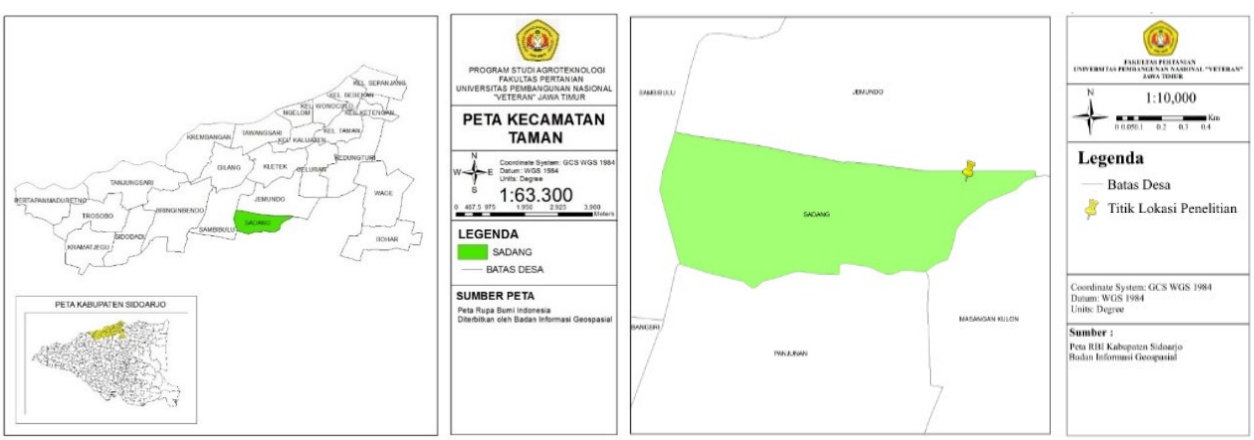

Figure 1. Map of sampling locations

2.6. Physiological and Biochemical Tests of Bacteria

2.6.1. Bacterial Gram Test

Test on pure bacterial colonies to show whether the bacteria are gram-negative or gram-positive bacteria. Bacterial colonies were taken with a loop needle and placed on a glass slide, then dripped with 3% KOH solution. The bacterial suspension is stirred and lifted slightly. If the bacterial suspension is slimy or sticky then the bacteria are Gram negative bacteria, but if the suspension is not slimy or not sticky then the bacteria are gram positive bacteria (Nuraini, 2015).

2.6.2. YDC (Yeast Extract Dextrose Carbonate) Media Test

Bacterial cultures were grown on YDC media for 3 days for optimal growth. The bacterial colonies that form when they are yellow are bacteria from the genus *Xanthomonas* and give positive results (Herwati, 2016; Vinodhini *et al*., 2017).

2.7. Determination of Observation Samples

Determining the research sample points used a purposive sampling method, namely by calculating the incidence of bacterial leaf blight in rice plants. Sampling was carried out on land with an area of 5000 m² with a quadrant measuring 1.5 x 1.5 m² with a total of 50 pieces consisting of 10-20 rice plants. The GPS Coordinate Converter application is also used in determining research sample points (Alizadeh *et al*., 2017).

2.8. Taking Aerial Photo Images using Drones

Aerial photography was taken using a DJI Phantom 4 PRO drone equipped with a camera lens to photograph the images. The height of the drone ranges from 40 meters from the ground and is carried out at 07.30 – 10.30 WIB (Andika *et al*., 2019; Rahadi *et al*., 2019).

2.9. Environmental Factors

Abiotic environmental factors influence the dominance of bacterial leaf blight in rice plants in the field. The environmental factors that are the observation variables in this research are pH, temperature and humidity, which are factors that support the growth of *Xanthomonas oryzae* bacteria in causing bacterial leaf blight disease in rice plants. PH measurement uses a tool in the form of a pH meter.

2.10. Data Analysis

The observation data that has been obtained is processed using several software, including: MATLAB R2018a used for image processing using the Thresholding method (Zahrah *et al*., 2016). Microsoft Excel 2016 was used to process descriptive statistical data and data distribution (scatter plot) then analyze the data geospatially statistically using the SGEMS tool by entering variable data, namely disease incidence and coordinates of disease occurrence.

