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Research Article

Determination of Land Suitability Criteria for Maize Hybrid in Boalemo Regency Based on Optimum Yield and Selected Land Quality

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The significant effect of land quality on maize production has not been fully considered in the existing land suitability criteria. Therefore, this study aims to determine land suitability criteria for hybrid maize in Boalemo Regency based on the optimum yield and land quality. It was carried out in Boalemo Regency, Indonesia, where the land unit of 67 units was surveyed to obtain land characteristics data. A partial least square of structural equation model (PLS-SEM) with SmartPLS 8.0 was used to select a robust land quality controlling hybrid maize yield, while the boundary line method was used to determine optimum yield and differentiating of land suitability criteria. The result showed that land qualities that define the optimum yield of hybrid maize were root conditions, nutrient availability, nutrient retentions, land preparation, and erosion hazard. The soil characteristics were effective depth, coarse material, organic C, total N, K exchangeable, slopes, soil erosion, rock outcrops, and surface rocks. Furthermore, the highest optimum yield of 8.54 ton/ha was achieved by the total N and slopes for a very suitable class (S1), while the lowest of 5.58 ton/ha was obtained by exchangeable K for class S1. This showed that the combination of PLS-SEM and boundary line analysis was a better approach to developing new land suitability criteria for hybrid maize.

1. Introduction

Food security and farmer prosperity are global concerns; this makes every country increase crop production as well as farmers' income. An important issue for countries with developing economies is ensuring food security, where the agricultural sector plays a strategic role in increasing food availability [1]. Although the global food system has placed maize (*Zea mays* L.) as the leading cereal crop [2], its productivity is being disrupted by land degradation, water scarcity, and climate change [3].

In Indonesia, the wet tropical climate with rainfall and high temperatures tends to reduce the quality of land and agricultural products [4]. This country ranked 8th among the maize-producing nations with a contribution of 2.19% and 2.42% of the world's total harvested area [5]. However, the main problem is the relatively low level of yield in several regions because the achievement of maize production has not been followed by an increase in yield per unit area [6]. This is indicated by the average yield in 2020, which was up to 5.57 ton/ha [5]. According to a previous investigation, maize production in Indonesia can reach between 10 and 12 ton/ha [7, 8], thereby making the country the 21st leading importer in the world.

In Indonesia, Gorontalo Province is one of the centers of maize production, where the hybrid type is the most widely grown species [9]. The maize production in the province reached 1.8 million tons in 2021 [10], with several export advantages and competitiveness [11]. Furthermore, the planting of hybrid, composite, and local maize types has reached more than 98.90%, 0.68%, and 0.41% only, respectively [12], including Boalemo Regency.

Boalemo Regency ranks third as a maize-producing center in Gorontalo Province with a contribution of 18.90% [13]. The maize plant dominates the use of agricultural land in this district by 37.43% [14]; therefore, the commodity has competitive and comparative advantages with a PCR value of 0.80 and 0.91 DRC. This is because maize plant is supported by land area, climatic conditions, production facilities, as well as market guarantees, and the basic price of buying corn from the government [15]. In 2021, the average hybrid and local maize yields in the regency reached 5.20 tons/ha [16] and 2.34–3.30 tons/ha, respectively [17]. This indicated that the productivity of hybrid maize is still higher than local maize [18], but with lower achievement compared to the national maize production of 5.57 tons/ha [5], and has not yet reached the target of 5.60 tons/ha in 2021 [19]. The production of hybrid maize in Gorontalo can reach 9.78–13.11 tons/ha [20] because it is often cultivated on land that does not meet the required qualities [6]. Therefore, there is a need to determine land quality-based hybrid maize land suitability criteria for site-specific land use planning in Boalemo District.

Maize is usually grown on land with low yield potential [21] and soil fertility, thereby causing low productivity [22]. Moreover, land productivity is determined by quality and characteristics [23, 24], while land quality has a close relationship with maize yields [25]. The land quality affecting the optimum yield of maize needs to be determined [26] and increased by using hybrid varieties that have high yields. This makes it necessary to evaluate the suitability of the hybrid maize in a region to ensure optimal production. The land suitability criteria for hybrid maize are not yet available because the current criterion is the general suitability of maize plants without distinguishing between hybrids and inbreds. Therefore, there is a need to make land suitability criteria for hybrid maize plants.

A previous study has shown that land quality has a significant effect on suitability for certain uses [27]. Meanwhile, land suitability is also important due to the continuous increase in the demand for agricultural land [28]. The land suitability criteria for existing maize fields are still general [29], and there are no specific criteria for hybrid maize varieties. The class assessment outcomes obtained using the existing criteria are relatively many and are not in line with the actual field results [30]. The current criteria consist of 3 components, namely, land quality, characteristics, and ranges of land characteristic values to determine its suitability. Therefore, the problem in developing criteria is choosing land quality, characteristics, and determining the range of land characteristic values associated with suitability classes, namely, suitable, somewhat suitable, marginally suitable, and not suitable.

The selection of land quality and characteristics can be carried out through the partial least square of the structural equation model (PLS-SEM), while the range limits are being determined by the boundary line method. Land qualities and characteristics in the current criteria can be used temporarily since structural equation model analysis with partial least squares produces better indicators and models than other multivariate analyses [31–35]. This is because the variant-based PLS-SEM has a higher level of flexibility and the size of the sample used is relatively small ranging from 30 to 100 [36–39]. The use of PLS-SEM to determine land characteristics and qualities that control maize crop yields is still relatively rare, except for Syaf [40] on older cocoa plants, maize composite [41], and on local varieties [6]. The boundary line method can help determine nutrient adequacy concentrations and the optimum yield range of a plant that affects nutrients, as well as other land characteristics [42, 43]. Currently, the land suitability criteria for maize plants have not been determined using the boundary line method, except by Ridayanti et al. [44], although the investigation was not specific to hybrid maize.

After obtaining the quality and characteristics of land affecting maize yields with PLS-SEM, the boundary line method can be used to determine the optimum yield as well as land suitability criteria simultaneously. This is carried out by drawing the intersection of the boundary line at the yield and projecting with the land characteristics [29]. Therefore, this study aims to determine land suitability criteria for hybrid maize in Boalemo Regency based on the optimum yield and land quality.

2. Materials and Methods

2.1. Study Area. The study area extends from 0°28′5.6″–0″57′30.02″ N to 122°8′34.25″–122°43′10.41″E (Figure 1) on a scale of 1 : 40,000, which is located in the agricultural land of Boalemo Regency, Gorontalo Province, Indonesia. The maximum air temperature was 28.19°C and the minimum was 26.79°C with an average of 28.01°C. Meanwhile, the maximum rainfall was 1,849 mm and the minimum was 1,246 mm with an average of 1,478 mm [45]. The wet and dry seasons last for 3 months and 5 months, respectively. The soil mapping carried out by Ritung et al. [46] at a scale of 1 : 50,000 become the initial reference for determining 35 soil units, where each unit has information on land characteristics, namely, effective depth, drainage, texture, pH, cation exchange capacity, base saturation, landform, parent material, relief, and land unit area. Meanwhile, the new soil unit is 1 : 40,000 in scale, and there has been a change in the agricultural land use existing. This indicated that the slope class of 8–15% or hilly is more dominant in the study area with a percentage of 29.77% and slopes >40% or mountainous which is only 2.67%. Furthermore, the dry land is dominant with a value of 59.86% and a little shrub which was only 9.21%, while the dominant Typic Haplustalfs of soil subgroup classification was 22.47%; then, the Fluventic Haplustepts was 21.31% and very little Vertic Haplustepts of soil subgroup classification was 0.04% only (Figure 1).

2.2. Dataset Collection for Land Quality and Land Characteristics. The quality and characteristics of the land in this study refer to Wahyunto et al. [47], consisting of 10 land qualities and 24 characteristics. The set of temperature land

SPT	Slopes (%)	Relief	Land Use	Soil Types	Elevation (m asl)	Area (Ha)
1	0 - 3	Flat	Plantation	Typic Endoaquepts	100 - 250	156.78
2	0 - 3	Flat	Plantation	Vertic Haplustepts	100 - 250	26.92
3	3 - 8	Wavy	Plantation	Typic Haplustalfs	0 - 100	4,756.57
4	3 - 8	Wavy	Plantation	Aquic Haplustepts	100 - 250	48.15
5	3 - 8	Wavy	Upland	Typic Haplustepts	100 - 250	91.77
6	3 - 8	Wavy	Plantation	Typic Haplustults	0 - 100	684.95
7	3 - 8	Wavy	Upland	Typic Haplustepts	100 - 250	249.07
8	3 - 8	Wavy	Plantation	Typic Haplustults	100 - 250	129.12
9	3 - 8	Wavy	Plantation	Aquic Haplustepts	0 - 100	3.51
10	8 - 15	Wavy	Plantation	Typic Rhodustalfs	100 - 250	65.54
11	8 - 15	Wavy	Upland	Typic Haplustalfs	100 - 250	471.97
12	8 - 15	Wavy	Upland	Lithic Haplustolls	0 - 100	302.43
13	8 - 15	Wavy	Plantation	Typic Haplustults	0 - 100	1,412.81
14	8 - 15	Wavy	Upland	Typic Haplustepts	0 - 100	1,071.76
15	8 - 15	Wavy	Plantation	Typic Haplustalfs	100 - 250	297.87
16	8 - 15	Wavy	Scrub	Typic Haplustepts	100 - 250	254.62
17	8 - 15	Wavy	Upland	Typic Haplustalfs	250 - 500	853.23
18	8 - 15	Wavy	Plantation	Lithic Haplustepts	100 - 250	3,304.32
19	8 - 15	Wavy	Scrub	Typic Haplustults	100 - 250	793.13
20	8 - 15	Wavy	Upland	Typic Haplustepts	100 - 250	3,293.28
21	8 - 15	Wavy	Plantation	Typic Haplustults	250 - 500	364.88
22	8 - 15	Wavy	Scrub	Typic Haplustalfs	100 - 250	165.87
23	8 - 15	Wavy	Upland	Typic Haplustults	100 - 250	2,038.84
24	8 - 15	Wavy	Plantation	Aquic Haplustepts	0 - 100	169.98
25	8 - 15	Wavy	Upland	Typic Haplustalfs	100 - 250	349.74
26	15 - 30	Hilly	Scrub	Lithic Haplustolls	100 - 250	749.22
27	15 - 30	Hilly	Upland	Typic Haplustalfs	250 - 500	1,528.98
28	15 - 30	Hilly	Upland	Typic Haplustults	100 - 250	3,748.72
29	15 - 30	Hilly	Upland	Lithic Haplustolls	100 - 250	434.63
30	15 - 30	Hilly	Upland	Lithic Haplustalfs	250 - 500	3,908.31
31	15 - 30	Hilly	Scrub	Typic Haplustepts	250 - 500	154.35
32	15 - 30	Hilly	Scrub	Lithic Haplustalfs	250 - 500	1,474.02
33	> 45	Mountainous	Scrub	Lithic Haplustolls	100 - 250	229.51
34	> 45	Mountainous	Upland	Lithic Haplustalfs	100 - 250	853.11
35	> 45	Mountainous	Scrub	Typic Rhodustalfs	0 - 100	86.40
36	8 - 15	Hilly	Plantation	Typic Haplustalfs	0 - 100	254.52
37	> 45	Mountainous	Scrub	Fluventic Ustropepts	0 - 100	286.81
38	> 45	Mountainous	Scrub	Typic Haplustalfs	250 - 500	27.33
39	> 45	Mountainous	Upland	Fluventic Ustropepts	250 - 500	101.55
40	0 - 3	Flat	Plantation	Pluventic Haplustepts	0 - 100	3,052.35
41	0 - 3	Flat	Upland	Pluventic Haplustepts	0 - 100	3,834.11
42	0 - 3	Flat	Upland	Typic Argiustolls	0 - 100	1,072.70
43	0 - 3	Flat	Upland	Typic Tropaquepts	100 - 250	65.04
44	15 - 30	Hilly	Plantation	Fluventic Ustropepts	250 - 500	1,043.31
45	15 - 30	Hilly	Scrub	Typic Argiustolls	100 - 250	791.23
46	15 - 30	Hilly	Scrub	Typic Haplustalfs	0 - 100	53.32
47	15 - 30	Hilly	Upland	Fluventic Ustropepts	100 - 250	336.36
48	15 - 30	Hilly	Upland	Pluventic Haplustepts	250 - 500	705.51
49	15 - 30	Hilly	Upland	Typic Argiustolls	250 - 500	2,196.41
50	15 - 30	Hilly	Upland	Typic Haplustalfs	0 - 100	104.35
51	15 - 30	Hilly	Upland	Typic Haplustalfs	250 - 500	871.02
52	15 - 30	Hilly	Upland	Typic Haplusteps	100 - 250	28.16
53	15 - 30	Hilly	Upland	Typic Tropaquepts	0 - 100	89.21
54	3 -8	Wavy	Plantation	Pluventic Haplustepts	0 - 100	1,442.70
55	3 -8	Wavy	Plantation	Typic Argiustolls	100 - 250	1,475.90
56	3 -8	Wavy	Scrub	Typic Haplustalfs	250 - 500	413.33
57	3 -8	Wavy	Upland	Pluventic Haplustepts	250 - 500	3,864.27
58	3 -8	Wavy	Upland	Typic Argiustolls	0 - 100	151.63
59	3 -8	Wavy	Upland	Typic Dystrudepts	0 - 100	63.14
60	3 -8	Wavy	Upland	Typic Haplustalfs	250 - 500	2,054.29
61	30 - 45	Mountainous	Plantation	Typic Haplustalfs	100 - 250	52.44
62	30 - 45	Mountainous	Scrub	Typic Haplustalfs	100 - 250	63.05
63	30 - 45	Mountainous	Upland	Typic Haplustalfs	0 - 100	48.35
64	30 - 45	Mountainous	Upland	Typic Haplustalfs	100 - 250	171.54
65	8 - 15	Hilly	Upland	Typic Argiustolls	0 - 100	136.96
66	8 - 15	Hilly	Upland	Typic Haplustalfs	250 - 500	1,063.61
67	8 - 15	Hilly	Upland	Typic Haplusteps	250 - 500	79.96
Total						60,518.81

