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Impacts of parametric methods on land suitability classification and land management prioritization for porang, *Amorphophallus onchophyllus* in Indonesia: A comparative study

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ABSTRACT
Porang is becoming recognized as a strategic commodity due to its high demand and substantial economic value. However, the lack of a standardized set of site-specific land suitability criteria for porang presents challenges in conducting land suitability assessments and planning for its use. Therefore, this study addressed the knowledge gap by evaluating land suitability classes and the implications of land management for porang cultivation, using different parametric methods. A comprehensive survey of 32 land units was conducted, followed by soil analysis in the laboratory. The square root (SRM) and the Rabia and Terribile (RTM) parametric methods were employed for the land suitability assessment. Subsequently, the land management priorities were determined based on the results of the land suitability class analysis derived from both methods. The results showed that land suitability for porang plants with SRM and RTM was dominated by the very suitable class (S1), however, the distribution of S1 was wider with RTM. The remaining classes with SRM consisted of moderately suitable (S2), marginally suitable (S3), currently not suitable (N1), and permanently not suitable (N2), while the remaining classes with RTM only consisted of S1, S2, and S3 classes without class N. The priority of land management for porang plants for both parametric methods is dominated by priority I, however, in SRM there are priorities II, III, and NP (not priority), while in RTM, there are only II and III. Based on land suitability class and land management priority, RTM was still better than SRM.

Keywords: Class, Land, Management, Porang, Parametric, Suitability.
Article type: Research Article.

INTRODUCTION
Porang, *Amorphophallus onchophyllus* has become a strategic agricultural commodity in Indonesia. This is because the commodity has high economic value and its demand continues to be increased (Riptanti *et al.* 2022). This plant is popular in the community (Utami 2021) due to containing high levels of glucomannan (Yanuriati *et al.* 2017; Lufiana *et al.* 2023) widely used in the food, health, cosmetic, and other industries (Gusmalawati *et al.* 2022). It is also good to be consumed for diet programs (Azizi & Kurniawan 2021; Sharma & Wadhwa 2022) with low cholesterol value to prevent heart disease and reduce high blood pressure (Azizi & Kurniawan 2021). There are numerous and diverse benefits associated with this porang plant, prompting considerable interest from multiple stakeholders. Pohuwato is among the five districts in the province of Gorontalo, showing significant potential for porang development. There are limitations on adequate information, leading to relatively limited and small-scale local cultivation across several areas. However, there is considerable interest among farmers, owing to the high market value of the tubers. The Regional Government of Pohuwato Regency is actively seeking to

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foster the development of porang cultivation through collaborative efforts with various competent entities, such as the BPTP of South Sulawesi. The aim is to tap into the potential of the commodity and promote its sustainable growth in the region (Setyo 2021). This refers to the existence of people who can be an alternative food source (Pasaribu *et al.* 2022). In addition, porang can grow in various types of soil (Kusnarta *et al.* 2021), including dry and humus soil with a pH of 6-7 (Siswanto & Karamina 2016). To grow and develop properly (Banjarnahor & Simanjuntak 2016), each plant requires specific and different environmental suitability (Zainudin *et al.* 2020; Demina 2020; Abolhasani *et al.* 2021; Firdaus *et al.* 2022; Amraei 2022, Al-Dulaimy *et al.* 2022). The land requirements for cultivating porang are based on the proposal of Siswanto & Karamina (2016). However, the set of land requirements is not complete and some of the main characteristics such as drainage class, texture, soil depth, total N content, available P_2O_5, and exchangeable K_2O do not have land suitability class interval values. This is quite difficult in assessing land suitability for porang using the usual matching method. One solution in assessing land suitability with limited criteria is to use the parametric method. This is in line with Nurdin *et al.* (2022) that the limitations of the land suitability criteria can be overcome by applying the parametric method. The results are better than the matching method in the assessment of land suitability classes for liberika coffee at Pinogu Plateau of Gorontalo Province. In principle, the parametric method identifies combinations of land characteristics affecting agricultural production and land suitability classes using mathematical equations (Elaalem 2013; Marbun *et al.* 2019; Nwer *et al.* 2020). In this method, different land suitability classes (LSC) are defined as completely separate groups with different but consistent ranges (Bagherzadeh & Gholizadeh 2016; Bagherzadeh *et al.* 2016). Quantitative ratings are assigned to each attribute, ranging from 0 to a maximum of 100 (Shiri & Farbodi 2022). Subsequently, the correlations between all variables are calculated to assess their relationships and interdependencies (Rabia & Terribile 2013). The interpretation and calculation of the parameters is carried out based on the assessment of the increase in the degree of limiting factor (Dengiz *et al.* 2010). The parametric method is a composite land suitability assessment based on selected land characteristics, affecting crop production to minimize interactions. Results of the land suitability analysis using the parametric method can help make decisions about land management and crop cultivation practices (Shik & Solomon 2020). However, using different rating factors in the application of the parametric method results in different land suitability classes and use limitations (Shiri & Farbodi 2022). The consequences affect the most rational and applicable land management decision-making for porang. Therefore, this study assesses land suitability classes and the implications of the management for porang as a consequence of using different parametric methods.