Processing descriptive statistical data to determine the average (mean), minimum and maximum values, range values, variance and standard deviation based on data on the incidence of bacterial leaf blight in the field. The processed data is then analyzed geospatially using SGEMS. The data that will be processed geospatially with the SGEMS device is in the form of X, Y and Z coordinates which show that point X is the east direction (m), point Y is the north direction, and Z is the incidence of disease.

2.11. Image Processing and Analysis

The aerial photography results obtained during the research are images in the RGB color space (Red, Green, and Blue) or RGB images. Next, the air image is processed using Matlab software for processing including filtering, segmentation, feature extraction and classification. The segmentation process is one of the stages in the image processing process. The segmentation process is carried out to identify an object in the image so that it becomes the basis for sorting/separating objects from one another. This segmentation activity can be carried out through the Color Thresholding feature in Matlab software (Indrawan *et al*., 2024).

The Color Thresholding process includes several procedures, including: determining the color threshold value of an object and the image thresholding process. Determining color values is done by providing points that represent an object in the image as part of sampling. The results of the pinpointing become a reference for the software to determine the color range of an object based on the previous sampling point. Based on the sampling results, a range of soil colors will be obtained, leaf colors of healthy plants, and leaf colors of plants affected/with symptoms of leaf blight (Thenmozhi & Reddy, 2018).

The color range values obtained are then used to eliminate soil objects and the color of healthy plant leaves in the image so that only a new image is obtained which displays symptomatic leaves. The land image with symptomatic leaf objects is then converted into a binary image to increase the contrast of the symptomatic plant parts (Aprillian *et al*., 2020; Bhahri & Rachmat, 2018). Next, visual analysis was carried out on the processed image with disease spread/distribution parameters by observing the distribution of symptomatic leaves on the land (Indrawan *et al*., 2024; Setiawan *et al*., 2023).

2.12. Geospatial Data Processing with SGEMS

The data that will be processed geospatially with the SGEMS device is in the form of coordinate points the stages of data processing with SGEMS include the following:

a) The semivariogram is determined by the tolerance values for the angle classes ($\theta \pm \alpha/2$). Angle classes in the search area were chosen because the observation points are random (irregular). The search area used in this research uses 4 angular directions, namely 0°, 45°, 90°, and 135°.
b) Disease incidence data were tested for normality using the Q1 and Q2 statistical tests before creating a semivariogram model.
c) The semivariogram model is validated by determining the parameters in the semivariogram, namely sill, range and nugget effect.
d) Selection of the appropriate semivariogram model, namely spherical, exponential, or Gaussian based on the curve formed visually.
e) After obtaining the best variogram model, spatial-based data interpolation is carried out using points whose values are unknown (data interpolation) using the ordinary Kriging method.

The image data analysis steps carried out in this research were by processing aerial photo images from drones with MATLAB R2018a. Aerial photo images obtained from drone cameras were processed using the MATLAB R2018a device with the Color Thresholding method, which is an image segmentation method to separate objects from the background so that the color of bacterial leaf blight symptoms can be detected in detail.

3. RESULTS AND DISCUSSION

3.1. Survey of Bacterial Leaf Blight in Rice Fields

Bacterial leaf blight can infect rice plants in both highland and lowland areas, however, rice plants planted in lowland areas are more susceptible to bacterial leaf blight infection (Laraswati *et al*., 2021). The development and spread of bacterial leaf blight caused by *X. oryzae* bacteria in rice plants is influenced by environmental factors. Sudir & Yuliani, (2016) stated that the development of bacterial leaf blight is greatly influenced by environmental conditions, especially high humidity and an environmental temperature of around 25-30°C, while the pH for growing *X. oryzae* bacteria ranges from 5-7, with an optimum pH of around 6-7 for stable bacterial growth (Fadlilah *et al*., 2022). Environmental factors during observations on the research land included, air temperature around 23.0-32.1°C, average rainfall over the last five years was 150.33 mm with 8 rainy days, and average humidity around 77.1%.