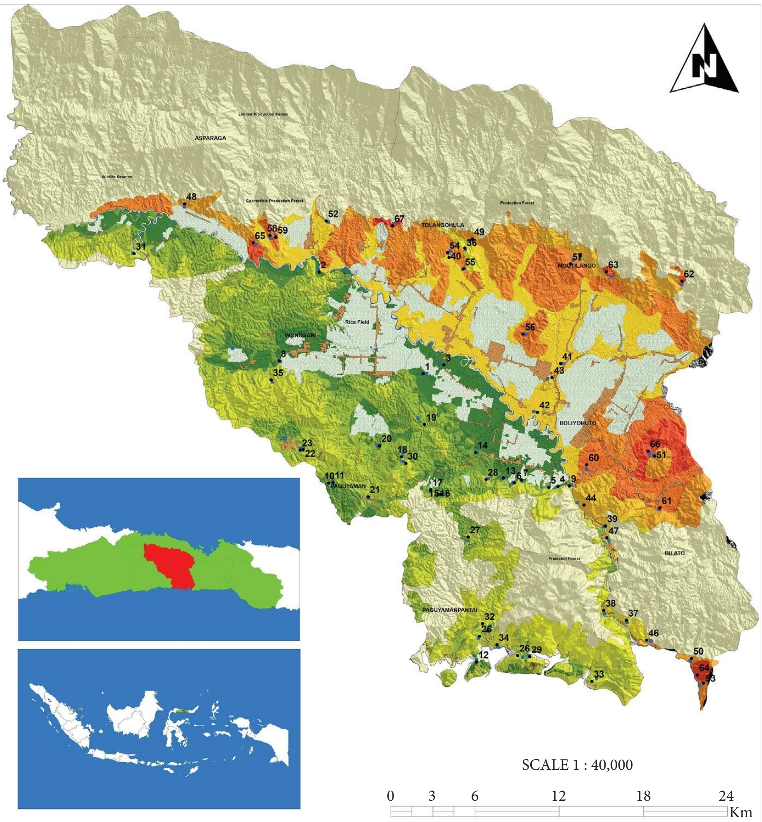

Figure 1: Study area.

quality is determined from the characteristics of the annual average air temperature, while the land quality water availability is determined from the characteristics of annual rainfall, wet months, dry months, and the length of the growth period (LGP). Land quality oxygen availability is determined from soil drainage characteristics, rooting conditions are determined from the soil texture, coarse material, and soil effective depth, and nutrient retention is identified from the pH value, C-organic, cation exchange capacity (CEC), and base saturation. Furthermore, the available nutrient is determined from the characteristics of total N, P, and exchangeable K, the sodicity is obtained from the exchangeable sodium percentage (ESP), while erosion hazard is determined from slopes and soil erosion. The quality of the flood-hazard land is determined by identifying the height and the duration of the inundation, while preparation is carried out from the characteristics of outcrops and surface rocks. The selection of this set of land qualities and characteristics is based on the availability of data and their impact on maize production [26].

Data on average annual air temperature and rainfall for 10 years (2010–2021) were collected from different climate stations, namely, the Bandungrejo with 0°41′ N–122°38′ E, the elevation 40 m asl, while Harapan has 0°42′ N–122°29′ E and an elevation of 37 m asl. It also includes Lakeya Rain Post with 0°42.82′ N–122°32.07′ E, 32 m asl, Mohiyolo has 0°46.41′ N–122°26.41′ E and an elevation of 39 m asl, Saritani 0°46.45′ N–122°20.40′ E, with 26 m asl, Tangkobu 0°37.25′ N–122°36.36′ E, 25 m asl, Bubaa 0°31.36′ N–122°33.39′ E, 16 m asl, Wonggahu 0°38′ N–122°33′ E, 35 m asl, and Sambati Rain Post with 0°31.184′ N–122°27.074′ E, and an elevation of 9 m asl managed by BWS II Sulawesi. Furthermore, these data determined wet months (>200 mm) and dry months (<100 mm), which refers to the Oldeman and Darmiyati criteria [48]. The land water balance was determined using the Thornwaite and LGP methods based on the number of surplus and deficit rainy days [49].

Based on the previous soil unit [46], then these soil units were detailed again by adding 32 of soil units to be surveyed and observed, making up to 67 soil units in the area as shown in the legend Figure 1. Soil characteristics such as drainage, coarse material, effective soil depth, slope, inundation height and duration, rock outcrops, and surface rocks were determined by conducting soil profile descriptions and direct observation on 67 pedons referring to the description guidelines in the field [50]. Meanwhile, soil erosion was determined by the USLE method [51]. Other soil characteristics were further analyzed in the soil laboratory using samples from each pedon.

Soil samples were dried for 3 days and sieved through a 2-mesh sieve. The method of soil physics laboratory analysis was carried out according to the procedures by

Kurnia et al. [52]. Based on this procedure, soil texture was analyzed in terms of sand, clay, and silt fractions using the pipette method, while soil moisture storage was evaluated using the gravimetric method that can be applied in water balance analysis. The method of soil chemistry laboratory analysis was carried out according to the procedures by Eviyati and Sulaiman [53]. The soil pH was determined with a pH meter in a 1 : 2.5 soil and water solution, while the organic C content was assessed using the Walkley and Black method. The total N was assessed using the Kjeldahl method, while the available P content was measured using the Olsen method. The basic cations and CEC were extracted with 1N NH_4OAc pH 7.0 (ammonium acetate) on a dry sample of 105°C. The base saturation was determined by calculating the percentage of basic cations number with CEC, and ESP was evaluated using the percentage ratio of sodium to CEC [54, 55]. Subsequently, the data from the chemical analysis were averaged to a depth of 0–30 cm using the weighted averaging technique. The framework of this study is presented in Figure 2.

2.3. Dataset Collection for Hybrid Maize Yield. The areas currently planted with hybrid maize were identified and blocks with a size of 2.5 m × 2.5 m were made in each map unit (Figure 1). Maize plants in each block passed through standardized management according to farmers' technology. After harvesting, weighting was carried out to obtain hybrid maize yield data from the results of tiles on each land unit. Subsequently, the results were calculated using the following formula [56]:

$$Y(t) = H\ x \frac{A}{6.25\,m^2}. \quad (1)$$

Meanwhile, productivity is calculated using the following formula [56]:

$$Y\left(tha^{-1}\right) = \frac{H\ x\ 1.64\ x\ 56.73}{100}, \quad (2)$$

where Y is the hybrid maize yield, H is the tile yield (kg), A is the maize area 1 per hectare (ha), and 1.64 and 56.73 are the constants.

2.4. Selection of Land Quality and Land Characteristics. The quality and characteristics of the land in the suitability criteria are used as presented in Tables 1 and 2, which show brief statistics. Generally, most data are relatively homogenous, except for coarse material, available P, slopes, soil erosion, height and inundation, as well as rock outcrops and surface rocks. The selection used the partial least squares of the structural equation model (PLS-SEM) refers to Hair et al. [38] with tools SmartPLS, where land quality and characteristics were selected as the latent and manifest variables, respectively. The analysis in PLS-SEM has 2 main steps, namely, the measurement model (outer model) and the structural model test (inner model).

Step 1 consists of validity and reliability tests, wherein the validity test is conducted with convergent and discriminant validity. The convergent validity is in form of outer loadings (loading factor) and average variance extracted (AVE), while discriminant validity is in form of cross-loading and the Fornell–Larcker criterion. Meanwhile, the reliability test uses composite reliability and Cronbach's alpha.

Convergent validity was observed from the magnitude of the outer loading and the AVE value of each indicator on the latent variable. The validity was calculated according to the following equation [57–60]:

$$\begin{aligned} x_i &= \lambda x_i \xi_1 + \delta_i, \\ y_i &= \lambda y_i \eta_1 + \varepsilon_i, \end{aligned} \quad (3)$$

where x and y are the exogenous (ξ) and endogenous (η) latent variable indicators, λ_x and λ_y are the loading factors, δ and ε are the residual/measurement errors or noise.

Meanwhile, the average variance extracted (AVE) value was calculated using the following equation [61–65]:

$$\text{AVE} = \frac{\sum \lambda^2 i}{\sum \lambda^2 i + \sum i \text{var}(\varepsilon_i)}, \quad (4)$$

where λ_i^2 is the loading factor, var is the variance, and ε_i is the error variance.

The loading factor of an indicator with the highest value is the strongest or most important measure in reflecting the latent variable. In this study, the loading factor value is >0.70 for selecting best land characteristics, but values ranging from 0.50 to 0.60 can still be tolerated with a t-statistic >1.96 or a small p value of 0.05 [37, 66]. Meanwhile, the AVE value used was more than 0.50, showing that the convergent validity on the latent variable has been reached.

The discriminant validity test used the cross-loading value and the Fornell–Larker criterion to test discriminantly valid indicators in explaining or reflecting latent variables. When the correlation between the latent variables and the core measurement of each indicator is high, the latent variable can predict the indicator better and is considered valid. The discriminant validity is measured by the square root of the average variance extracted, which will be compared with the correlation value between variables. The value calculated based on the square root of AVE must be higher than the correlation between constructs [61]. The equation is expressed as follows [61, 63–65, 67]:

$$\text{Square root of AVE} = \sqrt{\frac{\sum \lambda^2 i}{\sum \lambda^2 i + \sum i\ \text{var}(\varepsilon_i)}}, \quad (5)$$

where λ_i^2 is the loading factor, var is the variance, and ε_i is the error variance.