MATERIALS AND METHODS

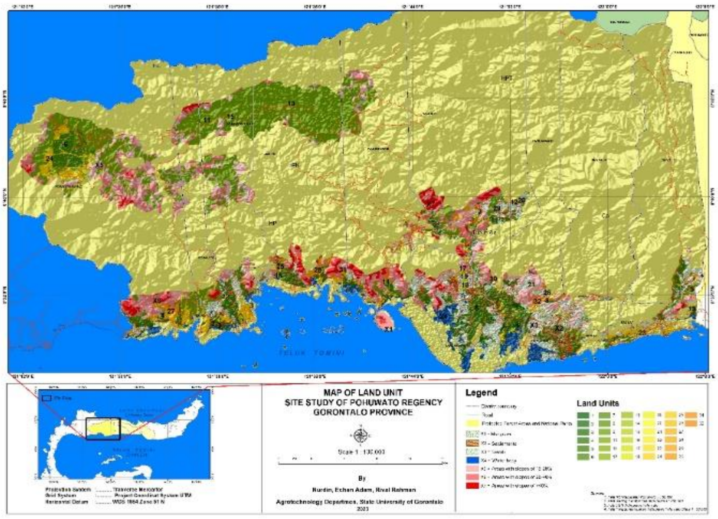
General description of site study

This study was conducted in the Pohuwato Regency of Gorontalo Province, geographically located at 0°26'5.4″ to 0°42'25.03″ latitude and 121°12'41.02″ to 122°08'11.37″ longitude. This location covers an area of 59,527.52 ha with an elevation of 3 – 754 m asl on the coast of Tomini Bay (Fig. 1). Furthermore, land use was dominated by plantations at 80.42%, followed by the dry land agriculture and shrubs at 17.55% and 2.03%. The landform primarily consists of gently sloping hills, accounting to 95.62% of the area, with the remaining 4.38% being plains. Given the geological formation units, the Tinombo (Teot) formation dominates, covering approximately 61.96% of the region, while the Lokodidi (TQls) formation covers a smaller proportion, approximately 0.08%. The slopes are dominated by a sloping class of 64.43% and at least a flat class of 4.38%. The location has a tropical climate with annual rainfall and air temperatures ranging from 1.603 – 1.894 mm and 28.71 – 28.80 °C respectively (Table 1).

Soil and other land characteristics data collection

Data on other land characteristics were acquired through a combination of soil surveys and land observations, along with soil analysis in a laboratory setting. Before initiating the soil survey and land observation, the first step involved preparing land unit maps at a scale of 1:100,000 (Fig. 1). These maps were superimposed with slope maps, landform maps, geological maps, and land use maps to obtain 32 distinct land units. Subsequently, a set of soil survey tools was assembled, including the soil drill auger Belgi types, a clinometer, GPS device, pH meter, soil knife, soil belt, hoe, spade, and permanent marker F. Specific materials such as fastening rubber, label paper, plastic bags, soil mini-pit cards, and climate data from the local BMKG station covering a period of 7 years (2016-2022) were used during the survey. The soil samples collected were intended for laboratory analysis, where further investigations on soil characteristics will be conducted. The soil survey was carried out using a minipit as deep as

40 cm and a further depth with a drill in each selected land unit. Furthermore, field observations were carried out to determine the land characteristics such as elevation, slope, and drainage. A total of 1 kg of soil samples were also taken for analysis in the laboratory.



