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Research Article

Analysis of degraded land suitability and regional comparative advantages for maize development in the Gorontalo sustainable agriculture areas, Indonesia

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Abstract

Maize has attracted the attention of local governments due to its high yield potential and economic prospects, but the strategic value of this commodity has not been specific to particular locations. Therefore, this study aimed to assess degraded land suitability and determine the regional comparative advantages for maize development in the Gorontalo sustainable agriculture areas. The suitability class was assessed using Automatic Land Evaluation System software, while comparative advantages were determined using input-output and regional analysis. The input-output analysis was based on maize farming data from interviews with 80 farmers. This study also employed location quotient, specialization index, and localization index analyses based on maize, rice, and soybean production data for 2014, 2016, and 2018. The results showed that land degradation caused by soil erosion was dominated by moderate, heavy, and very heavy categories. Most of the actual land suitability for maize was classified as marginal suitable (S3) but became very suitable (S1) and moderately suitable (S2) after the limiting factors were improved. Furthermore, maize was profitable for the land suitability classes of S1, S2, and S3, and the commodity was most concentrated in Mootilango District. Based on the results, land management recommendations followed a pattern of recommendation I > II > III > not recommended.

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Introduction

Over the years, there has been a continuous increase in the demand for land along with population growth and physical development. However, the available land area is limited in meeting this growing demand, leading to uncontrolled land usage (Wahyunto et al., 2003). This condition has negatively affected agroecosystems, particularly agricultural land, due to the high rate of conversion and fragmentation. Agricultural land is essential for producing basic food and must be maintained to meet the growing demand for food commodities. At present, agriculture has expanded into the upstream watersheds, which must be maintained as a conservation area. This indicates that it is essential to plan agricultural land use to optimize the potential of land resources while preserving conservation and sustainability.

In 2001, Gorontalo Province announced Agropolitan as its flagship program, focusing on the superior commodity of maize (Nurdin et al., 2021a). This has led to the implementation of various programs and activities to increase the production and productivity of the crop. According to the Indonesian Ministry of Agriculture report in 2020, East Java Province is the leading maize producer, with a production of 5.37 million tons, followed by Central Java, Lampung, and North Sumatra Provinces with volumes of 3.18, 2.83, and 1.83 million tons, respectively. The report also showed that Gorontalo Province ranked ninth with a production of 0.91 million tons. However, the massive development of maize in the Gorontalo areas has led to land degradation, specifically in areas that have penetrated the slopes and upstream watersheds.

Land degradation refers to the process of decreasing the productivity of an area, which can either be temporary or permanent (Wahyunto and Dariah, 2014). Furthermore, this process is characterized by decreased physical, chemical, and biological properties (Sitorus et al., 2011). According to Nurdin (2012), soil erosion caused by the maize Agropolitan program in Biyonga Sub-watershed, Gorontalo, was 108.11 t/ha/year, with a runoff of 153.02 m^3/ha/year. Moha et al. (2020) also reported that the sub-watershed contributed to an erosion rate of 5,870,145.93 t/ha/year for five years, with the largest sedimentation of 1,402,507.01 t/ha/year. This indicates that the development of maize in Gorontalo Province has increased soil erosion to levels above the tolerance limit of 10 t/ha/year. Based on the BPS Report (2020), there has been a downward trend in maize productivity in the province from 4.8 t/ha in 2015 to 4.5 t/ha in 2019. Therefore, it can be inferred that degradation has been occurring over the past twenty years since the development of the Agropolitan program.

The Gorontalo sustainable agriculture area is a major center for maize production in Gorontalo Province. The designation of this area is based on Perda No. 4 of 2011, which outlines the Provincial Spatial Planning for 2010-2030 and the Regional Regulation No. 4 of 2013 regarding Gorontalo Regency Regional Spatial Planning 2012-2032. A previous study revealed that the potential land for agricultural development in this area was 31,645 ha accounting for 32.07% of the total area. Furthermore, the potential land for food crops is 20,800 ha or 65.73% (Rahman et al., 2015). As of 2020, the maize planting area in the region has reached 27,612.00 ha with a production achievement of 110,093.32 tons, accounting for 32.55% of the total volume in Gorontalo Regency (BPS Gorontalo Regency, 2020).

Despite the importance of the Gorontalo sustainable agriculture area as a center for maize production, the high intensity of cultivation has led to a decrease in land quality and productivity. Nurdin et al. (2021b) showed that the quality of land in the Bulia sub-watershed, which was included in the region, was classified as class IV and class VI, accounting for 25.11% of the total area. Furthermore, the main factors contributing to this decline include low soil compaction, water-holding capacity, and soil structure stability. The study area is located in the critical Paguyaman watershed, known for high erosion and sedimentation levels (Staddal, 2020). The erosion caused by maize cultivation in this area ranges from 3.66-1,772.43 t/ha/year (Nurdin et al., 2023). Meanwhile, the average productivity of local maize is only 4.68 t/ha (Astuti et al., 2021; Putri and Mustofiq, 2022), which is still below the average national productivity level, namely 5.70 t/ha (Astuti et al., 2021). This indicates that it is necessary to reassess the land suitability class for the degraded area for maize crops.

Every plant has specific requirements and criteria for optimal growth, development, and productivity. These requirements vary depending on the characteristics and qualities of the land on which the plants are grown. Consequently, the response of plants to these diverse land characteristics also differs. As with other commodities, land-based agriculture requires certain requirements for optimal growth, life, and production (Rayes, 2007; Ritung et al., 2011). Each land use type also requires different conditions for optimal growth, including maize (Subardja and Sudarsono, 2005).

Maize is a crucial food crop commodity and serves as the second-largest food source after rice, animal feed sources, bioethanol raw materials, and export commodities (Azrai, 2013; Draseffi et al., 2015; Wahyudin et al., 2017; Panikkai et al., 2017). In 2020, the national maize production reached 24.95 million tons, indicating an increase of 18.55% compared to the previous year. This was achieved from the total land area of 5.16 million ha, which increased by 20.95% from the previous year, but the productivity decreased by 1.98% (Indonesia Ministry of Agriculture, 2020). Despite the significant increase in national maize production, productivity is still far from its potential. This is in line with Sutoro (2015) that the productivity is still below the genetic potential of existing superior varieties. Although the maize in Indonesia can produce 10-11 t/ha (Yasin et al., 2014), the yield is very diverse at 4.83 t/ha/year (Indonesia Ministry of Agriculture, 2020). This is because maize is often planted on land with low productivity potential (Swastika, 2002). Land quality has been reported to have a close relationship with the productivity of the crop (Subardja and Sudarsono, 2005), and it has a significant effect on land suitability (FAO, 1976).

The potential economic benefits of maize have attracted the interest of many parties, including local governments, such as Gorontalo Province. Furthermore, the province has been developed as an export commodity, with a value of US$2,005,992 in September 2022 (BPS Gorontalo Province, 2022). The crop is also considered a leading commodity, indicating that it has strategic value based on physical considerations (land and climate conditions), socio-economic and institutional (technological mastery, human resource capacity, infrastructure, and socio-cultural conditions, making it suitable to be developed in a particular area (Sitorus et al., 2014). Determination of superior agricultural commodities in an area needs to pay attention to comparative advantage (Safrizal and Shalil, 2019). A commodity is deemed feasible for development if it can be cultivated according to its agro-ecological zone, provide business opportunities, and be accepted by the local community, thereby increasing the impact on employment and the economy (Syarifuddin et al., 2004; Susanto and Sirappa, 2007).