Rice plants in the field at the age of 21 DAT (day after transplanting) show yellowish symptoms on some leaves (Figure 2). Symptoms of leaf blight disease become more visible when the plants are around 35 DAT, namely the tips of the rice leaves begin to dry out, turning brownish green as in Figure 2. This is in accordance with Wening & Susanto,

(2016) that the symptoms of bacterial leaf blight disease on plants are characterized by leaves that are brownish green, gray, leaves curl and dry out. Planting rice at the tillering and primordia stages is a critical period for the growth of bacterial leaf blight (Sudir & Yuliani, 2016).

Figure 2. Symptoms of bacterial leaf blight on rice plants aged 21 DAT

Bacterial leaf blight can appear on rice plants due to several supporting factors, including the selection of rice seeds, planting patterns, fertilization and irrigation as well as environmental factors that support the growth of *X. oryzae* bacteria. The results of interviews with farmers found that the seeds used were Inpari-42. According to the Dinas Pertanian dan Ketahanan Pangan Daerah Istimewa Yogyakarta (2019), the Inpari-42 rice variety in the generative phase is susceptible to bacterial leaf blight strain IV, slightly susceptible to bacterial strain VIII, and somewhat resistant to pathotype III. The presence of bacterial leaf blight attacks on this land is thought to be due to differences in planting times and the continuous monoculture planting pattern for rice without interruption. Dinata *et al.* (2021) explained that the pattern of continuous rice planting throughout the year creates environmental conditions that support leaf blight disease to persist in each planting season, also the habit of farmers who always plant one type of rice variety for a long period of time can trigger disease attacks due to the reduced resistance of rice varieties as a result of the spread of pathogens on the land.

3.2. Causes of Bacterial Leaf Blight

The results of the isolation of pure bacteria on Yeast Extract Dextrose Carbonate (YDC) media showed that the colonies that grew were yellowish in color, the surface had a smooth texture. This is in accordance with research by Suresh *et al.* (2013), namely that *Xanthomonas oryzae* bacteria cultured in Yeast Extract Dextrose Carbonate (YDC) media will be yellow in color, have a smooth and convex surface.

The next identification was to test the bacteria with a gram test using a 3% KOH solution and the results showed that the bacterial suspension was slimy or sticky and adhered which corresponded to the characteristics of *X. oryzae* bacteria which are gram negative bacteria when dripped with KOH solution (Jabeen *et al*., 2012). A 3% KOH solution can cause lysis of the cell walls of gram-negative bacteria, causing the destruction of DNA material in the bacterial body and showing a slimy and sticky reaction (Syamsiah & Nurlailah, 2018).

3.3. Disease Incidence

Direct observation data on plants in the field including the distribution of disease during 6 weeks of observation is presented descriptively including the average, mode, minimum value, maximum value, range value, variance and standard deviation shown in table. Based on Table 1, the minimum value increases from week to week, while the maximum value tends to fluctuate from the first to the sixth week. The range value from the first week to the sixth week of observation tends to decrease, this shows that the incidence rate between sample plots tends to be uniform or homogeneous. It is suspected that almost all plants in the sample plots were infected by *X. campestris* bacteria, followed by an increasing incidence rate. The results of the variance values in the first week to the fifth week of observation show that the variance values are decreasing and this is followed by the average value of attack incidence increasing. This shows that the attacks are becoming more evenly distributed, followed by an increasingly higher attack rate, but in the sixth week the variance value increases and the average incidence increases. Conditions in the sixth week showed a lack of uniformity or high incidence grouping.

The results of the histogram analysis in Figure 3 show that on average, it tends to be in the range of 20-30%. This shows that the planting conditions at the time of the study were damaged due to attack by leaf blight bacteria in the moderately resistant category (Khan *et al.*, 2015). Observations of incidence in the first week to the last week with an attack value above 30% were relatively less than five percent. This condition shows that there is a grouping of incidents with a moderately resistant category ranging from 95% of all plants affected.