Land Units	Land Use	Landform	Geology Formation	Slope Class (%)	Widely Ha	Widely %
1	Plantation	Plains	*Qal*: Alluvium and Coastal Deposites	0 - 3	508.48	0.85
2	Shrubs	Plains	*Qal*: Alluvium and Coastal Deposites	0 - 3	374.28	0.63
3	Upland	Plains	*Qal*: Alluvium and Coastal Deposites	0 - 3	1,724.65	2.90
4	Plantation	Sloping Hills	*Gr*: Breakthrough Rock	3 - 8	83.54	0.14
5	Plantation	Sloping Hills	*Qal*: Alluvium and Coastal Deposites	3 - 8	9,054.18	15.21
6	Plantation	Sloping Hills	*Teot*: Tinombo Formation	3 - 8	2,308.27	3.88
7	Plantation	Sloping Hills	*Tmr*: Randangan Formation	3 - 8	84.22	0.14
8	Plantation	Sloping Hills	*Tpb*: Bumbulan Granodiorite	3 - 8	142.65	0.24
9	Plantation	Sloping Hills	*Qal*: Alluvium and Coastal Deposites	8 - 15	2,886.49	4.85
10	Plantation	Sloping Hills	*Teot*: Tinombo Formation	8 - 15	31,294.56	52.57
11	Plantation	Sloping Hills	*Tmd*: Dolokapa Formation	8 - 15	1,072.06	1.80
12	Plantation	Sloping Hills	*Tmr*: Randangan Formation	8 - 15	169.11	0.28
13	Plantation	Sloping Hills	*Tpb*: Bumbulan Granodiorite	8 - 15	57.05	0.10
14	Plantation	Sloping Hills	*Tppv*: Pani Volcano Rocks	8 - 15	163.86	0.28
15	Plantation	Sloping Hills	*TQlt*: Lokodidi Formation	8 - 15	46.37	0.08
16	Shrubs	Sloping Hills	*Qal*: Alluvium and Coastal Deposites	3 - 8	311.36	0.52
17	Shrubs	Sloping Hills	*Teot*: Tinombo Formation	3 - 8	40.31	0.07
18	Shrubs	Sloping Hills	*Qal*: Alluvium and Coastal Deposites	8 - 15	240.23	0.40
19	Shrubs	Sloping Hills	*Teot*: Tinombo Formation	8 - 15	158.91	0.27
20	Shrubs	Sloping Hills	*Tmr*: Randangan Formation	8 - 15	59.47	0.10
21	Shrubs	Sloping Hills	*Tpb*: Bumbulan Granodiorite	8 - 15	22.34	0.04
22	Upland	Sloping Hills	*Gr*: Breakthrough Rocks	3 - 8	101.32	0.17
23	Upland	Sloping Hills	*Qal*: Alluvium and Coastal Deposites	3 - 8	4,123.66	6.93
24	Upland	Sloping Hills	*Teot*: Tinombo Formation	3 - 8	2,132.75	3.58
25	Upland	Sloping Hills	*Tppv*: Pani Volcano Rocks	3 - 8	139.27	0.23
26	Upland	Sloping Hills	*TQpv*: Pinogu Volcano Rocks	3 - 8	43.90	0.07
27	Upland	Sloping Hills	*Gr*: Breakthrough Rock	8 - 15	414.60	0.70
28	Upland	Sloping Hills	*Teot*: Tinombo Formation	8 - 15	949.13	1.59
29	Upland	Sloping Hills	*Tmr*: Randangan Formation	8 - 15	57.86	0.10
30	Upland	Sloping Hills	*Tpb*: Bumbulan Granodiorite	8 - 15	199.80	0.34
31	Upland	Sloping Hills	*Tppv*: Pani Volcano Rocks	8 - 15	337.77	0.57
32	Upland	Sloping Hills	*TQpv*: Pinogu Volcano Rocks	8 - 15	225.07	0.38
			Total (Ha)		59,527.52	100.00

Fig. 1. Map of the study area's land units.