The replacement of maize with other food crops in Gorontalo Province has proven to be challenging due to the long-standing traditions of local farmers. However, allowing extensive cultivation poses a risk to sustainability and exacerbates land degradation. To address this issue, there is a need to reassess the suitability of degraded land and the comparative advantage of maize commodities. This is expected to facilitate optimal production, increase economic value, and promote sustainable cultivation. Therefore, this study aimed to determine the suitability class of degraded land and the regional comparative advantage for maize development in the Gorontalo sustainable agriculture area.

Materials and Methods

Descriptions of the study site

This study was carried out in the sustainable agricultural area of Gorontalo, Gorontalo Province (Table 1 dan Figure 1), from June to November 2019. The materials studied were the land in the study area and soil samples. A total of 1 kg of soil sample was taken from each representative pedon profile through soil surveys and land observations outlined by Rayes (2006). The materials used for this study consisted of land, geological, slope, landform, land use maps, 5-years climate data (2013-2018) from the local BMKG station, and laboratory analytical instruments. The tools used consisted of a soil knife, a Munsell Soil Color Chart, soil profile forms, sample rings, ground drills, a hoe, a shovel, binoculars, an altimeter, a clinometer, GPS, compasses, plastic bags, rubber bands, paper labels, 1 set of computer and printers, F markers, Microsoft Excel and Word data processing programs, and a set of laboratory analysis tools.

Study procedures

This study was carried out in five stages: determining land units, land surveys and observations, soil analysis in the laboratory, analysis of land suitability and comparative advantage of commodities, and recommendations for land management. Determination of land units was performed using a physiographic approach based on the results of superimpose between geology, slope, and land use maps on a scale of 1: 50,000, which produced 33 land units and their area, as shown in Figure 1 and Table 1. Furthermore, a map of land units was prepared on a scale of 1:50,000 using ArcGIS version 10. The map contained lithology and topography conditions, slope class, type of land use, and distribution in the study area. Soil surveys were carried out on land units by describing the characteristics and quality of the selected area for land suitability evaluation, which ended with soil sampling. Meanwhile, land observation was performed by observing and assessing the suitability of land unit attributes in the field, including elevation (masl) determined by GPS, soil drainage (class) by observation, soil depth (cm) by soil drill and measurement, coarse material (%) by observation, slope by Clinometer, soil erosion by USLE method, flood hazard by observation and measurement, and relief condition by observation. Climate data, such as rainfall, wet month, and the monthly temperature, was collected from the local rain post, Bandungrejo climate station, and Harapan climate station based on the region they covered.

Soil sampling analysis

The soil analysis (soil chemistry and physics) was carried out in the Soil and Land Resources laboratory of the Faculty of Agriculture, Brawijaya University. The characteristics analyzed included soil texture using the pipette method, pH in 1:2.5 soil and water solution determined with a pH meter, and organic C content using the Walkley and Black method. Furthermore, the total N and available P content were assessed using the Kjeldahl and Olsen methods, respectively. The basic cations and CEC were extracted from the dry sample with 1N NH_4OAc pH 7.0 (ammonium acetate) at 105 °C. Base saturation was determined by calculating the percentage of base cation number with CEC, and ESP was evaluated using the ratio of sodium percentage to CEC.

Computation of soil and land parameters

Assessment of land degradation with soil erosion as an indicator was carried out with the USLE method (Wischmeier and Smith, 1978) using the following equation:

$$A = R \times K \times L \times S \times C \times P$$

where: A = soil erosion (t/ha/year); R = rainfall erosivity factor (EI units /year); K = soil erodibility factor (tons /ha/EI unit); L = slope length factor; S = slope gradient factor; C = cover and management factor, and P = erosion control practice factor.

Furthermore, the status of soil erosion that occurred was compared with the criteria proposed by the Indonesia Ministry of Forestry (2013). Assessment of suitability classes for maize was performed with the framework of land evaluation (FAO, 1976) by comparing the characteristics and quality of a particular area with the suitability criteria for maize crops (Table 2), as proposed by Djaenudin et al. (2011). The process was carried out using the Automatic Land Evaluation System (ALES) and Geographical Information System (GIS) software. Comparative advantage analysis was performed using various methods, including input-output (i-o) maize farming, specialization index (SI-Specialization

Index), as well as maize commodity base (LQ-Location Quotient) and location index (LI-Localization Index) analyses. Besides maize cultivation, rice and soybean production were also compared in the study areas between 2014, 2016, and 2018.

Table 1. The description of land units (LU) in the study areas.

LU	Description			Land Use	Areas	
	Lithology	Topography	Slopes		ha	%
1	Clay rocks	Hills	3-8%	Upland agriculture	1,066.9	9.07
2	Clay rocks	Hills	3-8%	Upland agriculture	63.1	0.54
3	Clay rocks, sandstones, and gravel	Hills	3-8%	Upland agriculture	1,442.7	12.26
4	Clay rocks, sandstones, and gravel	Mountains	15-30%	Upland agriculture	28.2	0.24
5	Clay rocks	Flats	0-3%	Upland agriculture	140.7	1.20
6	Clay rocks	Hills	3-8%	Upland agriculture	14.7	0.12
7	Clay rocks	Hills	3-8%	Upland agriculture	62.4	0.53
8	Clay rocks	Hills	3-8%	Upland agriculture	472.7	4.02
9	Clay rocks	Flats	0-3%	Upland agriculture	596.9	5.07
10	Clay rocks	Flats	0-3%	Upland agriculture	128.0	1.09
11	Agglomerates, tuffs, lava, andesite-basalt	Hills	0-3%	Upland agriculture	65.0	0.55
12	Lava basalt	Mountains	15-30%	Upland agriculture	39.9	0.34
13	Agglomerates, tuffs, lava, andesite-basalt	Mountains	15-30%	Shrubs	302.3	2.57
14	Clay rocks	Hills	3-8%	Shrubs	18.3	0.16
15	Clay rocks	Hills	3-8%	Shrubs	34.1	0.29
16	Clay rocks	Mountains	15-30%	Shrubs	249.5	2.12
17	Clay rocks	Mountains	15-30%	Upland agriculture	296.6	2.52
18	Clay rocks	Hills	3-8%	Upland agriculture	65.9	0.56
19	Clay rocks	Mountains	15-30%	Upland agriculture	1,026.2	8.72
20	Clay rocks	Mountains	15-30%	Shrubs	248.4	2.11
21	Clay rocks	Hills	3-8%	Plantation	61.9	0.53
22	Diorite, granodiorite	Mountains	30-45%	Upland agriculture	48.3	0.41
23	Clay rocks	Hills	3-8%	Upland agriculture	1,977.3	16.80
24	Clay rocks	Flats	0-3%	Upland agriculture	107.3	0.91
25	Clay rocks	Flats	0-3%	Plantation	2,297.8	19.53
26	Clay rocks	Hills	8-15%	Upland agriculture	254.5	2.16
27	Clay rocks	Flats	0-3%	Upland agriculture	79.3	0.67
28	Clay rocks	Hills	3-8%	Upland agriculture	24.5	0.21
29	Agglomerates, tuffs, lava, andesite-basalt	Flats	0-3%	Upland agriculture	100.2	0.85
30	Clay rocks	Hills	3-8%	Upland agriculture	89.5	0.76
31	Agglomerates, tuffs, lava, andesite-basalt	Mountains	15-30%	Upland agriculture	89.2	0.76
32	Agglomerates, tuffs, lava, andesite-basalt	Mountains	30-45%	Upland agriculture	171.5	1.46
33	Lava basalt	Mountains	15-30%	Upland agriculture	104.3	0.89
	Total area (ha)				11,768.33	100.00

Maize farming data were obtained through field surveys with local farmers (respondents) using the interview method with questionnaire instruments. The sample population consisted of 80 participants (<100) who were interviewed in the field (Singarimbun and Effendi, 1995). The analysis of regional comparative advantage for maize development was performed with production data of the crop and other food commodities that were available in 2014, 2016, and 2018 in the Gorontalo sustainable agriculture areas.

