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Geospatial analysis of factors affecting index of rice harvest success in West Java using INLA-based Bayesian models

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Abstract

Rice production during the 2012-2022 period tends to decline. Many factors lead to a decline in production, one of which is the low on potential of rice success. This issue is an obstacle to achieve food security. West Java is the third largest rice producing province in Indonesia. For this reason, the aim of this research is to establish the potential value of harvest success in West Java Province and form a spatial Bayes regression model of the potential value of harvest success of rice plants in West Java whose inference using the *Integrated Nested Laplace Approximation* (INLA) approach. The spatial Bayes regression model created is a linear mixed model which includes spatial random effects using the BYM2 method. The explanatory variables of the model are the number of farmer economic institutions, the number of agricultural extension workers, the number of farmer groups, the human development index, and the number of disaster events from 27 districts/cities in West Java with the potential value of harvest success as the response variable. The results of the spatial model show that the variables of the number of farmer economic institutions and the number of farmer groups have a significant influence on the potential value of harvest success. From the results of spatial mapping, it can be seen that there are neighborhood relationships that influence the value of potential harvest success where the eastern region in West Java tends to have a higher probability of harvest success.

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INTRODUCTION

Indonesia is an agricultural country, namely a country that relies on the agricultural sector. The majority of Indonesian people rely on the agricultural sector both as a profession and to support development (Mulyadi et al., 2020). Based on data from the Central Statistics Agency, rice consumption is always increasing in Indonesia, so it is necessary to import rice every year to

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meet consumption levels. On the other hand, rice production over the last 10 years has tended to decline. This will be a problem if the rice supply is not sufficient for consumption levels. According to the Central Statistics Agency, West Java is the province with the largest population in Indonesia. The increase in population is directly proportional to the increase in rice consumption (Jiuhardi, 2023). To compensate for the increase in population, rice production must also be increased. Based on data from the Central Statistics Agency in 2020, West Java has rice fields covering an area of 1,578,836 hectares. With this land area, West Java is the third largest rice producing province in Indonesia. Rice production must be maximized so that there is no shortage of rice to meet consumption. One of the factors causing insufficient rice availability in Indonesia is production process problems, namely crop failure.

Harvest failure is an unsuccessful harvest that causes a decrease in production, resulting in losses due to various reasons experienced by farmers (Mendelsohn, 2007). Crop failure can be caused by various factors. However, crop failure can be prevented if every part of the agricultural sector carries out its duties, both the main actors, namely farmers, and other supporting aspects. Reducing the risk of crop failure will increase the potential for harvest success. Research conducted by Zogar et al., (2022) proves that farmer institutions have a role in increasing agricultural productivity.

The Ministry of Agriculture as the main institution in the agricultural sector has attempted to increase the potential for harvest success by implementing several methods, including the existence of agricultural instructors and farmer economic institutions in each district/city. An agricultural instructor has the task of improving the welfare of farmers by maximizing harvest yields and preventing crop failures and increasing the potential for successful harvests (Bagas & Sunaryanto, 2021) . Meanwhile, agricultural economic institutions were formed to assist farmers in carrying out farming activities from pre-planting to post-harvest (Haryanto et al., 2022). In carrying out farming activities, farmers, agricultural extension workers and farmer economic institutions form an organization called a farmer group. Farming groups have an important role as a place to exchange information regarding technological updates, superior seeds, fertilizer and other components that support farming (Riani et al., 2021). Apart from that, there are other unavoidable factors that can cause crop failure, namely natural disasters. Extreme rainfall can affect rice production (Faradiba, 2021). This extreme rainfall results in various kinds of disasters such as floods and landslides. In addition, the resulting temperature changes can result in hurricanes. Apart from that, crop failure can also be caused by economic factors due to high fertilizer distribution costs, high seed prices, and so on. The human development index as a socio-economic indicator can describe the economic conditions and human development in an area(Azfirmawarman et al., 2023). Factors that cause crop failure will result in a decrease in the potential for harvest success.