Table 1. Summary statistics of land characteristics.

Land characteristics		**Descriptive statistics**					
Parameters	**Units**	**n**	**Maximum**	**Minimum**	**Mean**	**Median**	**SD**
Elevation	m sl	32	754	3	69	25	145.99
Slope	%	32	15	1	8	8	4.41
Temperature	ºC	32	29	29	29	29	0.02
Rainfall	mm	32	1,894	1,603	1,768	1,807	89.47
Drainage	class	32	5	1	3	3	1.40
Sand	%	32	34	14	23	22	5.02
Silt	%	32	50	10	30	29	9.37
Clay	%	32	60	29	47	47	7.12
Effective depth	cm	32	100	22	56	48	23.43
pH		32	6	4	5	5	0.44
Organic C	%	32	2	1	1	1	0.47
Cation exchange capacity	cmol	32	30	17	24	24	3.03
Base saturation	%	32	50	18	27	27	6.28
Total N	%	32	0	0	0	0	0.04
P_2O_5	mg kg^{-1}	32	11	5	8	9	1.55
K_2O	cmol	32	0	0	0	0	0.07
ESP	%	32	1	0	0	0	0.23

Note: *n* = the number of the land unit; *SD* = standard deviation; *ESP* = exchangeable sodium percentage.

Soil laboratory analysis initiated by drying the sample in a place that was not exposed to direct sunlight for 3 days, then pulverizing and sifting through a 0.5 mm and 2.0 mm sieve. The analysis of selected soil properties referred to the procedure of Eviyati & Sulaeman (2009). Soil texture was analyzed based on the fraction of sand, clay, and silt using the pipette method, and the reaction (pH H_2O) was extracted in the soil and water solution (1: 2.5) using a pH meter. Meanwhile, the percentage of organic carbon was analyzed using the Walkley and Black method (Walkley & Black 1934), while total nitrogen was analyzed by the Kjeldahl method (Kjeldahl 1883). For cation exchange capacity (CEC), base saturation and available potassium (K_2O) were extracted with NH_4OAc 1 N at pH 7 (Chapman 1965). Meanwhile P_2O_5 content was available using the Olsen method (Olsen *et al.* 1954), and the sodium exchange percentage was calculated based on the ratio of exchangeable sodium to CEC. All soil data and selected land characteristics were validated according to standard criteria and transferred to an Excel spreadsheet.

Porang yield estimation

Due to the limited availability of data for land units, the estimation of porang yield was performed using an equation derived from the relationship with land characteristics, as reported by Siswanto & Karamina (2016):

$Y = 0.023\text{elevation} + 3.7697$ $R^2 = 0.55$
$Y = 0.8741\ln(\text{slope}) + 7.3837$ $R^2 = 0.98$
$Y = -0.0235\text{effective depth} + 11.659$ $R^2 = 1.00$
$Y = 2.6887\text{drainage} - 0.9487$ $R^2 = 0.51$
$Y = -0.0028\text{sand}^2 + 0.3645\text{Sand}$ $R^2 = 0.81$
$Y = -0.601\ln(\text{silt}) + 11.293$ $R^2 = 0.95$
$Y = 1.4159\ln(\text{clay}) + 4.625$ $R^2 = 0.97$
$Y = -4.2669\text{pH}^2 + 52.393\text{pH} - 149.8$ $R^2 = 0.56$
$Y = 0.7194\ln(\text{organic carbon}) + 7.3171$ $R^2 = 0.96$
$Y = 1.1565\ln(\text{total nitrogen}) + 12.339$ $R^2 = 0.98$
$Y = 2.5293\ln(P_2O_5) + 0.2434$ $R^2 = 0.89$
$Y = 0.0626K_2O + 6.3424$ $R^2 = 0.63$
$Y = 1.4493\ln(\text{cation exchange capacity}) + 3.2639$ $R^2 = 0.97$
$Y = -0.1472\text{ base saturation} + 15.73$ $R^2 = 1.00$
$Y = -21.007\text{ exchangeable sodium percentage} + 14.538$ $R^2 = 0.68$
$Y = 0.0626\text{ temperature} + 6.3424$ $R^2 = 0.84$
$Y = -0.0014\text{ rainfall}^2 + 0.2014\text{rainfall} + 4.0108$ $R^2 = 0.83$