Analysis of i-o maize farming was carried out with the operating procedures of the ALES (Rossiter and Van Wambeke, 1997) and Soekartawi (2006) using the following equation:

$$R = Y.P$$

$$RCR = R/C$$

$$GM = R - C$$

$$BCR\ (\text{discount factor } 15\%) = 0{,}869565.R/C$$

where: R = return; Y = production (t); P = prices (Rp); C = cost (Rp); GM = gross margine (Rp); RCR = return cost ratio; BCR = benefit-cost ratio; 0.869565 = 15% discount factor values.

Location Quotient Analysis (LQ) was performed using the following equation (Blakely and Leigh, 2010):

$$LQ_{IJ} = \frac{X_{IJ} / X_{I.}}{X_{.J} / X_{..}}$$

where: Xij = degree of j-activity in the i-th region; Xi. = total activity in the I region; X.j = total jth activity in all regions; and X = degree of total area activity.

Based on the LQ analysis, an LQIJ value>1 indicated the presence of a higher concentration of activities in the i-th sub-region compared to the total area. LQIJ value = 1 showed that the first sub-region had a share of activities equivalent to the total share, or the activity concentration in the first area was equal to the average of the total area. Values <1 indicated that the sub-region I had a relatively smaller share compared to all regions.

Specialization Index (SI) analysis was carried out using the following equation (Blakely and Leigh, 2010):

$$SI_I = \frac{1}{2}\sum_{J=1}^{P}\left\{\left|\frac{X_{IJ}}{X_{I.}} - \frac{X_{.J}}{X_{..}}\right|\right\}$$

In the SI analysis, value ≈ 0 indicated the absence of specificity, showing that the observed sub-regions did not have prominent development activities compared to other areas. The value ≈ 1 indicates the presence of specialty, showing that the observed sub-region had a unique activity whose development was relatively prominent compared to other sub-regions.

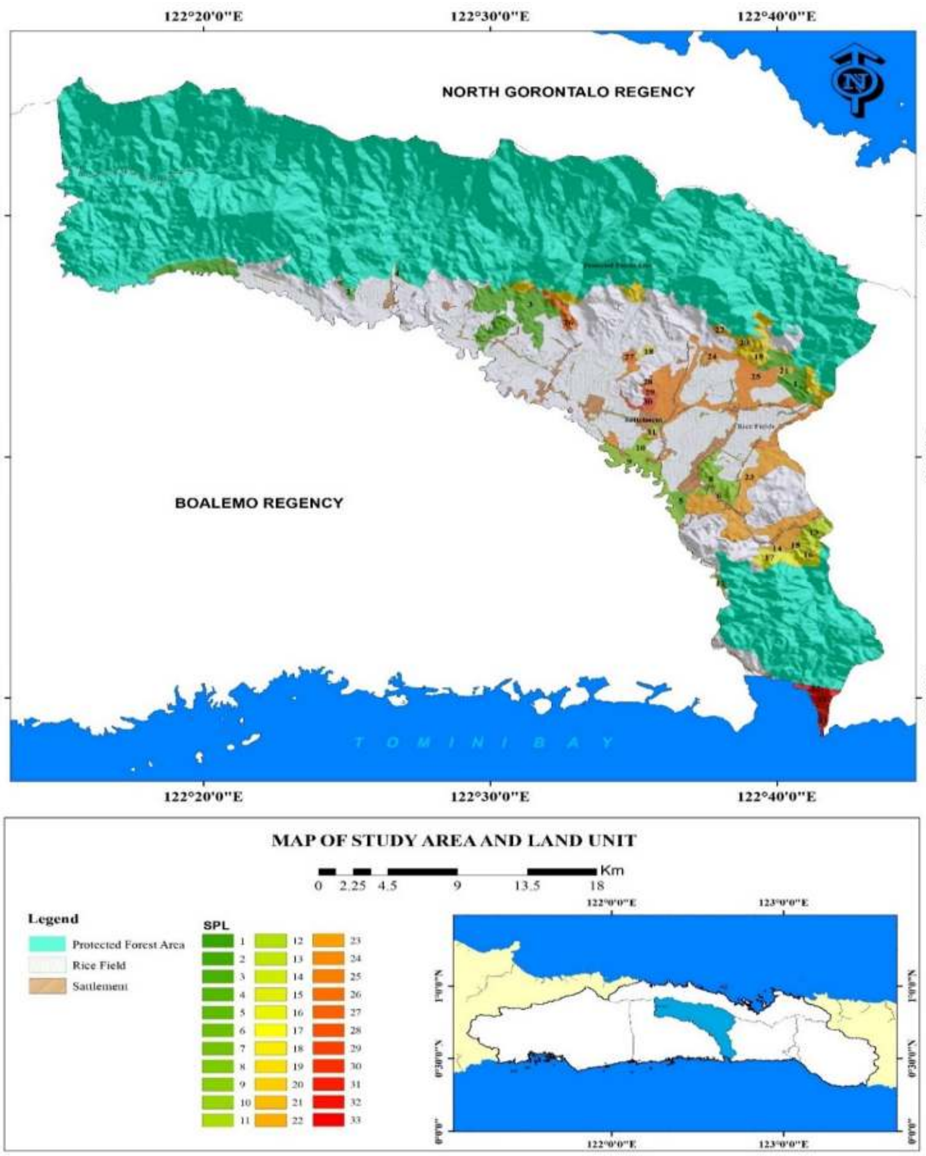

Figure 1. Study area and land unit.

Localization Index (LI) analysis was performed using the equation below (Blakely and Leigh, 2010):

$$LI_J = \frac{1}{2}\sum_{I=1}^{n}\left\{\left|\frac{X_{IJ}}{X_{.J}} - \frac{X_{I.}}{X_{..}}\right|\right\}$$

Based on the LI analysis, value ≈ 0 showed that the development of activity tended to have the same level as the region in a wider scope, indicating the presence of indifference in all locations. Meanwhile, value ≈ 1, indicated that the activities observed tended to develop centrally in a location. This shows that the activities could develop better when carried out in certain areas. Recommendations for land management were prepared based on the priority of the intervention land with the criteria of severity and risk of soil erosion, potential suitability class for maize, farming profit with R/C ratio, and comparative advantage of maize, as shown in Table 3. The recommendations were then described, and their spatial distribution was presented in the form of a map.

Table 2. Land suitability criteria for maize (Djaenudin et al., 2011).