Furthermore, the composite reliability and Cronbach's alpha were used to test the reliability value between indicators of the latent variables. They are considered good and accepted when the value is >0.70 and has a minimum value of 0.60 [37]. The composite reliability value is calculated using the following equation [62, 65, 68, 69]:

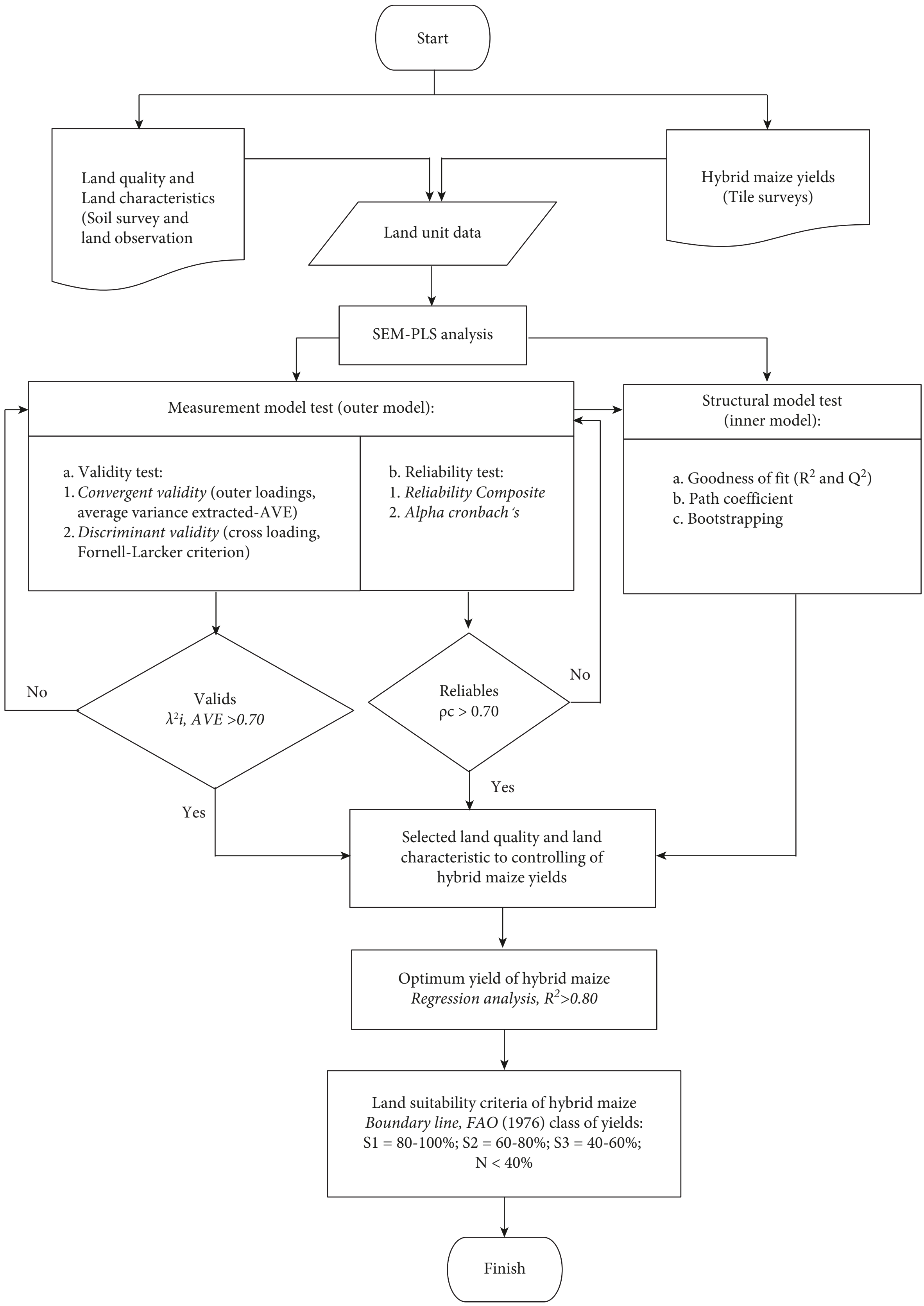

Figure 2: Research framework.

Table 1: Latent variables and indicators used in this study.

Latent variables		Indicators		
Notation	Land quality	Notation	Land characteristics	Data sources
X1	Temperature (t)	X1.1	Temperature	[45]
X2	Water availability (wa)	X2.1	Rainfall	[45]
		X2.2	Wet month	Rainfall >200 mm
		X2.3	Dry month	Rainfall <100 mm
		X2.4	Long growth period (LGP)	Water balance (Thornwaite method), soil moisture storage (gravimetric method), water surplus, and deficit days
X3	Oxygen availability (oa)	X3.1	Drainage	Soil survey and land observation
X4	Rooting condition (rc)	X4.1	Texture	Pipet method
		X4.1.1	Sand fraction	
		X4.1.2	Silt fraction	
		X4.1.3	Clay	
		X4.2	Coarse material	Soil survey and land observation
		X4.3	Effective depth	
X5	Nutrient retention (nr)	X5.1	pH, H_2O	pH meter (1 : 2.5)
		X5.2	pH, KCl	
		X5.3	Organic C	Walkley and Black method
		X5.4	Cation exchange capacity (CEC)	1N NH_4OAc, pH 7.0, extracted
		X5.5	Base saturation	Calculation
X6	Nutrient availability (na)	X6.1	Total *N*	Kjeldahl method
		X6.2	*P* availability	Olsen method
		X6.3	*K* exchangeable	1N NH_4OAc, pH 7.0, extracted
X7	Sodicity (xn)	X7.1	Exchangeable sodium percentage (ESP)	Calculation
X8	Erosion hazard (eh)	X8.1	Slopes	Soil survey and land observation
		X8.2	Soil erosion	
X9	Flooding hazard (fh)	X9.1	Inundation height	Soil survey and land observation
		X9.2	Inundation period	
X10	Land preparation (lp)	X10.1	Rock outcrops	Soil survey and land observation
		X10.2	Surface rock	
Y	Hybrid maize yield	Y.1	Hybrid maize yield	Tile box methods

Table 2: Brief statistics of land quality and characteristics.

Latent variables/indicators	Unit	n	Min	Median	Mean	Max	SD
X1 (temperature)							
X1.1 (temperature)	°C	67	26.79	27.80	28.01	28.19	0.63
X2 (water availability)							
X2.1 (rainfall)	Mm	67	1,246.00	1,533.42	1,478.00	1,849.00	232.69
X2.2 (wet month)	Month	67	0.00	1.03	1.00	3.00	0.85
X2.3 (dry month)	Month	67	2.00	3.39	4.00	5.00	1.06
X2.4 (LGP)	Day	67	211.00	246.00	214.00	304.00	44.54
X3 (oxygen availability)							
X3.1 (drainage)	Class	67	0.00	3.76	4.00	6.00	1.82
X4 (rooting conditions)							
X4.1 (texture)	Class	67	1.00	2.21	2.00	5.00	0.99
X4.1.1 (sand fraction)	%	67	5.00	41.58	43.00	81.33	18.51
X4.1.2 (silt fraction)	%	67	7.33	27.31	24.50	51.50	11.54
X4.1.3 (clay)	%	67	11.33	31.90	30.00	56.33	12.72
X4.2 (coarse material)	%	67	5.00	17.27	10.00	70.00	16.58
X4.3 (effective depth)	Cm	67	10.00	74.55	74.00	160.00	36.40
X5 (nutrient retention)							
X5.1 (pH, H_2O)		67	5.00	5.92	5.90	7.15	0.52
X5.2 (pH, KCl)		67	4.35	5.24	5.17	6.60	0.56
X5.3 (organic C)	%	67	0.41	0.85	0.77	2.35	0.39
X5.4 (CEC)	Cmol(+)/kg	67	8.94	24.89	22.43	59.57	11.41
X5.5 (base saturation)	%	67	45.03	56.22	52.85	81.89	9.76
X6 (nutrient availability)							
X6.1 (total N)	%	67	0.04	0.09	0.08	0.27	0.04
X6.2 (P availability)	Mg/kg	67	0.73	8.62	3.77	58.67	12.61
X6.3 (K exchangeable)	Cmol(+)/kg	67	0.07	0.39	0.24	1.92	0.42
X7 (sodicity)							
X7.1 (ESP)	%	67	0.76	7.06	6.20	24.17	5.62
X8 (erosion hazard)							
X8.1 (slopes)	%	67	1.00	9.58	6.00	25.00	7.29
X8.2 (soil erosion)	Tons/ha/year	67	3.66	334.51	110.27	1772.43	439.08
X9 (flooding hazard)							
X9.1 (inundation height)	Cm	67	0.00	7.58	0.00	50.00	17.10
X 9.2 (inundation period)	Day	67	0.00	0.64	0.00	5.00	1.52
X10 (land preparation)							
X10.1 (rock outcrops)	%	67	0.00	6.64	0.00	45.00	11.56
X10.2 (surface rock)	%	67	0.00	6.58	0.00	45.00	11.59
Y (hybrid maize yield)	Ton/ha	67	2.85	4.95	4.68	8.07	1.15

n, the number of the land unit; min, minimum; max, maximum; SD, standard deviation; LGP, long growth period; CEC, cation exchange capacity; ESP, exchangeable sodium percentage.

$$\rho c = \frac{\left(\sum \lambda_i\right)^2}{\left(\sum \lambda_i\right)^2 + \sum i \operatorname{var}\left(\varepsilon_i\right)}, \quad (6)$$

where λ_i is the loading factor, var is the variance, and ε_i is the error variance.

Meanwhile, the value of Cronbach's Alpha is calculated according to the following equation [65, 70]:

$$\alpha = \left(\frac{\sum p \neq p'^{\operatorname{cor}\left(X_{pq}\cdot X_{p'q}\right)}}{p_q + \sum p \neq p'^{\operatorname{cor}\left(X_{pq}\cdot X_{p'q}\right)}}\right)\left(\frac{p_q}{p_{q-1}}\right), \quad (7)$$

where P_q is the number of indicators or manifest variables and q is the indicator block.

For step 2, the structural model testing (inner model) was carried out after the relationship model was built in line with the observed data and the overall suitability, namely, goodness of fit. The structural equation (inner model) is as follows [59, 60, 62]:

$$\mathrm{H}_j = \gamma_j\xi_1 + \gamma_j\xi_2 + \ldots \gamma_j\xi_n + \varsigma_j, \quad (8)$$

where η_j is the endogenous variable vector (dependent), $\gamma_j\xi_1 + \gamma_j\xi_2 + \ldots \gamma_j\xi_n$ is the exogenous latent variable vector, and ς_j is the residual vector (error).

Meanwhile, the determinant coefficient and goodness of fit (Q^2) were calculated using the following equation [62, 64, 70]:

$$Q^2\,(\text{Predictive relevance}) = 1-\left(1-\mathrm{R}_1^2\right)\left(1-\mathrm{R}_2^2\right)\ldots\left(1-\mathrm{R}_\mathrm{p}^2\right), \quad (9)$$

where $R_1^2, R_2^2, \ldots R_p^2 = R$ square of endogenous variables in the equation model [68].

The quantity of Q^2 has a value with a range of $0 < Q^2 < 1$, the closer the value to 1, the better the model [37]. It is also equivalent to the coefficient of total determination in path analysis. Furthermore, the effect and significance were tested based on the estimated value of the path coefficient and the critical point value (t-statistics or p value) at = 0.05. The relationship model between variables was measured by testing the direct correlation coefficient between variables. The results of testing the relationship between X and Y variables were indicated by the correlation coefficient, as well as t-statistics, and are also presented in the path diagram.

2.5. Class Assignment. To determine the class-required data for optimum results, class limits were calculated from the percentage of optimum results. After knowing the highest and lowest yields, the values were connected with the range of land characteristics values. The land suitability class and yield used referred to FAO [71], namely, class S1 (very suitable) when the values reach 80–100%, S2 was moderately suitable 60–80%, S3 marginally suitable 40–60%, and N not suitable <40% of the optimum capacity.