The author will use these factors as predictor variables in modeling the potential value of rice harvest success in West Java. In mathematical terms, the factors that influence the value of the potential success of a rice plant harvest are referred to as predictor variables, while the value of the potential success of a rice plant harvest as an influenced variable is called the response variable. To see the relationship between these variables, a mathematical model, namely Linear Mixed Model, will be used with parameter estimation using Integrated Nested Laplace Approximation (INLA) to determine the potential value of rice crop harvest success due to the influence of farmers' economic institutions, number of agricultural instructors, number of farmer groups, development index. people, and the number of disaster events. INLA parameter estimation is used because Bayesian estimation with other methods such as Monte Carlo Markov Chain (MCMC) can result in problems such as convergence and programming time. INLA can provide more accurate results in a shorter time. A successful harvest will increase production. Increasing production will create national food security. Therefore, it is important to know the potential for success of rice crop to achieve national food security.

DATA AND METHOD

The data used in this research are obtained from the Indonesian Central Statistics Agency in 2021. The spatial bayes method is used to determine the map of rice crop potential sucess in 27 regencies and cities in West Java. The characteristic data of the indicator used to determine the potential of rice crop sucess are depicted in Table 1.

Table 1. Characteristic of The Indicators for Potential of Rice Crop Sucess

Indicator	Mean	Standard Deviation	Min	Max
LLT	21.124,15	26.226,311	0	108.685
LP	59.411,48	61.808,865	36	227.051
LAT	72.000,63	68.001,846	66	246.259
UREA	17.656,2	17.782,002	18,13	54.649,960
ZA	1.377,612	2.992,756	0	14.538,780
NPK	12.716,33	13.330,307	0	45.548,420
IP	64,46	6,825	55,79	76,89
BJR	12,407	16,204	0	75
PP	55,975	5,032	47,69	69,21

In Table 1, LLT stands for upland land, LP stands for crop area, LAT stands for planted area, IP stands for education index, BJR stands for the number of flood events, and PP stands for rice productivitiy. Meanwhile, UREA, ZA, and NPK in order, stands for the number of distribution of subsidized UREA, ZA, and NPK fertilizers.

The predictor variables are the number of farmer economic organization (x_1), agricultural extension officer (x_2), farmers group(x_3), human development index (x_4), and disaster (x_5). Those variables are depicted in Figure 1.

This research use analysis factor to determine the potential of rice crop sucess. The analysis factor is determined with following steps :

1. Choosing the indicators that will be analyzed.
2. Choosing the indicators that is good enough for further analysis by doing Bartlett's test of sphericity, Kaiser-Meyer-Okin (KMO) test, and Measure of Sampling Adequancy (MSA).
3. Interpretation of the result.
4. Normalization data with Min-Max normalization.
5. Determine the weighting factor.

$$Weight_i = \frac{loading\ factor_i}{average\ loading\ factor_i} \times RSSL_k$$

$$Standard\ weight_i = \frac{weight_i}{\sum weight_i} \tag{1}$$

6. Aggregation

$$Dimension_k = \sum Standard\ weight_i \times indicator_{ij}$$

$$Value = \sum Dimension_k \tag{2}$$

Remarks :

$Indicator_{ij}$= the value of indicator i city j

he result of the aggregation is the potential of rice crop sucess in every city/regencies in West Java which is a composite index to describe the probability of rice crop be sucess. For more detail about index composite can be seen in (Irfandha & Sitorus, 2021).

This research using spatial bayes regression model whose inference using INLA to form a model with response variables and predictor variables, including the random spatial effect. We use R software to do the inference and visualize the map of the potential of rice sucess using several package, one of which is R-INLA.