Requirement of land use/ land characteristics	**Land Suitability Class**			
	S1	**S2**	**S3**	**N**
Temperature (tc)				
Temperature (^{o}C)	25-27	27-30 18-25	30-35 15-18	>35 <15
Water availability (wa)				
Rainfall (mm)	400-900	300-400 900-1,200	130-500 1,200-1,400	<150 >1,400
Long dry months (month)	4-8	8-8.5 2.5-4	8.5-9.5 1.5-2.5	>9.5 <1.5
Oxygen availability (oa)				
Drainage	Somewhat hampered	Rather fast, Moderate	Hampered	Very hampered, Fast
Rooting media (rc)				
Texture	Fine, rather fine, moderate	-	Rather rough	Rough
Coarse material (%)	<15	15-35	35-55	>55
Soil depth (cm)	>60	40-60`	25-40`	<25
Nutrient retention (nr)				
CEC (cmol)	>16	≤16	-	-
Base saturation (%)	>50	35-50	<35	-
pH H_2O	5.5-8.2	5.3-5.5 8.2-8.5	<5.3 >8.5	-
Organic C (%)	>0.4	<0.4	-	-
Nutrient availability (na)				
Total N (%)	Moderate	Low	Very low	-
P_2O_5 (mg/100 g)	Moderate	Low	Very low	-
K_2O (mg/100 g)	Moderate	Low	Very low	-
Toxicity (xc)				
Salinity (dS/m)	<8	8-12	12-16	>16
Sodicity (xn)				
Alkalinity/ESP (%)	<20	20-28	28-35	>35
Sulfidic hazard (xs)				
Sulfidic depth (cm)	>100	75-100	40-75	<40
Erosion hazard (eh)				
Slopes (%)	<8	8-16	16-30	>30
Soil erosion (t/ha/year)	Very low	Low- moderate	Heavy	Very heavy
Flooding hazard (fh)				
Inundation	F0	F1	F2	>F2
High (cm)	-	25	25-50	>50
Long (day)	-	<7	7-14	>14
Land preparation (lp)				
Rock surface (%)	<5	5-15	15-40	>40
Rock outcrops (%)	<5	5-15	15-25	>25

Table 3. Combination of criteria for prioritizing land management.

Indicator and Criterion				Land Management Recommendations
Soil Erosion Rate (t/ha/year)	Potential Land Suitability	Farming Feasibility	Comparative Advantage	
Very Light (<15); Light (15 - <60)	S1	R/C >1.5	LQ >1.5	I
Moderate (60-180)	S2	R/C 1-1.5	LQ 1-1.5	II
Heavy (180-450)	S3	R/C 0.5-1	LQ 0.5-1	III
Very Heavy (>450)	N	R/C <0.5	LQ <0.5	Not Recommended

Results and Discussion

Land characteristics and land degraded by soil erosion

The soil characteristics of the study area were essential for the assessment of erosion and land suitability. Based on Table 4, the region received varying amounts of rainfall, ranging from 1,199-1,793 mm at the local rain post. Furthermore, the wettest months only occurred three times in a year, and the air temperature ranged from 28-29 ºC. These conditions produced a ustic humidity regime with an isohyperthermic soil temperature regime in the area (Van Wambeke, 2000). Observation also showed that the depth of the soil solum ranged from 10-150 cm, with poor to good drainage.

Table 4. Brief statistics of selected land characteristics.

Land characteristics	Number of samples	Maximum	Median	Minimum	Value (Mean ± StDev)
Elevation (m asl)	33	341	74	24	91.52 ± 64.77
Rainfall (mm)	33	1,793	1,246	1,199	1,274,09 ± 125.12
Wet month (month)	33	3	0	0	0.18 ± 0.58
Temperature (ºC)	33	29	28	28	28.15 ± 0.36
Soil drainage (class)	33	4	4	0	3.06 ± 1.30
Soil depth (cm)	33	150	74	10	72.55 ± 34.52
Sand (%)	33	85.50	44	6	42 ± 18,84
Silt (%)	33	51.5	27.50	6	27.67 ± 11.82
Clay (%)	33	53.5	29	9.5	30.33 ± 1.65
Coarse material (%)	33	60	0	0	12.58 ± 17.95
pH	33	7.2	5.80	4.9	5.92 ± 0.53
Organic C (%)	33	2.35	0.80	0.28	0.88 ± 0.39
Cation exchange capacity (me/100 g)	33	60	22	9	24.61 ± 11.31
Base saturation (%)	33	82	53	43	56.45 ± 10.24
Total N (%)	33	0,27	0.09	0,04	0.09 ± 0.04
C/N ratio	33	47	10	4	10.91 ± 6.81
Available P -Bray 1 (ppm)	33	58.67	3.65	0.73	8.83 ± 12.56
Exchangeable K (me/100 g)	33	1.92	0.21	0.07	0.37 ± 0.42
Slopes (%)	33	25	6	1	9.58 ± 7.29
Erosion (class)	33	4	2	0	1.91 ± 1.18
Floods	33	2	0	0	0.33 ± 0,65
Rocks (%)	33	2	0	0	0.39±0.66
Maize Yield (t/ha)	33	10.54	7.58	3.81	7.76 ± 1.88

The texture of the local soil varied from clay to sandy clay loam, with rough materials ranging from no (0%) to 60%, specifically on hilly and mountainous land units. Based on the criteria for assessing chemical properties (Eviyati and Sulaeman, 2009), the soil reaction varied, ranging from acidity to neutral. The levels of organic C and total N were classified as very low to moderate, while the C/N ratio was considered very low to very high. The available P levels (P-Bray 1) and exchangeable K were relatively similar to the C/N ratio pattern, while cation exchange capacity was classified as low to very high, and base saturation ranged from moderate to very high. This was presumably because it is influenced by the parent material in each soil unit (pedon). The nature and characterization of soils were shown to be strongly influenced by the parent material (Prasetyo, 2007; Suharta, 2007). The analysis results showed that the soil erosion rate of maize plantings was dominated by moderate, heavy, and very heavy categories, with an area percentage of 80.14%, as shown in Table 5 and Figure 2.

Table 5. Rate of soil erosion from maize planting areas.

Rate of Soil Erosion (t/ha/year)*	Land Unit	Area	
		ha	%
Very Light (<15)	19; 20; 27; 29	1,454.12	12.36
Light (15-60)	5; 9; 14; 18; 21	883.65	7.51
Moderate (60-180_	1; 2; 6; 7; 11; 15; 22; 24; 25	3,759.77	31.95
Heavy 180-480	3; 10; 23; 26; 30; 32; 33	4,167.83	35.42
Very Heavy (>480)	4; 8; 12; 13; 16; 17; 28; 30	1,502.97	12.77
Total area (ha)		11,768.33	100.00

*Indonesia Ministry of Forestry (2013).

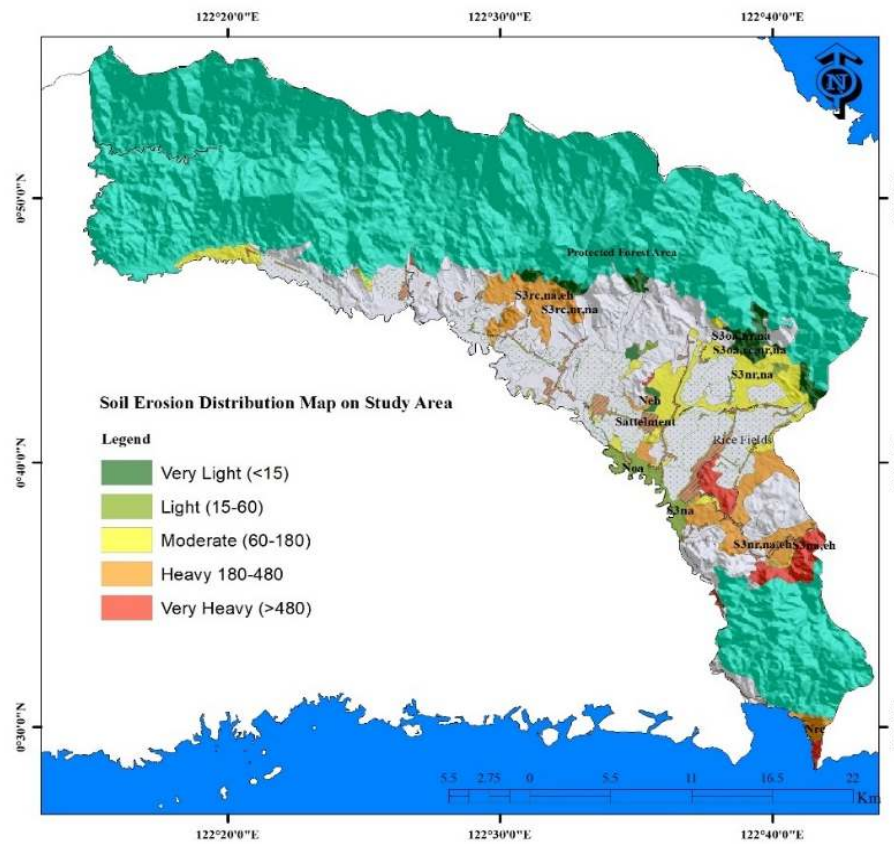

Figure 2. Soil erosion map on the study area.