The optimum yield was determined using the boundary line method. This method is carried out by drawing a boundary line on the graph of the relationship between yield and land characteristics to obtain optimum results. In the boundary line method according to Widiatmaka et al. [72], each land characteristic is plotted on the X-axis, while hybrid maize yields are plotted on the Y-axis. Bhat and Sujatha [42] stated that the preparation of the hybrid maize yield boundary line includes the preparation of a scatter diagram between the X and the Y variable, division of the X-axis into several classes of intervals, determination of the highest data points in each class interval, preparation of boundary lines based on the highest data points from each class interval, and drawing a line parallel to the X-axis according to the percentage of the result class.

Furthermore, with the Microsoft Excel application tools, the boundary between classes S1 to S2, S2 to S3, and S3 to N were determined by the Data menu ⟶ What-if-Analysis ⟶ Goal Seek ⟶ Set the cell at the location containing the regression equation ⟶ to value fill with the result limit values S1 to S2, S2 to S3, and S3 to N ⟶ By changing cell ⟶ the location where the value of the characteristics of the land will be sought ⟶ Ok. On location “By changing cell,” the number being searched will appear, and at the location, “set cell” will be equal to the limit value of the result.

3. Results and Discussion

3.1. Land Quality and Characteristics Controlling Hybrid Maize Yield

3.1.1. Validity Test Result. Table 3 shows the loading factor of the variables, where most indicators were more than the critical limit of 0.70 with a 95% confidence level ($P > 1.960$). Therefore, these variables are highly recommended and the indicators are considered convergently valid. In the soil texture indicator for the latent variable of root conditions as well as the cation exchange capacity (CEC) and base saturation (BS) indicators for nutrient retention, the loading factor was below the tolerance value of 0.50 at the 95% confidence level ($P < 1.960$); hence, it was not used. This implies that the indicators have not been established or explained properly because the standard value of the loading factor must be greater than or equal to 0.50 [37, 38, 66].

The average variance extracted (AVE) value of almost all variables was greater than 0.50; therefore, it was considered convergently valid [61, 62]. The AVE value of the available nutrient variable was not valid due to the smaller value of the loading factor for the CEC and BS indicators of 0.50, leading to the removal of both indicators. A similar result was discovered in the root condition variable, although the AVE value was greater than 0.50, while the soil texture indicator was not used because the loading factor value is only 0.013.

The measurement of the Fornell–Larcker criterion and cross-loading was used as the basis for assessing the discriminant validity of the model. The calculation results on the Fornell–Larcker criterion in Table 4 show that the average of the tested variables has a higher square root of AVE than the correlation value; hence, the latent variable was considered discriminantly valid. The square root value of the AVE must be greater than its correlation value with other constructs to meet the discriminant validity requirements [69, 73]. The average loading factor value for the latent variable indicator was above that of others as shown in Table 5.

3.1.2. Reliability Test Result. The variables are considered reliable because composite reliability and Cronbach’s alpha coefficient on average were more than 0.7 [61, 74], as shown in Table 6. However, certain indicators still had values less than 0.6, namely, soil texture, but the indicators used are reliable and adequate in forming the latent variables.

The highest composite reliability and Cronbach’s alpha coefficients were obtained for the variables of temperature, oxygen availability, and toxicity of 1 for the variables to be very reliable. The lowest coefficient was obtained on the root condition variable; therefore, the variable was not reliable. According to Bagozzi and Yi [75] and Hair et al. [74], variables are considered good and accepted when the value is >0.70.

The remaining variables are water availability, nutrient retention, available nutrients, erosion hazard, and land preparation variables. The coefficient of composite reliability and Cronbach’s alpha >0.6; therefore, the variable is considered reliable. The minimum value of composite reliability and Cronbach’s alpha coefficients was 0.60 [61, 74, 75].

3.1.3. Structural Model Test (Inner Models). Land characteristics that have a significant correlation with hybrid maize yields show a high level of contribution to land quality in influencing hybrid maize yields as indicated in Figure 3. The figure shows a structural model of the relationship between indicator variables, namely, 24 land characteristics, rectangular yellow, and latent variables, including 10 land qualities maize yield and oval blue. It also shows a model for

Table 3: Outer loading (loading factor) and the average variance extracted from study variables.

Indicators (land characteristics)		Latent variables (land quality)	Loading factors	t stat	Status	AVE
X1.1 (temperature)	⟶	X1 (temperature)	1.000**	11.192	Valid	1.000
X2.1 (rainfall)	⟶		0.838	0.085	Valid	
X2.2 (wet month)	⟶	X2 (water availability)	0.989	0.999	Valid	0.906
X2.3 (dry month)	⟶		0.850	0.428	Valid	
X2.4 (LGP)	⟶		0.993*	1.431	Valid	
X3.1 (drainage)	⟶	X3 (oxygen availability)	1.000	0.000	Valid	1.000
X4.1 (texture)	⟶		0.013	0.066	Invalid	
X4.2 (coarse material)	⟶	X4 (rooting condition)	0.921	1.086	Valid	0.573
X4.3 (effective depth)	⟶		−0.899	1.047	Valid	
X5.1 (pH, H_2O)	⟶		0.647	0.857	Valid	
X5.2 (pH, KCl)	⟶		0.570**	1.973	Valid	
X5.3 (organic C)	⟶	X5 (nutrient retention)	0.831**	3.135	Valid	0.360 (invalid)
X5.4 (CEC)	⟶		0.436*	1.381	Invalid	
X5.5 (base saturation)	⟶		0.365	0.845	Invalid	
X6.1 (total N)	⟶		0.760**	3.226	Valid	
X6.2 (P availability)	⟶	X6 (nutrient availability)	0.587*	1.385	Valid	0.585
X6.3 (K exchangeable)	⟶		0.897**	6.907	Valid	
X7.1 (ESP)	⟶	X7 (sodicity)	1.000	0.000	Valid	1.000
X8.1 (slopes)	⟶	X8 (erosion hazard)	0.954**	21.438	Valid	0.932
X8.2 (soil erosion)	⟶		0.941**	18.308	Valid	
X9.1 (inundation height)	⟶	X9 (flooding hazard)	0.984**	4.213	Valid	0.984
X9.2 (inundation period)	⟶		0.985**	3.918	Valid	
X10.1 (rock outcrops)	⟶	X10 (land preparation)	0.998**	189.133	Valid	0.995
X10.2 (surface rock)	⟶		0.998**	320.273	Valid	

AVE, average variance extracted; LGP, long growth period; CEC, cation exchange capacity; ESP, exchangeable sodium percentage.

Table 4: Fornell–Larker criterion test.

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	Y
X1	1.000										
X2	0.940	0.952									
X3	0.059	0.149	1.000								
X4	0.082	0.030	−0.162	0.757							
X5	−0.360	−0.239	−0.103	−0.368	0.600						
X6	−0.069	0.021	0.012	−0.518	0.694	0.765					
X7	0.382	0.429	0.084	0.228	−0.030	−0.217	1.000				
X8	0.019	−0.082	−0.501	0.285	−0.317	−0.370	−0.009	0.966			
X9	−0.104	−0.033	0.237	−0.204	0.073	0.090	0.202	−0.250	0.992		
X10	0.198	0.093	−0.223	0.873	−0.303	−0.538	0.362	0.304	−0.126	0.998	
Y	0.018	0.152	0.169	−0.578	0.387	0.456	−0.016	−0.517	0.164	−0.568	1.000

X1, temperature; X2, water availability; X3, oxygen availability; X4, rooting condition; X5, nutrient retention; X6, nutrient availability; X7, sodicity; X8, erosion hazard; X9, flooding hazard; X10, land preparation; Y, maize hybrid yield.

the relationship between latent variables such as land qualities and maize yield, as well as loading figures. The factor for each indicator and path coefficient for land qualities has a direct effect on the value of maize yields.

For example, X8 (erosion hazard) significantly determines the hybrid maize yield with a path coefficient of −0.392. The negative sign indicates that the erosion hazard is negatively related to maize yield, where the higher the erosion hazard, the lower the maize yield. Furthermore, nutrient retention (X5) contributes to the diversity of hybrid maize yields with a path coefficient of 0.252. A positive sign indicates that nutrient retention is positively related to maize yield, where the higher the value of nutrient retention, followed by the maize yield.

The results of this path analysis indicated that the land quality that can be a predictor of maize yield diversity were oxygen availability (X3), nutrient retention (X5), nutrient availability (X6), erosion hazard (X8), and land preparation (X 10). Figure 2 indicates that only 8 of the 24 indicators explain latent variance at the 5% real test level. The 8 indicators were coarse material and effective soil depth as an indicator of rooting condition, organic carbon content as nutrient retention, exchangeable K as nutrient availability, soil erosion and slope as erosion hazard, as well as rock outcrop and surface rock as an indicator of land preparation. It was also indicated that the drainage loading factor was unable to explain the diversity of oxygen availability. Therefore, oxygen availability cannot be used as a land

Table 5: Cross-loading of latent variables to indicators.

Indicators	Latent Variables										
	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	Y
X1.1	1	0.8300	0.0312	0.0240	−0.2959	−0.0592	0.3270	0.0195	−0.0837	0.1680	−0.0204
X2.1	0.9783	0.8379	−0.0035	−0.0063	−0.2488	−0.0320	0.3555	−0.0017	−0.0539	0.1552	0.0155
X2.2	0.8534	0.9887	0.1938	−0.0557	−0.1257	0.0988	0.4025	−0.1435	−0.0279	−0.0178	0.1748
X2.3	0.5223	0.8497	0.1523	0.2464	−0.2505	−0.1161	0.4641	−0.1494	0.0144	0.2154	0.0592
X2.4	0.8293	0.9928	0.1721	−0.0334	−0.1524	0.0833	0.4440	−0.1713	−0.0383	−0.0031	0.1331
X3.1	0.0312	0.1785	1	−0.1541	−0.1091	−0.0375	0.0843	−0.4964	0.2530	−0.2229	0.2156
X4.1	−0.0058	−0.0006	−0.1696	0.0126	0.2127	0.1013	0.2173	0.1761	0.0055	−0.0225	0.0050
X4.2	−0.0728	−0.1082	−0.0829	0.9212	−0.2754	−0.5494	0.1845	0.2891	−0.2674	0.7910	−0.5276
X4.3	−0.1289	−0.1240	0.2071	−0.8990	0.2046	0.3209	−0.2633	−0.1587	0.0730	−0.7693	0.4666
X5.1	−0.2975	−0.4140	−0.3824	−0.3027	0.6470	0.3024	−0.1283	0.1730	−0.0342	−0.1190	0.0718
X5.2	−0.2033	−0.2939	−0.4480	−0.2791	0.5701	0.3176	−0.0273	0.1935	0.0801	−0.1829	0.1445
X5.3	−0.2440	−0.0158	0.1276	−0.1134	0.8308	0.5651	0.0728	−0.5076	0.0545	−0.1147	0.3501
X5.4	0.0537	0.1002	0.0033	0.0110	0.4360	0.4081	0.3732	−0.0504	0.1426	−0.0137	0.1395
X5.5	−0.2717	−0.2512	−0.1053	−0.4382	0.3650	0.4343	−0.6008	−0.0619	−0.1498	−0.4876	0.0825
X6.1	−0.0256	0.1778	0.0335	−0.1950	0.7028	0.7604	0.0453	−0.3878	−0.0809	−0.2162	0.2623
X6.2	−0.1201	−0.2238	−0.4256	−0.2590	0.4149	0.5865	−0.2829	−0.0389	−0.0267	−0.2860	0.1025
X6.3	−0.0437	0.0283	0.0310	−0.5607	0.5145	0.8974	−0.3341	−0.2613	0.2133	−0.6520	0.3892
X7.1	0.3270	0.4411	0.0843	0.2420	0.0290	−0.2417	1	−0.0286	0.2142	0.3621	0.0487
X8.1	−0.0226	−0.2234	−0.5132	0.2998	−0.2625	−0.3475	−0.0481	0.9537	−0.3383	0.3031	−0.5274
X8.2	0.0649	−0.0590	−0.4223	0.1646	−0.2942	−0.2950	−0.0035	0.9409	−0.0988	0.2516	−0.4682
X9.1	−0.0996	−0.0225	0.2254	−0.1949	0.1126	0.1483	0.1939	−0.2440	0.9835	−0.1342	0.2278
X9.2	−0.0658	−0.0305	0.2717	−0.1860	0.0271	0.0449	0.2271	−0.2252	0.9849	−0.0901	0.2380
X10.1	0.1848	0.0403	−0.2340	0.8480	−0.2309	−0.5544	0.3760	0.3058	−0.1188	0.9977	−0.5424
X10.2	0.1503	0.0225	−0.2107	0.8629	−0.2274	−0.5592	0.3464	0.2812	−0.1076	0.9976	−0.5365
Y.1	−0.0204	0.1413	0.2156	−0.5479	0.3425	0.3790	0.0487	−0.5271	0.2367	−0.5408	1