Table 1. Descriptive statistical parameters 6 observation times

Descriptive statistical parameters	Observation of Incidence in the 3rd week					
	1	2	3	4	5	6
Average (mean)	25.84	27.36	25.76	24.4	29.68	32.64
Mode	24	20	28	20	24	32
Minimum value	8	12	16	16	20	20
Maximum value	64	64	56	56	64	68
Range value	56	52	40	40	44	48
Variance	137.28	123.66	69.98	66.12	68.63	126.92
Standard deviation	11.71	11.12	8.36	8.13	8.28	11.26

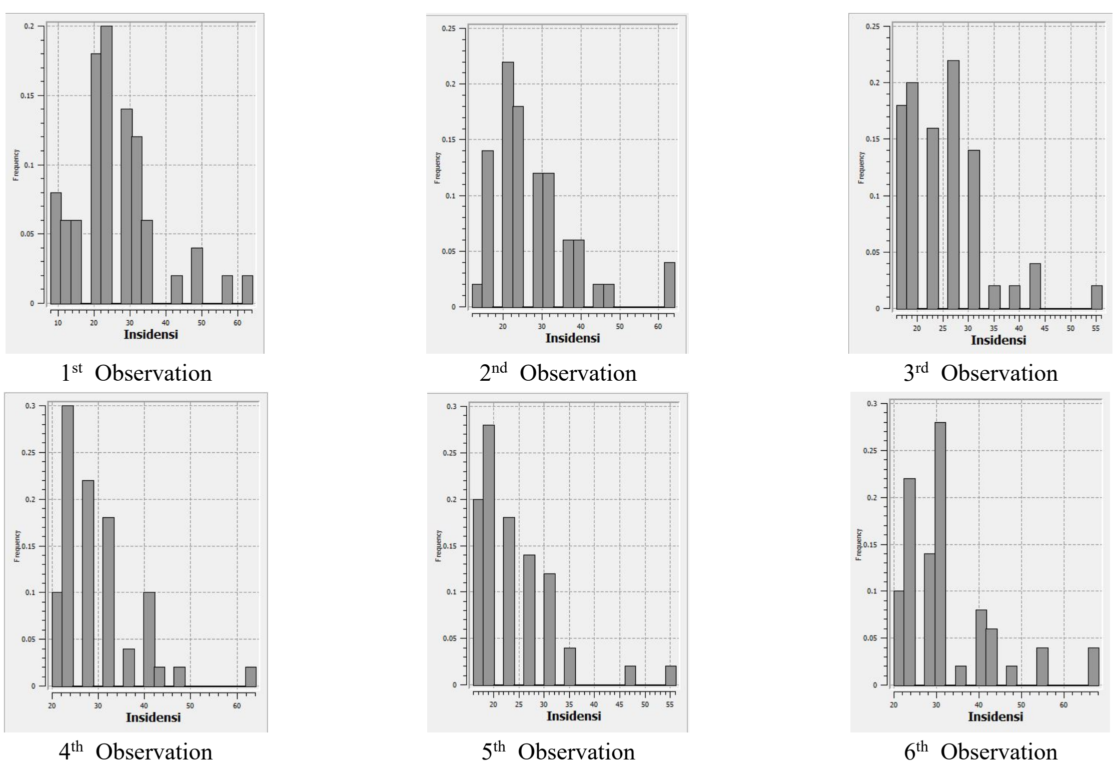

Figure 3. Histogram of incidence vs. frequency for 6 observation times

3.4. Disease Distribution Patterns

Geospatial distribution of disease uses a geostatistical approach with variogram parameters including nugget effect, sill, and range (Annan *et al*., 2019). Variogram models include spherical, exponential and Gaussian models. The accuracy of model selection is done by looking at the closeness between the curve and the experimental variogram values. The appropriate variogram model to represent the pattern of spread of bacterial leaf blight is the exponential model.