The region also experienced the mild and very light categories, with an area percentage of 19.86%. According to Stefano and Ferro (2016), an erosion rate of 4.5-11.2 t/ha/year was the maximum tolerance level of the rate, while Girmay et al. (2020) reported a value of 11 t/ha/year. As a comparison, the Ministry of Public Works of Indonesia in 2014 stated that the average level in the Paguyaman River area was only 16.5 t/ha/year, but this value had increased until 2023. Continuous erosion has been reported to cause a decrease in soil quality and productivity, which were a form of land degradation (Wahyunto and Dariah, 2014).

Land suitability for maize crops

The results of the actual land suitability analysis (ALS) for maize in the study area showed that most of the land (10,536.22 ha or 89.53%) was in the marginally suitable classes (S3) with the presence of various limiting factors, as shown in Table 6 and Figure 3. Furthermore, the remaining regions were classified as not suitable (N) for a maize area, with an area of 1,232.11 ha (10.47%). The ALS class was influenced by the limiting factors found in each land unit (LU). Among the land units classified as S3, 89.53% were affected by nutrient retention and availability, either alone or in combination with other limiting factors.

This finding was relatively reasonable from the aspect of nutrient retention, considering that soil pH in the study area was predominantly acidic, organic C content was low, and the CEC, as well as base saturation, were in the low to moderate classes. Wet tropical areas generally had low levels of organic matter (Ross, 1993), including Indonesia. From the aspect of nutrient availability, the region was considered to be in the very low to moderate categories, which inhibited the growth and production of maize. The results also showed that N, P, K, and organic matter were the limiting factors for the growth of maize in Inceptisols from Sukabumi (Nursyamsi et al., 2002). Among the land units classified as class S3, 28.22% were limited by root conditions, either alone or in combination with other limiting factors. This was relatively reasonable considering that several LU in the study area had slightly rough (sandy loam) and coarse (clay sand) textures, with coarse materials still present at a percentage of 15% to 60% and soil depths ranging from 10 cm - 59 cm. The ideal soil texture for maize was fine, slightly fine, and medium, with coarse material below 15% and soil depth exceeding 60% (Djaenudin et al., 2011; Wahyunto et al., 2016). Furthermore, 41,16% of the land classified as S3 was limited by erosion hazard, either alone or in combination with other limiting factors. This was reasonable considering that LU in the study area had slopes of >8% with moderate to severe soil erosion class.

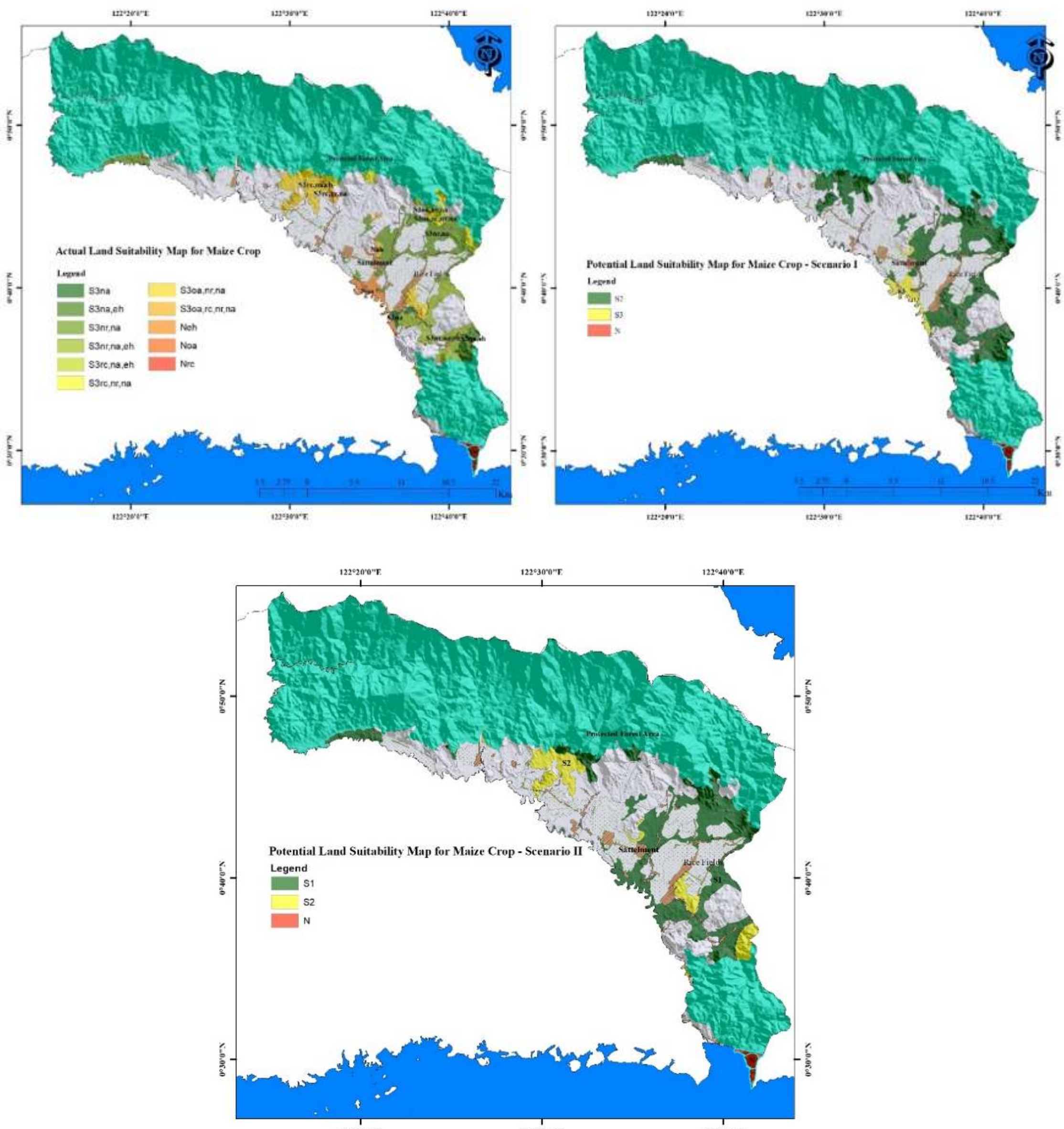

Figure 3. The actual and potential of maize land suitability.

Table 6. The actual and potential of land suitability for maize crops.