X1, temperature; X2, water availability; X3, oxygen availability; X4, rooting condition; X5, nutrient retention; X6, nutrient availability; X7, sodicity; X8, erosion hazard; X9, flooding hazard; X10, land preparation; Y, hybrid maize yield; X1.1, temperature; X2.1, rainfall; X2.2, the wet month; X2.3, the dry month; X2.3, long growth period; X3.1, drainage; X4.1, texture; X4.2, coarse material; X4.3, effective depth; X5.1, organic C; X5.2, cation exchanges capacity; X5.3, base saturation; X6.1, total *N*; X6.2, *P* availability; X6.3, *K* exchangeable; X7.1, the exchange sodium percentage; X8.1, slopes; X8.2, soil erosion; X9.1, inundation height; X9.2, inundation period; X10.1, rock outcrops; X10.2, surface rock; Y.1, hybrid maize yield. The yellow color shows the loading factor value for the indicators of the latent variables above the loading factor values for other latent variable indicators (>0.5), while the red color indicates the opposite (<0.5).

Table 6: Composite reliability and Cronbach's alpha test.

Indicators (land characteristics)	Cronbach's alpha	Composite reliability
X1.1 (temperature)	1.000	1.000
X2.1 (rainfall)		
X2.2 (wet month)		
X2.3 (dry month)	0.975	0.965
X2.4 (long growth periods)		
X3.1 (drainage)	1.000	1.000
X4.1 (texture)		
X4.2 (coarse material)	0.002[nor]	−1.055[nor]
X4.3 (effective depth)		
X5.1 (pH, H_2O)		
X5.2 (pH, KCl)		
X5.3 (organic C)	0.718	0.628
X5.4 (cation exchange capacity)		
X5.5 (base saturation)		
X6.1 (total *N*)		
X6.2 (*P* availability)	0.805	0.681
X6.3 (*K* exchangeable)		
X7.1 (exchangeable sodium percentage)	1.000	1.000
X8.1 (slopes)	0.965	0.928
X8.2 (soil erosion)		
X9.1 (inundation height)	0.992	0.984
X9.2 (inundation period)		
X10.1 (rock outcrops)	0.998	0.995
X10.2 (surface rock)		

nor, not reliable.

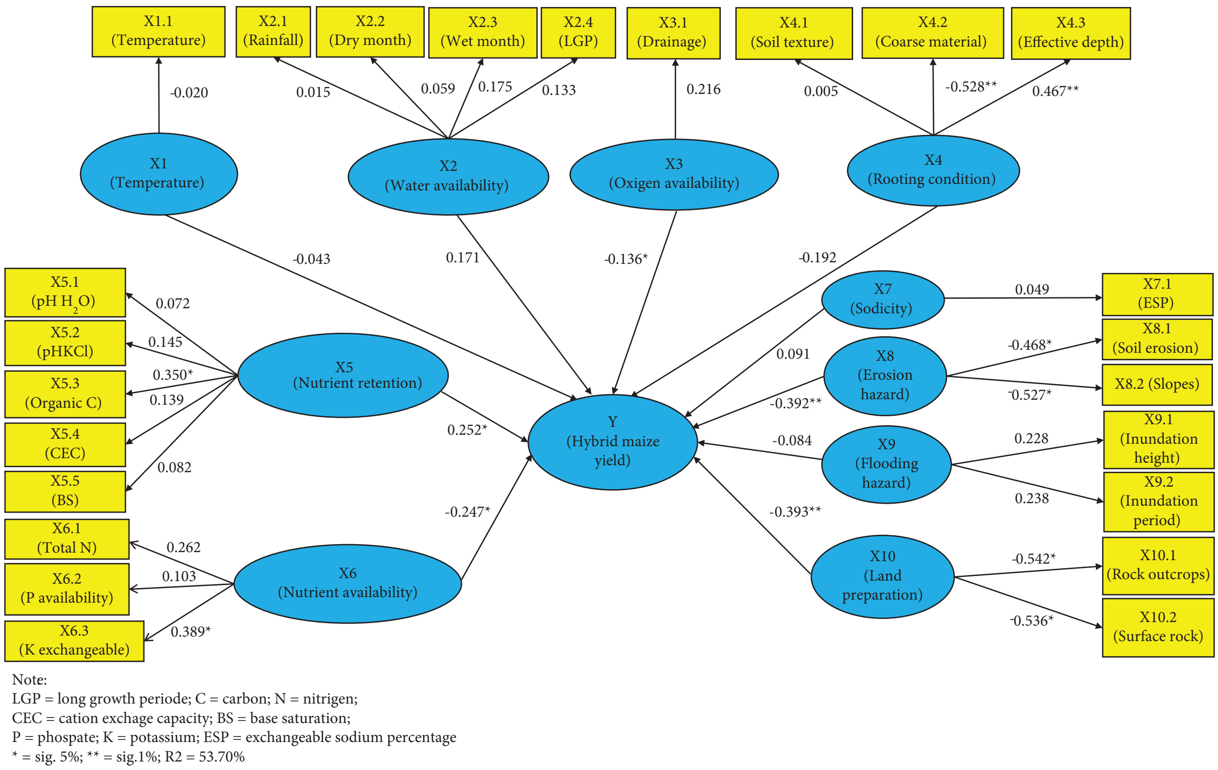

Figure 3: Path coefficient of land quality on hybrid maize yield.

quality because there are no indicators that can represent it. Only the land qualities of nutrient retention (X5), nutrient availability (x6), erosion hazard (x8), and land preparation (X10) were used next.

The indicators of land characteristics for effective depth, organic C, total *N*, and exchangeable *K* have a fairly strong positive relationship and a very significant effect on hybrid maize yields. In this relationship, an increase in these parameters by 1% will be followed by a rise in hybrid maize yields of 39% to 57.7%. According to Wirosoedarmo et al. [4], effective depth affects root growth and development, making plants grow and develop properly. Moreover, the levels of organic C, total *N*, and CEC are influenced by soil organic matter [76], while potassium plays a role in the growth and development of maize [77].

Indicators of rough soil characteristics, slopes, soil erosion, as well as surface and rock outcrops, have a strong negative relationship with a very significant effect on hybrid maize yields. In this relationship, 1% decrease in coarse material, slope, soil erosion, as well as surface, and rock outcrop is followed by an increase in hybrid maize yields by 39–57.7%.

3.2. Optimum Hybrid Maize Yield by the Land Quality and Land Characteristics. Table 7 shows the mathematical equations for each land characteristic and also the optimum hybrid maize yield for the land equation. Figure 4 shows the diagram of the relationship between land characteristics as an independent variable (*X*) and maize yield as an independent variable *Y*. Model fitting indicates that the quadratic equation is sufficient to describe the condition of data distribution.

The optimum of hybrid maize yield ranged from 5.58 to 8.54 ton/ha, where the highest yield was obtained from total *N* and slopes of 8.54 ton/ha with an R^2 value of 100% and 92%. Sutardjo et al. [78] showed that hybrid maize yields ranged from 7.43 to 9.2 ton/ha. This indicated that the optimum yield achieved is still within the range of hybrid maize yields that have been previously reported. Nitrogen is directly involved in the formation of amino acids, proteins, nucleic acids, enzymes, nucleoproteins, and alkaloids, which are needed in the plant growth process [79, 80]. An extremely high amount of *N* causes excessive vegetative growth, thereby making plants fall easily and increasing susceptibility to disease [81]. Meanwhile, the lack of *N* nutrients can limit cell division, enlargement [82], and the formation of chlorophyll, leading to stunted growth as well as yellowing of leaves [81].

The lowest optimum yield was obtained from exchangeable *K*, which was only 5.58 ton/ha with an R^2 value of 95%. This was presumably because the *K* content in the soil is very low, thereby affecting the hybrid maize yield. Potassium (K) is required by plants for physiological functions, including carbohydrate metabolism, enzyme activity, osmotic regulation, efficient water use, *N* uptake, protein synthesis, and assimilate translocation [83–86]. It also plays a role in improving the quality of crop yields [87, 83, 88].

The optimum hybrid maize yield of the remaining is relatively diverse. This includes effective depth and organic carbon, which were both 8.46 ton/ha with an R^2 value of 97%. Furthermore, coarse material and soil erosion were

Table 7: The optimum hybrid maize yield by the land quality and land characteristics.

Land quality/land characteristics	Optimum yield (ton/ha)	Yield equation	R^2
Rooting condition (rc)			
Coarse material	8.17	$Y = 0.0025900x^2 - 0.2568578x + 11.9093576$	0.96
Effective depth	8.46	$Y = -0.0008354x^2 + 0.29100569x - 1.3957496$	0.97
Nutrient retention (nr)			
Organic carbon	8.46	$Y = -25.492979x^2 + 47.9575089X - 8.9895067$	0.97
Nutrient availability (na)			
Total N	8.54	$Y = -305.5574654X^2 + 155.8690907X - 2.7439640$	1.00
K exchangeable	5.58	$Y = -10.6697409X^2 + 18.5239943X + 2.3179289$	0.95
Erosion hazard (eh)			
Slopes	8.54	$Y = 0.0183X^2 - 0.9559X + 14.806$	0.92
Soil erosion	8.17	$y = 0.0000184X^2 - 0.0198647X + 9.0537569$	0.89
Land preparation (lp)			
Rock outcrops	7.41	$Y = 0.0057496X^2 - 0.3845867X + 8.6269785$	0.92
Surface rock	7.41	$Y = 0.0057496X^2 - 0.3945867X + 8.6269785$	0.92

8.17 ton/ha with an R^2 value of 96% and 89%, while rock outcrops and surface rock were 7.41 ton/ha with an R^2 value of 92%. The absence of coarse material >2 mm in diameter indicated that plant roots can grow freely on the surface or deeper parts of the soil [89] because the deeper the roots of the maize, the greater the maize yield [90, 91]. The addition of organic matter will increase maize yield [92–94] and organic C content [95] because soil organic matter is a strong positive predictor of yield [96]. Kane et al. [96] also stated that the addition of more organic matter will improve water retention, thereby reducing maize yield losses due to drought. The slope has a significant effect on soil degradation [97]. According to a previous study, erosion and maize yield are negatively correlated; hence, increased erosion will reduce maize productivity [98]. Soil erosion on flat land is slower surface runoff [99]. It was also reported that surface rocks and outcrops are the limiting factors in the suitability of maize plantations [100]. Therefore, a high percentage of rock outcrops will complicate land cultivation and plant root growth.

3.3. Land Suitability Criteria for Hybrid Maize Crops. Table 8 shows the yield limit for each class from the calculation of the optimum yield, where the class range for each land characteristic is derived. Based on the optimum yield of the highest hybrid maize, there were 2 indicators, namely, the total N content and the slope. The total N indicator with a very suitable class (S1) was achieved when the value in the soil was greater than 0.11%, while in the moderately suitable class (S2), it was achieved when the total N in the soil ranges from 0.08 to 0.10%. In the marginally appropriate class (S3), the total N indicator was achieved when the total N in the soil ranges from 0.06 to 0.07%, while the not suitable class (N) was achieved when the content was less than 0.06%. On the slope indicator with class S1, it was obtained when the slope class ranges from 0 to 7.70%%, while class S2 was achieved when the slope class ranges from 7.71 to 11.84%. Furthermore, in classes S3 and N, it was obtained when the slope class ranged from 11.85 to 18.25% and greater than 18.25%, respectively.