To assess the accuracy and reliability of the estimation of porang production, it was assessed by the root mean square error (RMSE) based on the following equation:

$$RMSE = \left(\frac{\sum_{i=1}^{n}(Y_a - Y_f)}{n}\right)^{1/2}$$

where, Y_a = actual yield (tons ha^{-1}), Y_f = forecesting yield (tons ha^{-1}), and n = number of data. The smaller or closer to 0 the value of the RMSE, the more accurate the prediction results.

Land suitability analysis

After obtaining porang yield data for all land units, it was followed by an assessment of the rating index (RI) based on local achievements. The formulation for assessing RI followed the equation:

$$RI\ (\%) = \left(\frac{Y_f}{Y_a}\right) x\ 100$$

where, Y_f = forcesting yield (tons ha^{-1}) and Y_a = actual yield (tons ha^{-1}). The reference value for the actual yield of porang was 10.14 tons ha^{-1} (Siswanto & Karamina 2016).

To assess the land suitability class for porang plants, two different parametric methods were used, namely: the square root method (SRM) and the Rabia and Terribile method (RTM). LSI assessment with the SRM follows the proposed equation by Khiddir (1986) that is:

$$LSI = R_{min}\sqrt{\frac{A}{100}\ x \frac{B}{100}\ x\ \frac{C}{100}\ x \ldots x\ \frac{n}{100}}$$

where, LSI = land suitability index; R_{min} = minimum rating value for land characteristics; and A, B, C, … n = other land characteristic rating values. The RTM method was initiated by making a comparison matrix of parameters that are different from each other by giving values (weights) according to their relative importance. Values ranged from 1 to 17, where 1 and 17 mean that the two parameters compared have the same impact and are more important than the other, and the formulation used was as follow:

$$W = \frac{\mathrm{I}}{\sum \mathrm{I} - (\mathrm{n}+2)}$$

where, W = weight; I = priority parameter; n = number of parameters.

Furthermore, the LSI assessment using the RTM method follows the proposed equation by Rabia & Terribile (2013) that is:

$$LSI = W_{max}\sqrt{\frac{A}{100}\ x \frac{B}{100}\ x\ \frac{C}{100}\ x \ldots x\ \frac{n}{100}}$$

where, LSI = land suitability index; W_{max} = weight maximum rating for land characteristics; and A, B, C, … n =

other land characteristic rating values.
After obtaining the value, the LSI is integrated with the land suitability class as presented in Table 2.

Table 2. Equivalent LSI with land suitability classes

Description	Class	Land Suitability Index (LSI)*
Very suitable	S1	>75
Moderately suitable	S2	50 – 75
Marginally suitable	S3	25 – 50
Present not suitable	N1	10 – 25
Permanent not suitable	N2	<10

*Rabia & Terribile (2013).

Land Management Priority

Land management priorities for porang were determined based on land suitability class considerations, factor rating values, factor rating weights, and the possibility of improving factor ratings (Table 3). The order of priority was categorized as high priority (I), medium (II), low (III), and not prioritized (NP).

Table 3. Criteria for determining land management priorities

Criteria for determining land management			Priority
LSI	LSC	Improved factor rating	
>75	S1	Light, can be repaired farmers	I
50 – 75	S2	Medium, can be repaired farmers	II
25 – 50	S3	Heavy, the government can fix it with program subsidies	III
<25	N	Very heavy, difficult to repair	NP

LSC = land suitability class; LSI = land suitability index; NP = not priority.

RESULTS AND DISCUSSION

Performance of porang yield as the basis of rating factor determining

The estimation result showed that the elevation affected the highest porang yields with the achievement of 14.10 tons ha^{-1}. Meanwhile, the lowest yields were shown by pH and exchangeable sodium percentage (ESP), reaching 1.00 ton ha^{-1} (Table 4). The yield reached 8.00 - 16.67 tons ha^{-1} with an average of 12.33 tons ha^{-1} (Pasaribu *et al.* 2022). Based on the land unit (LU), the highest yields were found at LU 24, where the lowest at LU 7, 13, 14, and LU 27.