LU	ALS	Limiting factors	Improvement of limiting factors - 1	PLS-1	Improvement of limiting factors - 2	PLS-2	Areas	
							ha	%
1, 11, 21, 24, 25, 27	S3nr,na (*nutrient retention, nutrient availability*)	Organic C, nitrogen, phosphor, potassium	Addition of organic fertilizer, NPK fertilizer	S2	Subsidies of organic fertilizer, NPK fertilizer	S1	3,678.26	31.26
2, 5, 7, 15	S3na (*nutrient availability*)	Nitrogen, phosphor, potassium	NPK fertilizer	S2	Subsidies of NPK fertilizer	S1	300.33	2.55
3, 8, 12	S3rc,na,eh (*rooting condition, nutrient availability, erosion hazard*)	Coarse materials, potassium, slopes, erosion	Soil tillages, K fertilizer, terracing	S2	Subsidies of soil tillages, K fertilizer, terracing	S2	1,955.33	16.62
4, 28, 30	Neh (*erosion hazard*)	Slopes	Terracing	S3	Subsidies of terracing	S2	142.13	1.21
6, 13, 16	S3na,eh (*nutrient availability, erosion hazard*)	Phosphor, potassium, slopes	Adding PK fertilizer, terracing	S2	Subsidies of PK fertilizer, terracing	S2	566.56	4.81
9, 10	Noa (*oxygen availability*)	Drainage	Construction of *gulud* and *surjan*	S3	Subsidies of *gulud* and *surjan*	S1	724.88	6.16
14, 18, 26	S3rc,nr,na (*rooting condition, nutrient retention, nutrient availability*)	Texture, organic C, nitrogen, phosphor, potassium	Addition of organic fertilizer, NPK fertilizer, tillages	S2	Subsidies of organic fertilizer, NPK fertilizer, tillages	S1	338.71	2.88
17, 22, 23	S3nr,na,eh (*nutrient retention, nutrient availability, erosion hazard*)	organic C, nitrogen, phosphor, potassium, slopes, erosion	Addition of organic fertilizer, NPK fertilizer, terracing	S2	Subsidies of organic fertilizer, NPK fertilizer, tillages	S1	2,322.19	19.73
19	S3oa,rc,nr,na (*oxygen availability, rooting condition, nutrient retention, nutrient availability*)	Drainage, texture, organic C, nitrogen, potassium	Construction of *gulud* and *surjan*, tillages, organic fertilizer, NK fertilizer	S2	Subsidies of *gulud* and *surjan*, tillages, organic fertilizer, NK fertilizer	S1	1,026.23	8.72
20	S3oa,nr,na (*oxygen availability, nutrient retention, nutrient availability*)	Drainage, organic C, nitrogen, potassium	Construction of *gulud* and' *surjan*, organic fertilizer, NK fertilizer	S2	Subsidies of *gulud* and *surjan*, organic fertilizer, NK fertilizer	S1	248.40	2.11
29	S3oa,nr,na (*oxygen availability, nutrient retention, nutrient availability*)	Drainage, organic C, potassium	Construction of *gulud* and *surjan*, tillage, organic fertilizer, K fertilizer	S2	Subsidies of *gulud* and *surjan*, tillages, organic fertilizer, K fertilizer	S1	100.21	0.85
31, 32, 33	Nrc (*rooting condition*)	Surface rocks	Difficult to do repairs, shallow soil solum	N	Difficult to do repairs, shallow soil solum	N	365.10	3.10
Total area (ha)							11,768.33	100.00

LU = land unit; ALS = actual land suitability; PLS = potential land suitability.

The ideal slope for maize was <8% and soil erosion, as reported by several studies (Subardja and Sudarsono, 2005; Djaenudin et al., 2011; Wahyunto et al., 2016). Flat slopes could accelerate the flowering age of male and female flowers as well as increase the weight of dry-shelled seeds (Nurdin et al., 2020). The remaining land in the region was considered to be unsuitable (N) due to the limiting factor of shallow soil depth, obstructed drainage, and steep slopes. The application of a *surjan* system was effective in facilitating adaptation to environmental factors caused by climate change and low greenhouse gas emissions (Rusmayadi et al., 2022). This system also helped to mitigate the effect of inundation, as well as increase the efficiency of water use in combination with bunds (Dariah and Heryani, 2014; Haryati, 2014). The annual crops generally require land with a flat to a slightly sloping surface or a slope ranging from 0-8% without the danger of erosion (Hardjowigeno, 2003). Slope position also had a significant effect on the yields of maize plants (Changere and Lal, 1997). Furthermore, the slope of an area was closely related to the quantity of soil organic carbon, total N, and enzyme activity by changing the rate of litter decomposition and microbial activity (Nahidan et al., 2015). It also affected the quality of land and was one of the parameters in determining the level of suitability for a particular crop (Everest et al., 2021).

Maize required good soil drainage because it was associated with aeration in the soil for oxygen availability, which was essential for the proper development of plant roots and absorption of nutrients (Wirosoedarmo et al., 2012). The actual land suitability class showed a series pattern, of S3 > N. The results showed that most of the limiting factors in LU used for maize plantation with an area percentage of 96.9% could be improved for the ALS class, except for SPL 31, 32, and SPL 33. These exceptions, with an area percentage of 3.10%, were difficult to repair due to slope limiting factors and shallow soil solum, as shown in Table 4. Furthermore, the improvement efforts carried out were dependent on the level of knowledge and technology mastery, as well as the financial ability of farmers/land owners. Lands that naturally had a low land suitability class could be improved with technology (Ritung et al., 2011). The limiting factor for nutrient retention and available nutrients were improved through the addition of organic matter (Nursyamsi et al., 2002; Wirosoedarmo et al., 2012) and NPK fertilizers (Imanudin et al., 2020), while the coarse material was improved through soil cultivation (Elfayetti and Herdi, 2015). The limiting factor of soil drainage was enhanced with the use of *gulud* and *surjan*, while slopes and soil erosion were enhanced using terracing (Bahtiar et al., 2012; Husain et al., 2012; Wirosoedarmo et al., 2012). After the efforts to improve the potential suitability class in scenario 1 (PLS-1), most of the land (89.53%) was classified as moderately suitable (S2) for the maize plant. The remaining region was classified as marginally suitable (S3) (6.40%) and unsuitable (N) (4.07%). Based on PLS-1, maize plant suitability followed a series pattern, namely S2> S3> N. Although lands with low KLA naturally were improvable, only some qualities and characteristics could be improved. A previous study revealed that a higher level of management was required to raise the land suitability class (Ritung et al., 2011). The potential suitability assessment of scenario 2 (PLS-2) was based on the improved land quality by the government, which included subsidies for soil management, organic fertilizers, NPK fertilizers, improvement of drainage, liming, and subsidized terracing. After efforts to improve scenario 2 (PLS-2), most of the area (74.26%) was classified as very suitable (S1) for maize plants. Furthermore, the remaining region was classified as moderately suitable (S2) and unsuitable (N), accounting for 22.64% and 3.10% of the total area, respectively. Based on PLS-2, maize plants in the study area followed a series pattern, namely S1> S2> N.

The financial advantages commodity of maize

The input-output analysis of maize farming (Table 7 and Figure 3) showed that the average total cost (input) was Rp. 3,863,431.87/ha. The production of dry-shelled maize ranged from 719.2-2,876.70 t/ha, and the highest of 2,876.70 kg was obtained in the very suitable (S1) class. Meanwhile, the S2, S3, and N classes decreased by 80%, 60%, and 40% from the S1 class, respectively. The decline in production volume per hectare affected farmers' income and the profit obtained from the cultivation of the plant. The average price of dry-shelled maize with 17% water content in the study area was Rp. 3,500.