Based on the optimum yield of the lowest hybrid maize, only the exchangeable K was the indicator. In classes S1 and S2, it was achieved when the exchangeable K content in the soil was greater than 0.25 cmol(+)/kg and ranges from 0.14 to 0.24 cmol(+)/kg, respectively. Furthermore, class S3 was achieved when the exchangeable K content in the soil ranges from 0.05 to 0.13 cmol(+)/kg, while in class N, it was obtained when the exchangeable K content in the soil was less than 0.05 cmol(+)/kg. The remaining variables and indicators were relatively varied according to the optimum yield of hybrid maize and the range of land suitability classes obtained as presented in Table 8.

Based on the relationship between the quality and characteristics of the selected land with optimum results, the criteria for hybrid maize land suitability were obtained as shown in Table 8. These criteria described the actual state of achieving optimum, moderate, and minimum yields of hybrid maize in the field with values of 80%, 60%, and 40%, respectively. According to Sukarman et al. [101], the parameters used in the land suitability assessment must describe the actual conditions. This is due to the significant positive correlation between maize yield and land suitability class [102].

The land suitability criteria for the new hybrid maize are fewer and have referred to the optimum yield. Meanwhile, the land quality and characteristics in this new criterion are less because it only consists of root conditions with characteristics of coarse material and effective depth, nutrient retention with organic C, and nutrient availability with total N and K exchangeable. It also consists of erosion hazards with characteristics of slopes and soil erosion, as well as land preparation with surface rocks and rock outcrops only. The land qualities selected and maize yields consistent with the land potential are the basis for developing suitability criteria. This will reduce the land characteristics and make the evaluation process faster, cheaper, and easier with accurate results [26]. Some characteristics and land quality criteria were not made because they did not significantly affect the yield of hybrid maize. The number and distribution of the data were still limited, and the diversity of values was small or not measurable in the field [72].

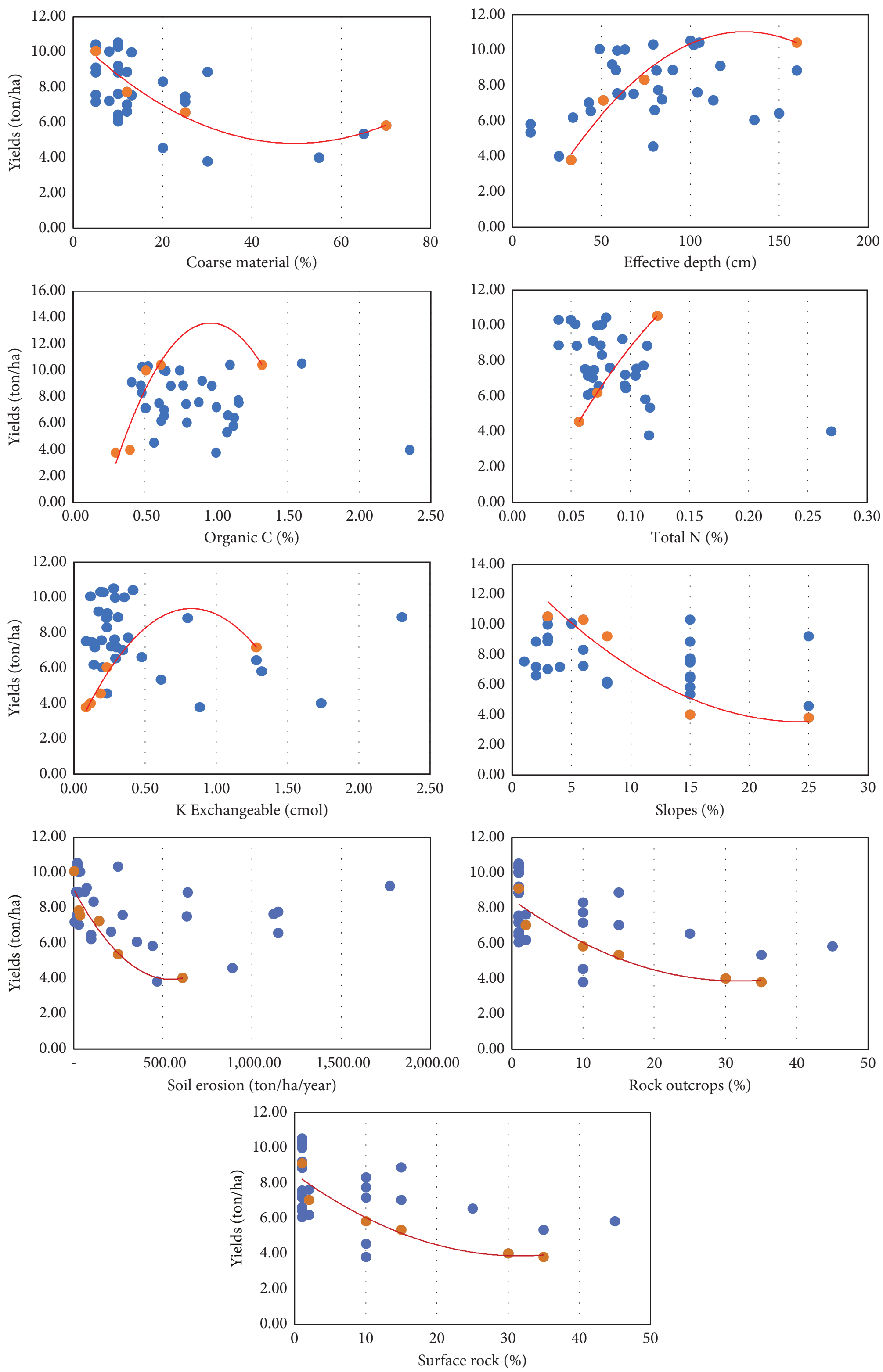

Figure 4: Scatter diagram relationship among maize yield and land characteristics.

Compared to Wahyunto et al. [47], the new land suitability criteria for hybrid maize plants in Table 9 are more realistic in value with the conditions in the field and is based on the achievement of optimum yields. The current land suitability criteria are still general and not specific to maize yields [26], although the agronomic and yield potential of each maize variety differ, based on the diversity of characteristics and land quality in the field. There are still

Table 8: Yield limits of hybrid maize and values obtained in each land suitability class interval by land quality and characteristics.

Land quality/land characteristics	Yield limits (ton/ha)			Value of land suitability criterion obtained			
	S1 – S2 (80% × Y_{optim})	S2 – S3 (60% × Y_{optim})	S3 – N (40% × Y_{optim})	S1	S2	S3	N
Rooting condition (rc)							
Coarse material (%)	8.17	6.05	4.04	0–13.51	13.51–27.48	27.48–52.41	>52.41
Effective depth (cm)	8.46	6.37	4.29	≥69.66	49.36–69.65	33.29–49.35	<33.29
Nutrient retention (nr)							
Organic carbon (%)	8.46	6.37	4.29	≥0.61	0.52–0.60	0.34–0.51	<0.34
Nutrient availability (na)							
Total N (%)	8.54	6.43	4.33	≥0.11	0.08–0.10	0.06–0.07	<0.06
K exchangeable (cmol(+)/kg)	5.58	4.42	2.98	≥0.25	0.14–0.24	0.05–0.13	<0.05
Erosion hazard (eh)							
Slopes (%)	8.54	6.43	4.33	0–7.70	7.71–11.84	11.85–18.25	>18.25
Soil erosion (ton/ha/year)	8.17	6.05	4.04	≤55.32	55.32–195.29	195.30–605.57	>605.57
Land preparation (lp)							
Rock outcrops (%)	7.41	5.69	3.97	0–4.46	4.47–13.10	13.11–31.89	>31.89
Surface rock (%)	7.41	5.69	3.97	0–4.46	4.47–13.10	13.11–31.89	>31.89

S1, very suitable; S2, moderately suitable; S3, marginally suitable; N, not suitable.

Table 9: Comparison of new and general land suitability criteria with land quality and characteristics.

Land quality/land characteristics	New land suitability criterion of hybrid maize				Land suitability criterion of general maize [47]			
	S1	S2	S3	N	S1	S2	S3	N
Rooting condition (rc)								
Coarse material (%)	0–13.51	13.51–27.48	27.48–52.41	>52.41	<15	15–35	35–55	>55
Effective depth (cm)	≥69.66	49.36–69.65	33.29–49.35	<33.29	>60	60–40	40–25	<25
Nutrient retention (nr)								
Organic carbon (%)	≥0.61	0.52–0.60	0.34–0.51	<0.34	>1.20	0.8–1.2	<0.8	—
Nutrient availability (na)								
Total N (%)	≥0.11	0.08–0.10	0.06–0.07	<0.06	Mo	Lo	VLo	—
K exchangeable (cmol(+)/kg)	≥0.25	0.14–0.24	0.05–0.13	<0.05	Mo-Hi	Lo	VLo	—
Erosion hazard (eh)								
Slopes (%)	0–7.70	7.71–11.84	11.85–18.25	>18.25	<8	8–15	15–25	>25
Soil erosion (ton/ha/year)	≤55.32	55.32–195.29	195.30–605.57	>605.57	—	VLi	Li-Mo	He-VHe
Land preparation (lp)								
Rock outcrops (%)	0–4.46	4.47–13.10	13.11–31.89	>31.89	<5	5–15	15–40	>40
Surface rock (%)	0–4.46	4.47–13.10	13.11–31.89	>31.89	<5	5–15	15–40	>40

S1, very suitable; S2, moderately suitable; S3, marginally suitable; N, not suitable; Hi, high; M, moderate; Lo, low; VLo, very low; He, heavy; Li, light; VLi, very light; VHe, very heavy.

limitations on the use of these results for the development of hybrid maize in the Boalemo Regency because the setting is only based on land characteristics and optimum yields in this regency. Therefore, further investigation to expand the scope of the research area nationally with more diverse and contrasting land characteristic values is recommended to determine the effect on hybrid maize production.

4. Conclusions

Land suitability criteria for the new hybrid maize are determined by land qualities, namely, root conditions, nutrient retention, available nutrients, erosion hazard, as well as land preparation, and land characteristics, including coarse material, effective depth, organic C, total N, exchangeable K, slopes, soil erosion, rock outcrops, and surface rocks. The highest optimum yield of 8.54 ton/ha was achieved by the total N and slopes for a very suitable class (S1), while the lowest value of 5.58 ton/ha was attained by exchangeable K for class S1. These results showed that the combination of the PLS-SEM and boundary line analysis can be an alternative approach to establishing new land suitability criteria for crops based on optimum yields and selected land quality.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References

[1] K. Pawlak and M. Kołodziejczak, "The role of agriculture in ensuring food security in developing countries: considerations in the context of the problem of sustainable food production," *Sustainability*, vol. 12, no. 13, 2020.

[2] O. Erenstein, M. Jaleta, K. Sonder, K. Mottaleb, and B. M. Prasanna, "Global maize production, consumption and trade: trends and R&D implications," *Food Security*, vol. 14, no. 5, pp. 1295–1319, 2022.

[3] U. Grote, A. Fasse, T. T. Nguyen, and O. Erenstein, "Food security and the dynamics of wheat and maize value chains in africa and asia," *Frontiers in Sustainable Food Systems*, vol. 4, pp. 1–17, 2021.

[4] R. Wirosoedarmo, A. T. Sutanhaji, and E. Kurniati, "Land suitability assessment of corn (Zea mays L.) using spasial analysis method," *agriTECH*, vol. 31, no. 1, pp. 71–78, 2012.

[5] B. Arifin, "High expectations on KSA maize production," *Stat. Policy Br. Indones.* vol. 18, pp. 37–41, 2021.