INLA is a Gaussian Latent model with observation $y = (y_1, \dots, y_n)$ and parameter ϕ_i defined as function of a structured additive predictor $\eta_i$through a link function $g(.)$ such that $g(\phi_i) = \eta_i$. The additive linear predictor η_i is defined as follows :

$$\eta_i = \beta_0 + \sum_{m=1}^{M} \beta_m x_{mi} + \sum_{l=1}^{L} f_l(z_{li}) \tag{3}$$

where β_0 is a scalar representing the intercept; the coeffiients $\beta = \{\beta_1, \dots, \beta_M\}$ represent the linear effect of the predictor variable $x = (x_1, \dots, x_M)$ on the response; and $f = \{f_1(.), \dots, f_L(.)\}$ is a collection of functions defined in terms of a set of covariates $z = (z_1, \dots, z_L)$. The terms $f_l(.)$ can assume as different form, in this research, this terms assumed as spatial random effects which will be modelled using BYM2 model. BYM2 consist of spatially structured component u_i and and an unstructured component v_i. For more details on INLA inference with inculuding BYM2 model for the spatial random effect can be seen in (Rachmawati et al., 2021; Rachmawati & Pusponegoro, 2021; Rachmawati et al., 2024; Blangiardo & Cameletti, 2015).

RESULTS AND DISCUSSIONS

The indicators are normalized using the min-max normalization to equate different measurement units. To see whether the data was good enough before factor analysis, Bartlett's Test of Sphericity and KMO were carried out on normalized data. The results of Bartlett's Test of Sphericity and KMO can be seen in Table 2.

Table 2. Bartlett Test of Sphericity and KMO test result

		Value
Kaiser-Meyer-Olkin Measure of Sampling Adequacy		**0,729**
Bartlett's Test of Sphericity	**Chi-Square**	**257,33**
	Df	**36**
	p-value	$\mathbf{3,11 \times 10^{-30}}$
	Indicator	**MSA**
	LLT	0,693
	LP	0,760
	LAT	0,731
	UREA	0,827
	ZA	0,516
	NPK	0,791
	IP	0,831
	BJR	0,256
	PP	0,356

Based on the processing results with the help of R software, a KMO value of 0.729 was obtained, which explains that the data held is good enough to further carry out factor analysis. The MSA value of each variable is more than 0.5, indicating data that can be used for factor analysis. Furthermore, with the Bartlett's Test of Sphericity test, the p-value was obtained with a value of 0.000, which is less than the alpha significance of 5%, so it can be interpreted that there is at least one variable that is significantly correlated. Therefore, factor analysis can be carried out.

Table 3 shows the result of the weighting factor of the indicators.

Table 3. Weight of each indicator

No	Dimensions	Sub	Compiler Indicator	Weight
1	Availability of planting area, agricultural subsidies and human resources	1	Harvest Area	4,622
		2	Planting Area	4,552
		3	Distribution of Urea Subsidized Fertilizer	4,198
		4	Education Index	3,498
		5	Distribution of NPK Subsidized Fertilizer	4,039
2	Availability of reserve areas and agricultural assistance	6	Distribution of ZA Subsidized Fertilizer	1,931
		7	Tegal Land Area	1,283

After that, we do the aggregation and get the potential values of rice crop success as shown in Table 4.

Table 4. Potential values of rice crop success in West Java

No	Regency/City	Value
1	Garut	1,595
2	Indramayu	0.884
3	Sukabumi	0.805
4	Karawang	0.727
5	Tasikmalaya	0.715
6	Majalengka	0.703
7	Subang	0.665
8	Cianjur	0.649
9	Bandung	0.593
10	Cirebon	0.537
11	Bogor	0.488
12	Sumedang	0.442
13	Ciamis	0.420
14	Bekasi	0.416
15	West Bandung	0.307
16	Brass	0.306
17	Pangandaran	0.204
18	Purwakarta	0.196
19	Bekasi city	0.184
20	Depok City	0.172
21	Bandung	0.166
22	Cimahi City	0.155
23	Tasikmalaya City	0.151
24	Bogor city	0.138
25	Sukabumi City	0.126
26	Cirebon City	0.116
27	Banjar City	0.113

Based on Table 4, it can be seen that there are 11 districts/cities in West Java whose potential harvest success value is higher than the potential harvest success value for West Java Province which is 0.443. The highest potential value for harvest success is owned by Garut Regency at 1.59 and the lowest is owned by Banjar City at 0.113. This means that Garut Regency has the smallest possibility of experiencing crop failure and Banjar City has the greatest possibility of experiencing crop failure. We visualize te result from table 4 by mapping the result as seen in Figure 1.