The nugget effect value is a value that shows the level of error when sampling which is close to zero or the starting point of the variogram. Table 2 shows the nugget effect value obtained from the first week of observation to the last was 0.75; 0.5; 0.7; 0.5; 0.5; and 0.2. A nugget effect with a value greater than zero indicates that there is data variability. This was shown in research by Guedes *et al*. (2020), that a high nugget effect value was obtained to minimize inaccuracies in spatial estimates. Lamichhane *et al*. (2013) revealed that determining spatial dependence is based on nugget values, namely <0.25 indicates strong spatial dependence, >0.25 to <0.75 indicates moderate spatial dependence, and >0.75 indicates weak spatial dependence. Based on this, the average nugget value obtained was 0.53, indicating spatial dependence on land of moderate value.

Table 2. Variogram parameter values

Week 1 Observation	Nugget effect	Sill	Range
1	0.75	137.28	18
2	0.5	123.66	32
3	0.7	69.98	26
4	0.5	67.0	26
5	0.5	68.63	14
6	0.2	126.92	44
Average	0.53	98.91	26.67

The sill values obtained from six observations tend to fluctuate, including: 137.28; 123.66; 69.98; 67; 68.63; and 126.92. The sill value influences data diversity. However, the data results show that the older the plant, the lower the sill value. This suggests that the older the plant, the more homogeneous the level of leaf blight attacks. Fluctuations in siil values are caused by the incubation process of leaf blight pathogens to produce symptomatic plants (Khaeruni *et al*., 2014). Apart from that, as time goes by, these symptomatic plants can also spread to other plants around them. This result is in accordance with the opinion of Fauzi & Hariyadi (2018) who stated that uniformity or homogeneity increases if the sill value is low and the range value is large. This condition also means that spatial influence is increasing. The impact is that in a certain period the level of attack will increase drastically, reflecting the increasing population of infected plants.

The results of variogram modeling in omnidirection or all directions as shown in Figure 4, which was carried out on observation data from the first week to the sixth week, show the range values in the first to last week respectively, namely 18, 32, 26, 26, 14 and 44. This indicates a tendency that the higher the population of symptomatic plants, the higher the range value. However, there are certain periods when the range value decreases drastically and tends to remain constant due to the transmission period and incubation period required for the pathogen to form symptoms on plants (Khaeruni *et al*., 2014). Based on this information, an increase in the population of symptomatic plants will appear, which is indicated by the expansion of the attack area in a certain period. Thus, a higher range value indicates a wider distance or spatial influence. This condition illustrates the spatial influence of the spread of bacterial leaf blight disease in certain directions which is influenced by factors that influence disease development, especially the environment.The analysis results are based on the variogram model which has been obtained with the best approach, namely the exponential model. Next, spatial interpolation was carried out from this model using the kriging method to produce a contour map as shown in Figure 5.

The results of the kriging analysis form a contour map that is graded in red, yellow, green and blue. Red indicates high incidence (more than 56%) and blue indicates low incidence (around 25%). The high incidence from observations 1 to 6 tends to be in the middle of the land that runs from north to south. This shows that bacterial diseases spread more easily in the middle of the field which is an area that is conducive to the development of rice plant leaf blight. This