Based on the return and total cost (input) of farmers, maize farming in classes S1, S2, and S3 was still profitable as the R/C ratio ranged from 1.56-2.61 (R/C ratio > 1). The results also showed the absence of profitability in the N class because the R/C ratio was only 0.65 (R/C ratio < 1). Based on these findings, R/C ratio > 1 indicated that farming was profitable and vice versa (Soekartawi, 2006). In S1, S2, and S3 classes, the R/C ratio was 1.56-2.61, which indicated the use of 1 rupiah for cultivation yielded a profit of 1.56 - 2.61 rupiah. Furthermore, when the same commodity was assigned to different LU with the same suitability class, the GM and BC ratio obtained were similar to that of the previous land unit. This was based on the assumption that the same level of farm management was used for all commodities, with a cropping pattern of monoculture and only one planting (Widiatmaka et al., 2012).

Maize advantages commodity in bases, specialization, and localization

The production of major food crop commodities, namely rice, maize, and soybean in the study area showed fluctuating trends in 2014, 2016, and 2018, as shown in Table 8. (BPS Gorontalo Regency, 2020). In these years, all commodities and districts experienced a decline in production, except for the maize commodity in Mootilango District, which increased. The results of the location quotient analysis indicated that maize was a basic commodity (LQ>1) in Mootilango District, as shown in Table 9. It was reported to be a basic commodity in Asparaga District, but only in 2014 and 2018. Rice was a basic commodity in Boliyohuto and Tolangohula District (LQ> 1), while this was achieved in Mootilango District only in 2016 and 2018. These findings were in line with Jumiyanti (2018) that the agricultural sector had an economic advantage in Gorontalo Regency. The soybean commodity only became a basic commodity (LQ>1) in Asparaga District in 2014 and 2016. In the food crop sub-sector, commodities with comparative advantage were determined based on the LQ value>1. Based on this approach, the commodities were produced through the dominance of natural resource support, which could not be easily replicated in other regions (Mulyono and Munibah, 2016; Jumiyanti, 2018).

Table 7. Analysis of maize farm input-output in the study areas.

Parameter	Unit of measure	Unit of price (Rp)	Amount input/output (1x)	Amount input/output (1 year)	Values (Rp.)
(Input)					
Seeds	kg	50,000.00	14.5	14.5	726,351.35
N fetilizer (Urea)	kg	1,200.00	159.6	159.6	191,554.05
NPK fetilizer (Phonska)	kg	1,150.00	176.01	176.0	202,415.54
P fetilizer (SP-36)	kg	1,701,56	0.0	0.0	0.00
K fertilizer (KCl)	kg	2,500.00	0.0	0.0	0.00
Herbicides	package	140,000.00	1.1	1.1	159,391.89
Pesticides	package	67,500.00	1.2	1.2	77,989.86
Organic fertilizer	tons	60,000.00	0.0	0.0	0.00
Rent a tractor	package	232,500.00	0.8	0.8	180,658.78
Livestock	cwd	67,083.33	0.3	0.3	18,130.63
Labor	wdp	62,361.11	37.0	37.0	2,306,939.75
Input total (Rp.)					3,863,431.87
(Output) for LSC S1					
Maize	kg	3,500.00	2,876.7	2,876.7	10,068,412.16
RCR					2.61
GM					6,204,980.29
BCR (discount rate 15%)					2.27
(Output) for LSC S2					
Maize yield	kg	3,500.00	2,301.4	2,301.4	8,054,729.73
RCR					2.08
GM					4,191,297.86
BCR (discount rate 15%)					1.81
(Output) for LSC S3					
Maize yield	kg	3,500.00	1,726.0	1,726.0	6,041,047.30
RCR					1.56
GM					2,177,615.43
BCR (discount rate 15%)					1.36
(Output) for LSC N					
Maize yield	kg	3,500.00	719.2	719.2	2,517,103.04
RCR					0.65
GM					-1,346,328.83
BCR (discount rate 15%)					0.57

wdp = working day people; cwd = cattle work day.

Table 8. The trend of rice, maize, and soybean production in the study area.

No	Districts	Rice (t)			Maize (t)			Soybean (t)		
		2014	2016	2018	2014	2016	2018	2014	2016	2018
1	Boliyohuto	16,765	16,576	9,527	3,765	1,669	1,669	48	0	0
2	Mootilango	23,950	23,165	12,831	15,200	19,091	19,091	49	18	0
3	Tolangohula	31,612	32,707	23,643	3,549	2,026	2,026	106	0	0
4	Asparaga	10,549	9,052	6,618	11,750	4,883	4,883	152	94	0
5	Bilato	1,183	376	376	10,890	7,995	7,995	96	26	0
	Total (ton)	84,058	81,875	52,996	45,154	35,664	35,664	451	138	0

Source: BPS Gorontalo Regency (2020).

Table 9. Trends of maize commodity base (LQ) compared to other food crop commodities.

No	Districts	Rice			Maize			Soybean		
		2014	**2016**	**2018**	**2014**	**2016**	**2018**	**2014**	**2016**	**2018**
1	Boliyohuto	1.26	1.31	1.42	0.53	0.30	0.37	0.67	0.00	0.00
2	Mootilango	0.95	1.83	1.92	1.12	3.45	4.24	0.36	0.84	0.00
3	Tolangohula	1.39	2.58	3.53	0.29	0.37	0.45	0.87	0.00	0.00
4	Asparaga	0.72	0.71	0.99	1.48	0.88	1.08	1.92	4.39	0.00
5	Bilato	0.15	0.03	0.06	2.57	1.45	1.78	2.27	1.22	0.00

A previous study revealed that maize had a comparative advantage in Gorontalo Province (Nurdin, 2011). The results of the specialization index analysis of major food crops showed that maize was a special commodity (SI ≈ 1) in Bilato District in 2014, 2016, and 2018, as shown in Table 10. Tolangohula District also showed maize as a special commodity, while it was considered common in the remaining district. Furthermore, the pattern was similar for rice, which was a special commodity in Bilato and Tolangohula Districts (SI ≈ 1). The results showed that soybean was common in all districts (SI = 0 or ≈ 0). A commodity was considered special for a region if the value of the specialization coefficient (SI)> 1, and vice versa. A specialization index close to zero showed that the distribution of activities, or in this case, the main food crop commodities, was evenly distributed (Yomalinda, 2015). The identification of superior commodities in a region was necessary for achieving efficiency, competitiveness, and sustainability compared to the same commodities in other areas (Fahri, 2017).

Table 10. Trends of maize commodities specialization index (SI) compared to other food crop commodities.

No	District	Rice			Maize			Soybean		
		2014	**2016**	**2018**	**2014**	**2016**	**2018**	**2014**	**2016**	**2018**
1	Boliyohuto	0.08	0.11	0.13	0.08	0.11	0.13	0.00	0.00	0.00
2	Mootilango	0.02	0.07	0.10	0.02	0.07	0.10	0.00	0.00	0.00
3	Tolangohula	0.12	0.12	0.16	0.12	0.12	0.16	0.00	0.00	0.00
4	Asparaga	0.09	0.03	0.01	0.08	0.02	0.01	0.00	0.00	0.00
5	Bilato	0.27	0.33	0.28	0.27	0.32	0.28	0.00	0.00	0.00

The results of the localization index analysis of the major food crop commodities showed that maize commodity was more centralized (LI ≈ 1) in Tolangohula District in 2014, 2016, and 2018, as shown in Table 11. The same trend was observed in Bilato and Mootilango Districts, while the crop was evenly distributed in other districts. Furthermore, the localization index of rice demonstrated a similar pattern, with the commodity being more centralized in Tolangohula, Bilato, and Mootilango Districts (LI ≈ 1). The results of this analysis were consistent with the findings of Syahrial and Herman (2019) on the distribution of rice, maize, and soybeans in several sub-districts in West Sumatra, as well as Nurdin (2011) report in Gorontalo Province. Soybean commodities were relatively concentrated in Mootilango, Asparaga, and Bilato Districts. A localization coefficient (LI) of >1 indicated that the food crop commodity was concentrated in a particular region, while values <1 showed its spread in each observed region. Furthermore, the smaller the coefficient value, the more the spread of the commodity (Nurdin, 2011). A localization index (LI) of <1 indicated that a commodity was not concentrated in one region but spread over several regions (Pasaribu and Soetriono, 2009).