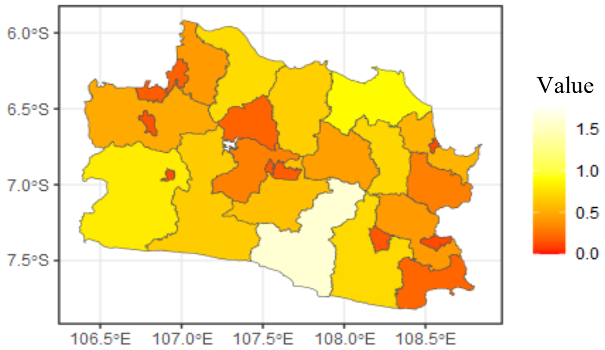

Figure 1. Map of Potential Value of Rice Crop Success.

The spatial regression model created was analyzed using the Bayes spatial model with the INLA approach. The model formed is a linear mixed model which was formed after adding several explanatory variables x_n as described. The results of the spatial model can be seen in the table 5. Table 5 shows that the number of farmers' economic organizations (x_1), farmer groups (x_3), and the human development index (x_4)have a positive influence on the potential value of rice crop harvest success, which means these variables can increase the potential value of rice crop harvest success. Meanwhile, the number of agricultural instructors $(x_2)$and the number of disaster events (x_5)have a negative influence on the value of potential harvest success, which means these variables can reduce the value of potential success of rice crop. Based on the confidence interval value, only the number of farmer groups and the number of farmer economic organizations have a significant effect on the potential value of rice crop success. In general, the *intercept value* α does not have a significant effect on the potential of rice crop success.

Table 5. Coefficient of Predictor Variables

Variable	Mean	95% Credibility Interval
α	-0,016	$(-1.770\,,1.756)$
x_1	0,002	$(0.001\,,0.004)$
x_2	-0,001	$(-0.003\,,0.001)$
x_3	0,002	$(0.001\,,0.003)$
x_4	0,001	$(-0.022\,,0.024)$
x_5	-0,001	$(-0.009\,,0.007)$

From the table above, the following regression equation can be formed

$$\widehat{y_i} = -0{,}016 + 0{,}002x_1 - 0{,}001x_2 + 0{,}002x_3 + 0{,}001x_4 - 0{,}001x_5 + \frac{1}{\sqrt{\tau_b}}(\sqrt{1-\phi}v_* + \sqrt{\phi}u_*) \tag{4}$$

In the variable farmer economic institutions (x_1)has a mean value of 0.002 with a credibility range of (0.001, 0.004) it can be interpreted that adding 1 unit to the number of farmer economic institutions can increase the potential value of harvest success by 0.002. Furthermore, the variable number of farmer groups (x_3) has a mean value of 0.002 with a credibility range$(0.001\,,0.003)$ it can be interpreted that the addition of 0.1 units or 10 farmer groups can increase the potential value of harvest success by 0.002. We can map the result from table 5 that contains the spatial structured random component. The result is shown in figure 3. It is shown that the area with the lowest potential of rice crop success was Banjar City, followed by Cirebon City and Sukabumi City.

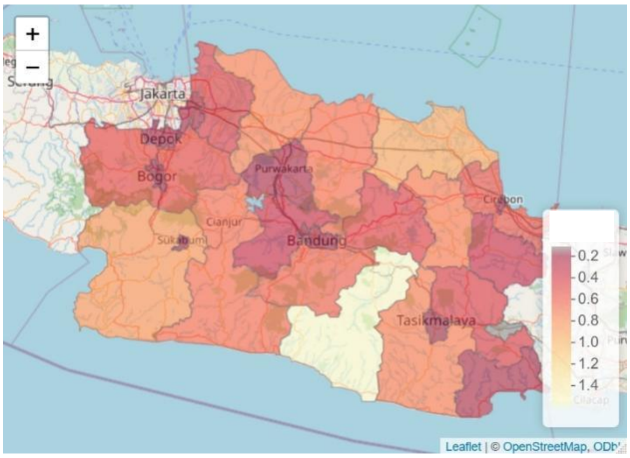

Figure 3. Map of Prediction Value of Potential Value of Rice Crop Success.