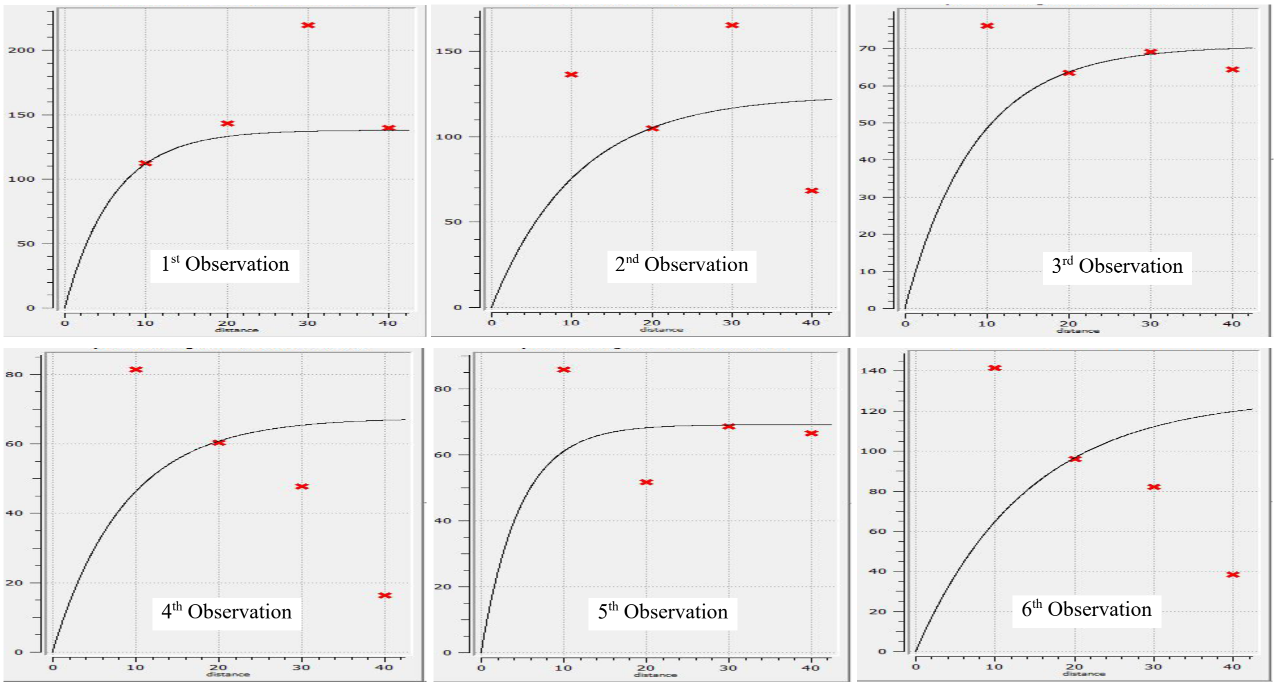

Figure 4. Variogram model analysis for the first to sixth observations

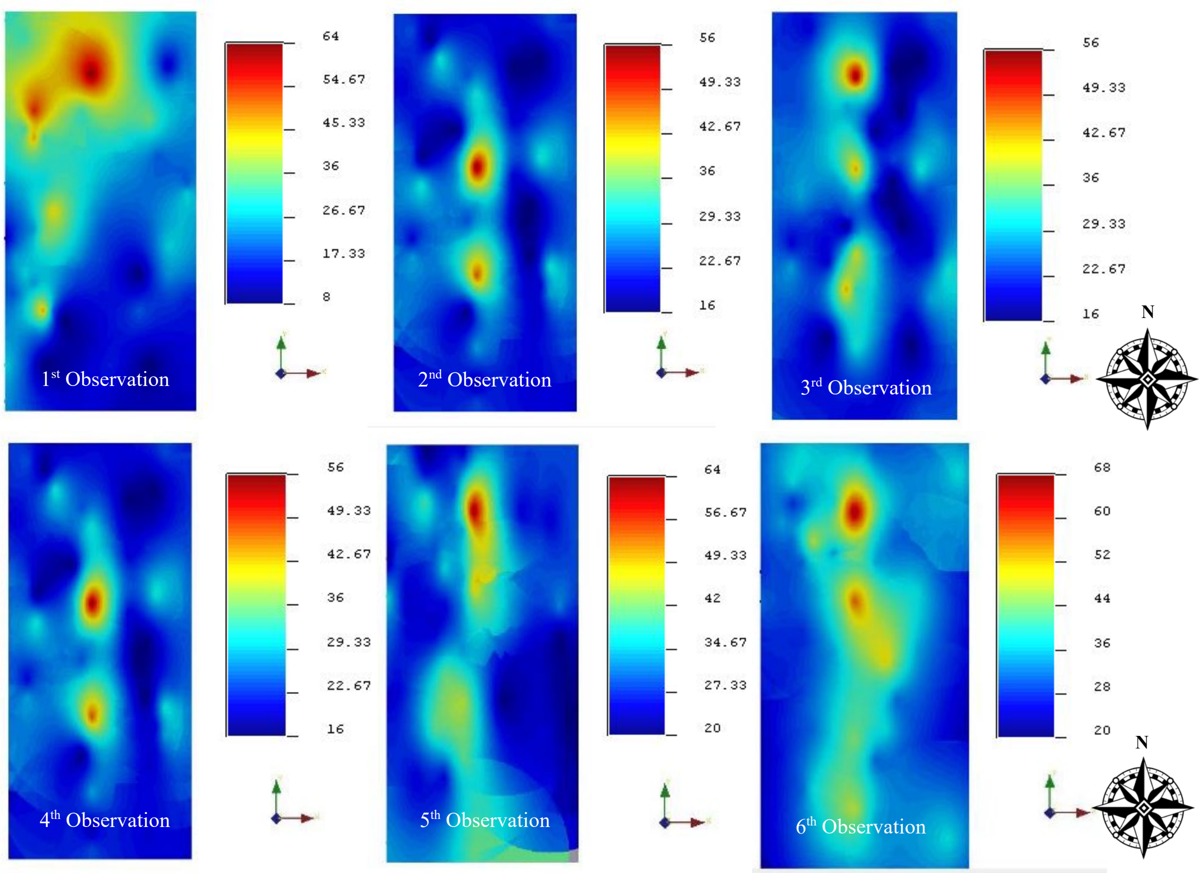

Figure 5. Kriging analysis for the first to sixth observations

condition indicates that the spatial influence has a vertical direction, while the horizontal influence is sensitive to changes in distance. It is suspected that the vertical spatial influence is influenced by the condition of soil acidity in the vertical direction, where the middle side of the land has a lower acidity value than the horizontal direction. This condition is in accordance with the results of the interpolation of soil acidity values in the previous analysis. The results of this research indicate that the distribution of bacterial leaf blight disease on land at the research location tends to be higher in the North-South direction compared to the east-west direction. The attack rate value at the end of the observation ranged in distance. It is suspected that the vertical spatial influence is influenced by the condition of soil acidity in the vertical direction, where the middle side of the land has a lower acidity value than the horizontal direction. This condition is in accordance with the results of the interpolation of soil acidity values in the previous analysis. The results of this research indicate that the distribution of bacterial leaf blight disease on land at the research location tends to be higher in the North-South direction compared to the east-west direction. The attack rate value at the end of the observation ranged between 20-68%. These results are in accordance with the results of the previous descriptive analysis in Table 1. The interpolation results also show that the contour in red from the first week to the sixth week of observation is relatively small compared to the other colors. This condition corresponds to the histogram results which show an attack incidence of more than 30 percent, relatively around 5%, with the red contour color being smaller than the other color contours. This shows that the geostatistical approach can describe the distribution pattern of leaf blight disease in rice plants.

3.5. Digital Image-Based Disease Distribution

The actual aerial photo images obtained from the drone camera appear as in Figure 6A. The results of aerial image processing using the Color Thresholding method as presented in the binary image in Figure 6B, plants infected with bacteria appear as scattered dots and tend to form groups (circled by the dotted blue line). The interpolation results using a geostatistical approach are presented in Figure 6C.