Table 4. Porang yield estimates.

LU	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8	Y_9	Y_{10}	Y_{11}	Y_{12}	Y_{13}	Y_{14}	Y_{15}	Y_{16}	Y_{17}	RMSE
	ton ha^{-1}																	
1	3.99	7.99	8.14	8.34	4.43	4.56	9.04	9.96	10.06	7.66	7.32	7.51	10.72	9.54	4.64	6.36	12.17	0.43
2	3.83	8.34	8.14	8.34	7.12	6.61	8.95	9.40	9.31	6.55	7.77	7.92	11.78	10.19	5.88	6.36	9.41	0.80
3	3.83	7.38	8.14	8.34	12.49	7.94	9.60	10.31	9.31	6.77	7.80	8.16	12.43	10.38	4.92	6.36	11.68	0.52
4	4.16	8.79	8.14	8.34	12.49	7.09	9.10	9.77	9.31	9.50	7.58	7.75	10.89	10.33	5.52	6.36	8.76	0.91
5	4.07	8.60	8.14	8.34	7.12	6.01	9.14	10.01	9.78	7.27	7.77	7.75	11.25	10.21	5.52	6.37	11.45	0.83
6	4.40	8.95	8.14	8.93	4.43	5.62	9.37	10.36	10.34	9.10	7.46	7.89	11.76	9.69	5.63	6.35	13.28	0.83
7	4.51	9.20	8.14	7.31	1.74	6.48	9.26	10.15	10.58	9.58	7.52	8.02	12.32	10.07	5.88	6.36	1.00	0.60
8	4.25	9.08	8.14	10.98	1.74	5.83	9.02	9.75	9.76	10.27	7.38	7.75	12.22	9.87	5.74	6.35	11.99	0.70
9	4.58	9.40	8.14	8.34	1.74	6.01	9.26	10.20	9.57	6.06	7.37	7.85	12.85	9.67	5.76	6.36	13.33	0.61
10	4.36	9.56	8.14	8.34	12.49	8.75	9.32	9.90	10.13	7.98	7.32	7.43	11.84	9.83	5.24	6.36	13.12	0.72
11	11.38	9.20	8.14	8.93	9.81	7.67	9.32	10.07	10.60	10.43	7.65	7.93	12.00	10.41	5.31	6.36	11.34	0.73
12	4.87	9.48	8.14	7.31	4.43	7.77	9.53	10.28	10.60	3.43	7.49	7.93	12.60	9.96	4.55	6.36	13.58	0.46