Table 11. Trends of maize commodities localization index (LI) compared to other food crop commodities.

No	Districts	Rice			Maize			Soybean		
		2014	**2016**	**2018**	**2014**	**2016**	**2018**	**2014**	**2016**	**2018**
1	Boliyohuto	0.02	0.02	0.03	0.04	0.05	0.04	0.03	0.08	0.00
2	Mootilango	0.01	0.04	0.06	0.02	0.09	0.09	0.10	0.11	0.00
3	Tolangohula	0.05	0.05	0.08	0.10	0.12	0.12	0.02	0.15	0.00
4	Asparaga	0.02	0.00	0.00	0.04	0.01	0.00	0.08	0.28	0.00
5	Bilato	0.04	0.03	0.04	0.07	0.08	0.06	0.06	0.06	0.00
	LI	0.15	0.15	0.21	0.27	0.35	0.31	0.28	0.68	0.00

Recommendation of maize land management priority

Based on the combination of soil erosion hazard levels, potential land suitability classes, bio-agriculture analysis, and maize commodity basis (Table 12), the widest land management for maize development was recommendation I, which covered 80.25% of the land. Recommendations II and III covered 13.13% and 3.52% of the land, respectively, and only 3.10% of the area was not recommended for maize production, as shown in Figure 4.

Table 12. Recommendations and priorities for land management efforts for maize development.

Land Management Recommendations	Priority of Land Management Efforts	LU	Area	
			ha	%
I	Balanced and location-specific NPK and organic fertilizer fertilization for cost efficiency, making terraces based on width, increasing planting area	1; 2; 3; 13; 14; 15; 16; 18; 19; 20; 21; 22; 23; 24; 25; 26; 27; 29	9,444.22	80.25
II	Balanced and location-specific NPK and organic fertilizers for cost efficiency, making *gulud* and *surjan*, increasing planting area	5; 6; 7; 8; 9; 10; 11; 12; 28	1,544.79	13.13
III	Balanced and location-specific NPK and organic fertilizers for cost efficiency, making bench terraces, increasing planting area	4; 17; 30	414.22	3.52
NR	Land rehabilitation, reforestation	31, 32, 33	365.10	3.10
Total area (ha)			11,768.33	100.00

NR = not recommended.

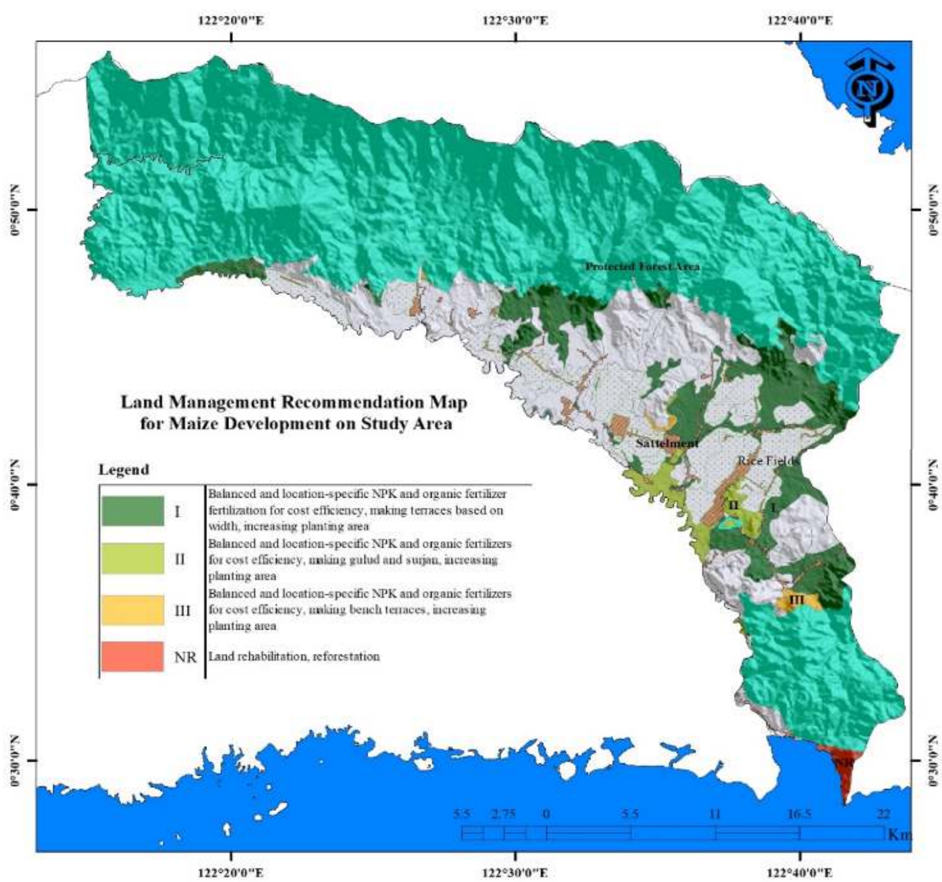

Figure 4. Land management recommendation map.

Recommendations I to III prioritize the use of location-specific balanced and organic fertilizers, as well as increasing the planting area to expand the commodity base, which was essential for achieving food security and cost efficiency (Burhan et al., 2011). These methods could also increase fertilization efficiency and farmers' income, support the sustainability of production systems (Syarifuddin, 2016), and improve maize yields (Susilowati and Kusumo, 2019). Maize field management efforts often differed in terms of the soil conservation techniques applied. The implementation of terraces based on width was recommended for land classified as recommendation I. Furthermore, making mounds and *surjan* was suggested for recommendation II, and making bench terraces was proposed for recommendation III land. Lands that were not recommended must undergo rehabilitation and reforestation. Terracing could be applied to sloping areas to reduce the rate of soil erosion (Bahtiar et al., 2012; Husain et al., 2012; Wirosoedarmo et al., 2012). Water use efficiency could be achieved by applying a combination of mounds and *surjans* (Dariah and Heryani, 2014; Haryati, 2014), specifically on poorly drained land. Rehabilitation was suggested for heavily eroded lands (Wahyuningrum and Putra, 2019), while reforestation was proposed for critical areas (Wahyudi, 2014).

Conclusion

Actual land suitability (ALS) for maize was partly classified as marginally suitable (S3), and the remaining areas were classified as not suitable (N). After the limiting factors were improved based on the knowledge and ability level of farmers, the potential land suitability of scenario 1 (PLS-1) was mostly moderately suitable (S2), and the remaining land area was classified as marginally suitable (S3) and not suitable (N). However, with the efforts to improve the limiting factors through government subsidies, scenario 2 (PLS-2) showed improvement, with most of the land being classified as very suitable (S1) and the remaining areas were moderately suitable (S2), marginally suitable (S3), and not suitable (N).

The maize commodity was profitable and feasible in all land suitability classes, except for N. Maize had a comparative advantage as a basic commodity in Mootilango and Asparaga Districts, while it was only considered a special commodity in Bilato and Tolangohula Districts. The results showed that the crop was more concentrated in Tolangohula, Bilato, and Mootilango Districts. Land management recommendations for maize based on land area followed a pattern of recommendation I > II > III > not recommended. Further studies using data on harvested area and production of maize and other food crop commodities from each LU are strongly recommended. The results are expected to help in determining the correlation with the suitability of agroecological maize fields.

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