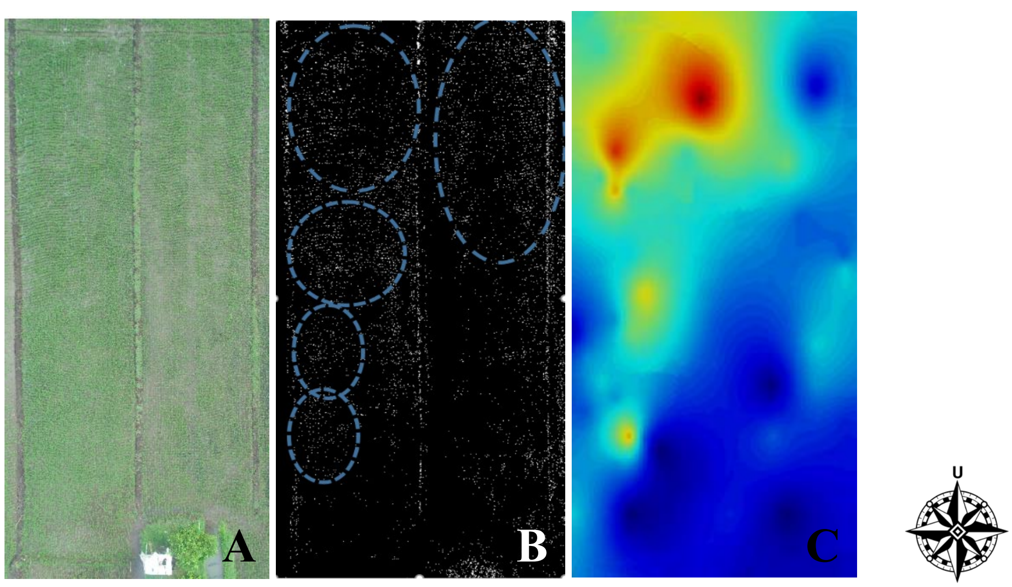

Figure 6. (A) Aerial image, (B) Binary image, and (C) Krigging image of field infected with leaf blight bacteria

Image processing using the Color Thresholding method is carried out to eliminate color elements originating from healthy plant parts, soil, other plants and ground cover grass, leaving the color elements of symptomatic plant parts, namely yellow to brownish yellow leaves. This is in accordance with the statement by Laraswati *et al*. (2021) that yellowish green to brownish yellow leaf color is a symptom of leaf blight disease. After going through the elimination process, the color conversion of the image which originally used the RGB color space was carried out into a binary image to increase the contrast in the image. A binary image is a digital image that has two possibilities for each pixel in the image (Bhahri & Rachmat, 2018). The impact of this conversion will increase the contrast in the image so that it can make it easier to identify the location of an object in the image. According to Aprillian *et al*. (2020) image contrast refers to the distribution of light and dark colors. So in this study, the object that is the focus, namely the symptomatic part of the leaf, is represented by a value of 1 or white, while the background which is not the focus is represented by a value of 0 or black. With very clear differences, the images produced from this process can be used as material for analyzing the distribution of leaf blight on land.

Based on observations of the binary image (6B) which shows that the spatial grouping of incidents is in the north and extends to the middle of the land. This is in accordance with the kriging image (Figure 6C) or the results of spatial interpolation of actual data on disease incidence using geostatistical methods which shows that there is a concentration of higher incidence in the north of the land marked by red to greenish colors. Apart from being concentrated in the northern part of the land, leaf blight infection also spreads vertically to the south of the land, marked with yellow to light blue colors. The dark blue part indicates a light level of attack. This grouping is thought to be due to environmental factors that support the development of disease in the northern part of the land.

The clustered distribution of leaf blight disease can be expected because leaf blight bacteria are more suited to growing in areas with lower acidity compared to areas with higher acidity. According to Parasayu *et al*. (2016) and Purwati & Nugrahini (2020) the development of pathogens will generally be suppressed at high pH, because high pH will result in environmental conditions that are not suitable for the development of soil-borne pathogens. Pathogens will generally be more infective in low soil pH conditions.

Based on the similarity of distribution patterns identified from binary images and kriging images, it can be seen that aerial images, especially binary images and kriging images, mutually confirm (crosscheck) the occurrence of leaf blight on land. So that aerial images that are processed into binary images have the potential to become a remote sensing method that can make it easier to observe the spread of disease on land, especially leaf blight. This is also in line with research by Vélez *et al*. (2023) which states that comparison of aerial imagery with images resulting from geostatistical processing is useful for method validation. After this research, it is hoped that there will be further research to measure the accuracy and reliability of the comparative method so that it can be used as a standard method for observing the distribution of disease based on remote sensing of the distribution of leaf blight in rice plants.

4. CONCLUSION

The results of this research indicate that the distribution of bacterial leaf blight disease on land at the research location tends to be higher in the northern part compared to the southern part of the land. The attack rate value at the end of the observation ranged between 20-68%. Aerial imagery, especially binary imagery and kriging imagery, mutually confirm (crosscheck) the occurrence of leaf blight on land. Aerial images that are processed into binary images have the potential to be a remote sensing method that can make it easier to observe the distribution of diseases on land, especially leaf blight.

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