[6] M. L. Nurdin, M. L. Rayes, and S. Sudarto, "Analysis of quality and land characteristics that control local maize production in Gorontalo," *Proceedings of the International Seminar on Promoting Local Resources for Sustainable Agriculture and Development (ISPLRSAD 2020)*, vol. 13, pp. 438–446, 2021.

[7] T. Kartika, "Pengaruh jarak tanam terhadap pertumbuhan dan produksi jagung (zea mays L) non hibrida di Lahan balai agro teknologi terpadu (ATP)," *Sainmatika: Jurnal Ilmiah Matematika dan Ilmu Pengetahuan Alam*, vol. 15, no. 2, 2018.

[8] A. N. A. Sutimawati, A. N. Aulia, and R. M. Muliasari, "Comparative analysis of hybrid corn farming based on business scale in tempurejo sub-district," *Jurnal Agribest*, vol. 3, no. 1, 2019.

[9] I. S. Anugrah, "Corn-based agribusiness for rural economic development in Gorontalo province," *Anal. Kebijak. Pertan.* vol. 8, no. 4, pp. 363–383, 2016.

[10] H. Limanseto, "The government encourages productivity of the leading commodities of Gorontalo province to increase people's welfare," *Coordinating Ministry for Economic Affairs of the Republic of Indonesia, Jakarta*, vol. 1, pp. 1-2, 2021.

[11] N. Endey, I. K. S. Arsana, A. Y. Katili, A. Sahabi, and M. A. Talalu, "Analisis daya saing komoditi unggulan Gorontalo dalam mendukung ibu kota negara baru republik Indonesia," *Equilibrium: Jurnal Pendidikan*, vol. 10, no. 3, pp. 380–396, 2022.

[12] K. Astuti, R. O. Prasetyo, and N. Khasanah, *Analysis of Maize and Soybean Productivity in Indonesia 2020 (The Result of Crop Cutting Survey)*, BPS RI, Indonesia, 2021.

[13] BPS-Statistic of Gorontalo, *Gorontalo Province in Figures 2018*, BPS-Statistic of Gorontalo, Indonesia, 2018.

[14] W. Ardiansyah, M. A. Indrianti, M. M. Djibran, and D. R. Hippy, "KERAGAAN USAHATANI LAHAN KERING PADA PETANI TRANSMIGRAN (skkwk," *Jurnal Agriovet*, vol. 4, no. 2, pp. 125–142, 2022.

[15] A. H. Samon, *The Analysis of Comparative and Competitive Superiority of Corn Farm Enterprises in Boalemo Regency*, Hasanuddin University, Makassar, Indonesia, 2005.

[16] A. M. D. Putri and Mustofiq, *Boalemo Regency in Figures 2022*, BPS-Statistics of Boalemo Regency, Indonesia, 2022.

[17] W. Tialo, M. Arief Azis, and N. Nurdin, "Pertumbuhan dan produksi jagung pulut lokal Gorontalo, efektivitas agronomi, dan ekonomi dengan pemberian pupuk organik di Bualo, Kabupaten Boalemo," *Journal Agercolere*, vol. 4, no. 2, pp. 44–53, 2022.

[18] K. P. Windra sukma, "Growth and production of local maize, hybrid and composite in pamekasan, madura," *Journal Agrosains: Karya Kreatif dan Inovatif*, vol. 4, no. 2, 2018.

[19] Bapelitbang Boalemo Regency, "Local government work plan for 2022," *Boalemo Regent Regulation Number 49 of 2020*, vol. 49, 2021.

[20] A. K. Lasiki, Nurdin, and I. Husain, "Growth and yield of hybrid corn in several classes of slopes and fertilization doses in bumela village, district of Gorontalo," *Journal of Agroteknotropika*, vol. 10, no. 2, pp. 59–69, 2021.

[21] D. K. S. Swastika, "Corn self-sufficiency in Indonesia: the past 30 years and future prospects," *Journal of Litbang Pertan.* vol. 21, no. 3, pp. 75–83, 2002.

[22] E. Kaya, A. Siregar, D. M. Y. Matulessy, and M. Hasan, "Growth and yield of corn (Zea mays L.) due to the granting of sago palm waste compost of sago palm waste compost and organic liquid fertilizer (OLF) in ultisols," *Journal of Budid. Pertan.* vol. 12, no. 1, pp. 16–19, 2016.

[23] R. Yacoub, "Land qualities as a function to estimate land productivity in the recently reclaimed calcareous soils, nubariya, Egypt," *Egypt. Journal of Geosci.* vol. 50, no. 4, pp. 1–13, 2010.

[24] M. Liyanda, A. Karim, and Y. Abubakar, "Analysis of land suitability criteria for cocoa production of three cluster development in pidie district," *Agri*, vol. 16, no. 2, pp. 62–79, 2012.

[25] R. Neswati, S. Baja, and C. Lopulisa, "A modification of land suitability requirements for maize in the humid tropics of South Sulawesi," in *Proceedings of the IOP Conference Series: Earth and Environmental Science*, vol. 921, no. 1, Indonesia, November 2021.

[26] D. Subardja and Sudarsono, "The influence of land quality on productivity of maize in soils derived from volcanic and sedimentary rocks in the bogor area," *Soil Clim Journal*, vol. 23, pp. 38–46, 2005.

[27] G. O. Awe and T. P. Abegunrin, "Land preparation practices for maize production: short term effects on some hydrophysical properties of analfisol and crop performance," *Middle-East Journal of Scientific Research*, vol. 25, no. 7, pp. 1420–1430, 2017.

[28] J. Janků, J. Jehlicka, K. Hermanova et al., "An overview of a land evaluation in the context of ecosystem services," *Soil and Water Research*, vol. 17, no. 1, pp. 1–14, 2022.

[29] D. Nadalia, A. Sutandi, and B. Nugroho, "Suitability criteria of land characteristics related to Eucalyptus pellita production," in *Proceedings of the IOP Conference Series: Earth and Environmental Science*, vol. 694, no. 1, March 2021, https://iopscience.iop.org/issue/1755-1315/694/1.

[30] N. Nurdin, F. Zakaria, M. A. Azis, Y. Rahim, R. Rahman, and M. Kasim, "Comparison of land suitability class for endemic

Coffea liberica Pinogu HP. acquired using different methods and recommendations for land management in Pinogu Plateau, Bone Bolango Regency, Indonesia," *SAINS TANAH - Journal of Soil Science and Agroclimatology*, vol. 19, no. 1, p. 42, 2022.
[31] A. D. Elisanti, W. Purnomo, and S. Melaniani, "Application of partial least square health status of children under 5 years in Indonesia," *Journal of Biometrika dan Kependud.*, vol. 2, no. 2, pp. 99–107, 2013.
[32] J. M. Becker, C. M. Ringle, and M. Sarstedt, "Estimating moderating effects in PLS-SEM and PLSC-SEM: interaction term Generation∗Data treatment," *Journal of Applied Structural Equation Modeling*, vol. 2, no. 2, pp. 1–21, 2018.
[33] M. S. Yim, "A study on factor analytical methods and procedures for PLS-SEM (partial least squares structural equation modeling)," *Journal of Industrial Distribution & Business*, vol. 10, no. 5, pp. 7–20, 2019.
[34] R. Schlittgen, M. Sarstedt, and C. M. Ringle, "Data generation for composite-based structural equation modeling methods," *Adv. Data Anal. Classif.*, vol. 14, no. 4, pp. 747–757, 2020.
[35] S. Kono and M. Sato, "The potentials of partial least squares structural equation modeling (PLS-SEM) in leisure research," *Journal of Leisure Research*, vol. 53, no. 5, pp. 1–21, 2022.
[36] M. E. Civelek, "Comparison of covariance-based and partial least square structural equation modeling methods under non-normal distribution and small sample size limitations," *Eurasian Econom. Stat. Emprical Econ. Journa*, vol. 10, no. 1, pp. 39–50, 2018.
[37] J. F. Hair, J. J. Risher, M. Sarstedt, and C. M. Ringle, "When to use and how to report the results of PLS-SEM," *European Business Review*, vol. 31, no. 1, pp. 2–24, 2019.
[38] J. F. Hair, C. M. Ringle, and M. Sarstedt, "Partial least squares structural equation modeling: rigorous applications, better results and higher acceptance," *Long Range Planning*, vol. 46, pp. 1–12, 2013.
[39] W. Reinartz, M. Haenlein, and J. Henseler, "An empirical comparison of the efficacy of covariance-based and variance-based SEM," *International Journal of Research in Marketing*, vol. 26, no. 4, pp. 332–344, 2009.
[40] H. Syaf, "The relationship evaluation between land quality, growth and production of advanced age cocoa in kolaka east district, southeast Sulawesi province," *Bioedukasi*, vol. 3, no. 1, pp. 267–276, 2014.
[41] M. L. Nurdin, S. Rayes, and Sudarto, "Study of land quality and land characteristics that determine the productivity of composite maize varieties in Gorontalo," *Systematic Reviews in Pharmacy*, vol. 11, no. 12, pp. 500–509, 2020.
[42] R. Bhat and S. Sujatha, "Stablishing leaf nutrient norms for arecanut by boundary line approach," *Journal of Plant Nutrition*, vol. 36, no. 6, pp. 849–862, 2013.
[43] A. M. Ali, "Nutrient sufficiency ranges in mango using boundary-line approach and compositional nutrient diagnosis norms in el-salhiya, Egypt," *Communications in Soil Science and Plant Analysis*, vol. 49, no. 2, pp. 188–201, 2018.
[44] M. Ridayanti, M. L. Rayes, and C. Agustina, "Evaluasi kesesuaian lahan tanaman jagung (Zea mays L.) pada lahan kering di kecamatan wagir kabupaten malang," *Jurnal Tanah dan Sumberdaya Lahan*, vol. 8, no. 1, pp. 149–160, 2020.
[45] B. W. S. Sulawesi II, "Climate Data In The Paguyaman River Area For 2012-2022, Balai Wilayah Sungai Sulawesi Ii Provinsi Gorontalo," 2022, https://sda.pu.go.id/balai/bwssulawesi2/data/wilayah-sungai/ws-paguyaman/.
[46] S. Ritung, F. Lukman, and R. Purnanto, *Atlas Of 1:50,000 Scale Semi-Detailed Soil Map Of Boalemo Regency*, Indonesian Center for Research and Development of Agricultural Land Resources, Gorontalo Province. Bogor, Indonesia, 2016.
[47] W. Wahyunto, *Technical Guidance Guidelines for Land Suitability Assessment for Strategic Agricultural Commodities Semi-detailed Scale 1:50.000*, Balai Besar Litbang Sumberdaya Lahan Pertanian, Bogor, Indonesia, 2016.
[48] L. R. Oldeman and S. Darmiyati, *An Agroclimatic Map Of Sulawesi Scale 1 - 2.500.000.Pdf*, Center Research for Agriculture, Bogor, Indonesia, 1977.
[49] E. Runtunuwu, I. Las, I. Amien, and H. Syahbuddin, "Untilizing cropping calendar in coping with climate change," *Journal Ecolab*, vol. 5, no. 1, pp. 1–14, 2011.
[50] M. L. Rayes, *Description of Soil Profile in the Field*, Agriculture Faculty of Brawijaya University, Malang, Indonesia, 2006.
[51] W. H. Wischmeier and D. D. Smith, "Predicting rainfall erosion losses—a guide to conservation planning," *Agric. Handb.*, vol. 537, pp. 1–60, 1978.
[52] E. Kurnia, F. Agus, A. Adimiharja, and A. Dariah, "Soil physical properties and analysis methods," *Bogor: Center for Research and Development of Agricultural Land Resources*, vol. 1, no. 1, 2006.
[53] E. Eviyati and S. Sulaeman, *Analysis of Soil, Chemical, Plants, Water, and Fertilizer*, Indonesia Centre of Soil Research, Bogor, Indonesia, 2009.
[54] M. Seilsepour, M. Rashidi, and B. G. Khabbaz, "Prediction of soil exchangeable sodium percentage based on soil sodium adsorption ratio," *Am. J. Agric. Environ. Sci.*, vol. 5, no. 1, pp. 1–4, 2009.
[55] M. Siosemarde, F. Kave, E. Pazira, H. Sedghi, and S. J. Ghaderi, "Prediction of soil exchangeable sodium ratio based on soil sodium adsorption ratio," *World Acad. Sci. Eng. Technol.*, vol. 46, no. 10, pp. 255–257, 2010.
[56] N. Sutrisna, Nadimin, I. Ishaq, and S. Putra, *Guide To The Jajar Legowo Rice Tiling Method*, pp. 1–27, Panduan. West Java Agricultural Technology Study Center, Bandung, Indonesia, 2012.
[57] H. Wold, "Model construction and evaluation when theoretical knowledge is scarce," in *Evaluation of Econometric Models*, J. Kmenta and B. J. Ramsey, Eds., pp. 47–74, Academic Press, Cambridge, MA, USA, 1980.
[58] K. Bollen and R. Lennox, "Conventional wisdom on measurement: a structural equation perspective," *Psychological Bulletin*, vol. 110, no. 2, pp. 305–314, 1991.
[59] M. Haenlein and A. M. Kaplan, "A beginner's guide to partial least squares analysis," *Understanding Statistics*, vol. 3, no. 4, pp. 283–297, 2004.
[60] J. F Hair Jr, M. Sarstedt, L. Hopkins, and V. G Kuppelwieser, "Partial least squares structural equation modeling (PLS-SEM): an emerging tool in business research," *European Business Review*, vol. 26, no. 2, pp. 106–121, 2014.
[61] C. Fornell and D. F. Larcker, "Evaluating structural equation models with unobservable variables and measurement error," *Journal of Marketing Research*, vol. 18, no. 1, pp. 39–50, 1981.
[62] W. W. Chin, "The partial least squares approach to structural formula modeling," in *Modern Methods For Business Reseacrh*, G. A. Marcoulides, Ed., pp. 295–336, Lawrence Erlbaum Associates, Mahwah, NJ, USA, 1998.
[63] D. Gefen, D. Straub, and M.-C. Boudreau, "Structural equation modeling and regression: guidelines for research