The spatial model in equation (1) contains a spatially structured random effect component (u_*) and a spatially unstructured random effect (v_*) which is formed using the Besag-York-Mollie (BYM2) model). The BYM2 model uses the scale of the spatial structured component and the spatial unstructured component.

$$\boldsymbol{b} = \frac{1}{\sqrt{\tau_b}}(\sqrt{1-\phi v_*} + \sqrt{\phi}u_*) \tag{5}$$

By using the INLA *package* from R, we can visualize the random effect as seen in figure 4.

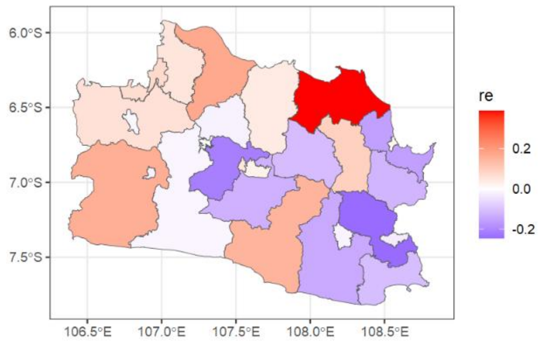

Figure 4. Map of Random Effect of Potential Value of Rice Crop Success.

Figure 4 explains the spatial pattern of the potential of rice crop success in West Java. The spatial random component can really represent the spatial pattern of the potential value of rice crop success in West Java Province. The spatial pattern can be seen in the eastern part of West Java which consists of Tasikmalaya, Banjar City, Ciamis, Kuningan Regency, and Cirebon in purple and the western part which consists of Sukabumi, Bekasi, Depok City, and Karawang in orange. This spatial pattern shows that neighboring regions can produce potential crop success values that are almost close to neighboring regions.

After that, we determine the root mean square error (RMSE) to determine the goodness of the model that formed. By using the RMSE function in the Metrics library in R software, an RMSE value of 0.0006 was obtained. The smaller the RMSE value, it indicates that the model formed predicts the data well and has higher precision in calculating the predicted value. Because the RMSE value is very low, even close to 0, it can be concluded that the model built is quite good.

CONCLUSION

This study developed a composite index to measure the potential value of rice harvest success across 27 regencies/cities in West Java and analyzed its determinants using an INLA-based Bayesian spatial regression model with BYM2 spatial random effects. Factor analysis and weighted aggregation were first applied to construct the harvest success potential index, which revealed clear spatial variation, with eastern parts of West Java tending to exhibit higher probabilities of harvest success. The subsequent spatial Bayesian modeling results indicate that the number of farmer economic institutions and the number of farmer groups have a statistically significant and positive effect on the potential value of rice harvest success, while other variables such as agricultural extension workers, disaster events, and human development index show weaker or non-significant effects. The inclusion of spatial random effects successfully captured spatial dependence among neighboring regions, and the very low RMSE value demonstrates that the proposed model provides a good fit and reliable predictive performance.

Despite these findings, this study has several limitations. The analysis relies on cross-sectional data from a single year, which restricts the ability to capture temporal dynamics and long-term trends in rice harvest success. In addition, the composite index construction depends on selected indicators and weighting schemes, which may influence the resulting potential values. Future research is therefore recommended to extend this framework by incorporating spatio-temporal data to better account for inter-annual variability and climate-related effects, as well as exploring alternative index construction methods or additional explanatory variables such as irrigation infrastructure, soil characteristics, and climate indicators. Such extensions are expected to provide a more comprehensive understanding of rice harvest success and support more effective, region-specific agricultural policy interventions.

AUTHOR CONTRIBUTIONS

NR conceived the research idea, designed the methodology, conducted data analysis, and drafted the manuscript. GZE contributed to study supervision, validation of results, interpretation of findings, and critical revision of the manuscript. Both authors reviewed, edited, and approved the final version of the manuscript.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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