practice," *Communications of the Association for Information Systems*, vol. 4, pp. 1–77, 2000.
[64] J. Henseler, C. M. Ringle, and R. R. Sinkovics, "The use of partial least squares path modeling in international marketing," *Advances in International Marketing*, vol. 20, pp. 277–319, 2009.
[65] M. Sarstedt, C. M. Ringle, and J. F. Hair, *Partial Least Squares Structural Equation Modeling*, Springer Books, Berlin, Germany, pp. 587–632, 2022.
[66] K. K. Wong, "Partial least squares structural equation modeling (PLS-SEM) techniques using SmartPLS," *Marketing Bulletin*, vol. 24, no. 1, pp. 1–32, 2013.
[67] J. Hulland, "Use of partial least squares (PLS) in strategic management research: a review of four recent studies," *Strategic Management Journal*, vol. 20, no. 2, pp. 195–204, Feb. 1999.
[68] D. Barclay, R. Thompson, and C. Higgins, "The partial least squares (PLS) approach to causal modeling: personal computer adoption and use as an illustration," *Technology Studies*, vol. 2, no. 2, pp. 285–309, 1995.
[69] J. F. Hair, G. T. M. Hult, C. . Ringle, M. Sarstedt, N. . Danks, and S. Ray, *Partial Least Squares Structural Equation Modeling (PLS-SEM) Using R: A Workbook*, Springer, Berlin, Germany, 2021.
[70] V. E. Vinzi, W. W. Chin, J. Henseler, and H. Wang, *Handbook of Partial Least Squares*, Springer, Berlin Germany, 2010.
[71] FAO, "A Framework for innovation," *FAO Soils Bulletin*, vol. 32, no. 22, pp. 1–92, 1976.
[72] A. Sutandi, A. Iswandi, U. Daras, M. Hikmat, and A. Krisnohadi, "Establishing land suitability criteria for cashew (anacardium occidentale L.) in Indonesia," *Applied and Environmental Soil Science*, vol. 2014, Article ID 743194, 14 pages, 2014.
[73] R. Darmawan, "Analysis of the effect of work-family conflict and job stress on the job performance of nurses at "X" hospital," *Agora*, vol. 6, no. 2, pp. 1–6, 2018.
[74] J. F. Hair, M. Sarstedt, C. M. Ringle, and J. A. Mena, "An assessment of the use of partial least squares structural equation modeling in marketing research," *Journal of the Academy of Marketing Science*, vol. 40, no. 3, pp. 414–433, 2012.
[75] R. P. Bagozzi and Y. Yi, "On the evaluation of structural equation models," *Journal of the Academy of Marketing Science*, vol. 16, no. 1, pp. 74–94, Mar. 1988.
[76] T. M. Basuki, D. R. Indrawati, and B. Haryadi, "The use of organic matter to improve productivity of Post lime mining land," *Jurnal Penelitian Hutan dan Konservasi Alam*, vol. 4, no. 1, pp. 1–8, 2007.
[77] M. S. Alfian and H. Purnamawati, "Dosis dan Waktu Aplikasi Pupuk Kalium pada Pertumbuhan dan Produksi Jagung Manis di BBPP Batangkaluku Kabupaten Gowa Sulawesi Selatan," *Buletin Agrohorti*, vol. 7, no. 1, pp. 8–15, 2019.
[78] Sutardjo, Sulastri, and W. Nawfetrias, "Optimization of production of four hybrid maize varieties in kertosono, nganjuk regency," *Journal of Sains dan Teknol. Indonesia*, vol. 14, no. 1, pp. 76–80, 2012.
[79] S. Nasreen, M. M. Haque, M. A. Hossain, and A. T. M. Farid, "Nutrient uptake and yield of onion as influenced by nitrogen and sulphur fertilization," *Bangladesh Journal of Agricultural Research*, vol. 32, no. 3, pp. 413–420, 2008.
[80] Y. Abdissa, T. Tekalign, and L. M. Pant, "Growth, bulb yield and quality of onion (Allium cepa L.) as influenced by nitrogen and phosphorus fertilization on vertisol I. Growth attributes, biomass production and bulb yield," *African Journal of Agricultural Research*, vol. 6, no. 14, pp. 3252–3258, 2011.
[81] I. Firmansyah and N. Sumarni, "Pengaruh dosis pupuk N dan varietas terhadap pH tanah, N-total tanah, serapan N, dan hasil umbi bawang merah (Allium ascalonicum L.) pada tanah entisols-brebes jawa tengah," *Jurnal Hortikultura*, vol. 23, no. 4, 2016.
[82] E. Sumiati and O. S. Gunawan, "Application of mycorrhizal biofertilizer to increase the efficiency of NPK uptake and its effects on yiled and quality of shallot bulbs," *Journal of Hort*, vol. 17, no. 1, pp. 34–42, 2006.
[83] H. R. McKenzie, "Potassium fertilizer application in crop production," *Agri-Facts*, vol. 542, no. 9, pp. 1–7, 2013.
[84] M. Dianawati, "Rates and application time of K2SO4 on production of G0 potato seed," *Journal of Kultiv.*, vol. 17, no. 1, pp. 531–536, 2018.
[85] N. Gunadi, "The use of potassium sulphate as an alternative source of potassium fertilizer in potato," *Journal of Hort*, vol. 17, no. 1, pp. 52–60, 2019.
[86] I. S. Rahmawan, A. Z. Arifin, and Sulistyawati, "The effect of potassium (K) fertilizer on growth and yield of cabbage (Brassica oleraceae var. capitata, L.)," *Journal of Agroteknologi Merdeka Pasuruan*, vol. 3, no. 1, pp. 17–23, 2019.
[87] IIED, "Potash case study: information supplied by the international fertilizer industry association," *Mining, Miner. Sustain. Dev*, vol. 65, 2002.
[88] Subandi, "Role and management of potassium nutrient for food production in Indonesia," *Agric. Innov. Dev*, vol. 6, no. 1, pp. 1–10, 2013.
[89] N. Nursjahbani and O. Rusdiana, "Kesesuaian Durio zibethinus Murr. DAN Nephelium lappaceum l. Pada Lahan Blok Pemanfaatan Tahura Gunung Menumbing, Bangka Barat Suitability of Durio zibethinus Murr. and Nephelium lappaceum L. on the Utilization Block at Menumbing Mountain Grand Forest," *Journal of Tropical Silviculture*, vol. 9, no. 1, pp. 1–6, 2018.
[90] I. W. Nyakudya and L. Stroosnijder, "Effect of rooting depth, plant density and planting date on maize (Zea mays L.) yield and water use efficiency in semi-arid Zimbabwe: modelling with AquaCrop," *Agricultural Water Management*, vol. 146, pp. 280–296, Dec. 2014.
[91] S. B. Wang, L. Guo, P. Zhou et al., "Effect of subsoiling depth on soil physical properties and summer maize (Zea mays L.) yield," *Plant Soil and Environment*, vol. 65, no. 3, pp. 131–137, 2019.
[92] H. Z. Khan, M. A. Malik, and M. F. Saleem, "Effect of rate and source of organic material on the production potential of spring maize (Zea mays L.)," *Pakistan Journal of Agricultural Sciences*, vol. 45, no. 1, pp. 40–43, 2008.
[93] A. Jalal, K. Azeem, M. C. M. T. Filho, and A. Khan, "Enhancing soil properties and maize yield through organic and inorganic nitrogen and diazotrophic bacteria," in *Sustainable Crop Production*, pp. 1–14, IntechOpen, London, UK, 2020.
[94] E. E. Kandil, N. R. Abdelsalam, M. A. Mansour, H. M. Ali, and M. H. Siddiqui, "Potentials of organic manure and potassium forms on maize (Zea mays L.) growth and production," *Scientific Reports*, vol. 10, no. 1, 2020.
[95] A. B. B. Mulyati, A. B. Baharuddin, and R. S. Tejowulan, "Improving Maize (Zea mays L.) growth and yield by the application of inorganic and organic fertilizers plus," in *Proceedings of the IOP Conference Series: Earth and*

Environmental Science, vol. 712, no. 1, Lombok, Indonesia, October 2021.
[96] D. A. Kane, M. A. Bradford, E. Fuller, E. E. Oldfield, and S. A. Wood, "Soil organic matter protects US maize yields and lowers crop insurance payouts under drought," *Environmental Research Letters*, vol. 16, no. 4, Article ID 044018, 2021.
[97] M. Mujiyo, W. Larasati, H. Widijanto, and A. Herawati, "The Effect of Slope Gradient of land on the Soil Damage in Giritontro, Wonogiri," *Agrotrop: Journal on Agriculture Science*, vol. 11, no. 2, 2021.
[98] D. O. Suparwata, Nurmi, and M. I. Bahua, "Using vertical mulch to upland for reducing erosion, runoff and its responses to maize growth and yields," *Agrotekno*, vol. 1, no. 3, pp. 138–145, 2012.
[99] R. E. Christanto, M. Suryono, and J. Winarno, "The degree of erosion hazard mapping in dry land at jatipuro sub district of karanganyar with geographic information system (GIS," *Sains Tanah - J. Soil Sci. Agroclimatol*, vol. 7, no. 2, pp. 114–119, 2013.
[100] E. Elfayetti and H. Herdi, "Evaluasi kesesuaian lahan untuk tanaman jagung di Desa saentis, percut sei tuan," *JUPIIS J. Pendidik. ILMU-ILMU Sos*, vol. 7, no. 1, 2015.
[101] S. Sukarman, A. Mulyani, and S. Purwanto, "Modifikasi meklbpi," *Jurnal Sumberdaya Lahan*, vol. 12, no. 1, 2018.
[102] W. Chivasaa, O. Mutanga, and C. Biradarc, "Mapping land suitability for maize (Zea mays L.) production using GIS and AHP technique in Zimbabwe," *South African Journal of Geology*, vol. 8, no. 2, pp. 265–281, 2022.