13	4.20	9.63	8.14	10.98	7.12	8.66	9.49	10.12	10.84	1.00	7.20	8.11	13.03	9.65	5.28	6.36	14.10	0.60
14	4.26	9.75	8.14	10.98	7.12	6.60	9.21	10.05	10.70	1.00	7.28	7.84	12.64	9.72	4.97	6.35	13.95	0.61
15	10.79	9.69	8.14	8.93	7.12	5.57	8.94	9.55	10.84	9.67	7.11	7.82	12.07	9.24	5.79	6.35	12.80	0.82
16	3.92	8.34	8.14	8.34	12.49	4.69	9.10	10.08	10.58	8.88	7.51	7.84	11.48	10.08	5.81	6.36	12.61	0.88
17	4.09	8.79	8.14	10.98	1.74	7.52	9.30	10.07	10.41	9.29	7.79	7.90	12.29	10.31	5.89	6.36	13.06	0.76
18	4.04	9.08	8.14	8.93	4.43	7.48	9.59	10.36	10.95	6.86	6.96	7.70	11.77	9.47	5.72	6.36	12.95	0.82
19	6.38	9.69	8.14	8.34	7.12	5.58	9.41	10.41	10.25	7.63	7.61	7.81	11.75	10.35	5.28	6.36	13.35	0.41
20	5.42	9.56	8.14	7.31	4.43	8.42	9.90	10.42	10.48	10.07	6.97	7.89	11.38	9.39	5.97	6.35	13.36	0.62
21	6.13	9.75	8.15	8.52	7.12	6.36	9.22	10.10	9.73	7.27	7.19	7.94	10.44	9.63	5.55	6.35	13.02	0.50
22	4.09	7.99	8.14	8.34	7.12	7.33	9.29	10.08	10.65	8.10	7.76	8.07	11.96	10.01	5.77	6.35	12.45	0.50
23	4.50	8.95	8.14	8.34	1.74	6.18	9.14	9.99	9.31	6.24	7.72	7.48	8.31	10.19	6.38	6.36	12.41	0.79
24	14.10	9.20	8.14	8.93	4.43	6.14	9.25	10.17	10.30	1.12	6.93	8.17	12.44	9.34	6.24	6.35	13.29	0.58
25	4.06	8.34	8.14	8.93	12.49	7.49	9.28	10.04	10.70	2.50	7.70	7.88	11.53	9.99	5.73	6.35	12.96	0.87
26	3.93	8.79	8.14	10.98	1.74	7.51	9.33	10.11	10.39	10.81	7.48	7.80	11.09	9.87	5.03	6.35	12.06	0.76
27	4.76	9.63	8.14	8.34	4.43	6.29	9.36	10.29	10.60	1.00	6.89	7.96	11.54	9.24	4.99	6.36	6.39	0.81
28	4.33	9.75	8.14	8.34	7.12	6.49	9.24	10.11	11.02	9.45	7.93	7.83	12.24	10.41	5.46	6.36	11.82	0.62
29	4.41	9.40	8.14	7.31	12.49	8.01	9.38	10.11	10.79	8.88	7.52	7.95	11.51	9.89	4.47	6.36	13.23	0.85
30	4.45	9.56	8.14	10.98	4.43	9.11	9.45	10.01	11.14	10.98	7.44	8.05	11.45	9.97	6.25	6.36	9.75	0.79
31	4.67	9.30	8.14	8.93	12.49	5.21	9.04	9.90	10.86	10.14	7.72	7.40	9.96	10.27	6.14	6.36	13.25	0.71
32	3.84	9.63	8.15	8.52	4.43	6.37	9.16	9.99	10.84	6.36	7.30	7.78	12.36	9.76	6.00	6.36	12.81	0.61

Note: LU = land unit; Y_1 by elevation; Y_2 by temperature; Y_3 by rainfall; Y_4 by slope; Y_5 by drainage; Y_6 by sand; Y_7 by silt; Y_8 by clay; Y_9 =by effective depth; Y_{10} by pH; Y_{11} by organic C; Y_{12} by cation echange capacity; Y_{13} by base saturation; Y_{14} by total N; Y_{15} by P_2O_5; Y_{16} by K_2O; Y_{17} by exchangeable sodium percentage; RMSE = root mean square error.

The elevation above sea level was directly proportional to the yield of porang, since it can grow on plains up to an elevation of 1,000 m asl (Mufidah *et al.* 2021; Fitriyanti *et al.* 2023). Soil reactions also affect porang yields, where the ideal pH is between 5 and 7 (Indriyani *et al.* 2011; Siswanto & Karamina 2016). Meanwhile, in the study area, soil pH was only < 4.5, and the yield of porang was relatively low. Porang plants are also susceptible to saline soils and the susceptibility is due to sodium toxicity with levels ≥ 1.05 cmol (Soedarjo *et al.* 2020). Meanwhile, at LU 7, 1.34 cmol of sodium was found, and the porang yield was relatively low. The level of reliability of porang estimation data based on RMSE values ranged from 0.41 to 0.91 with an average of 0.69, meaning that the estimation results were better and the error rate was relatively low. According to Amelia *et al.* (2021), an RMSE value close to 0 (zero) indicates a better estimation result due to a low error rate. Furthermore, testing a model is more precise and reliable using RMSE (Chai & Draxler 2014). The RMSE value proposed for model reliability testing averaged 0.71 (Raghuvanshi *et al.* 2021), meaning that the results achieved by porang is still relatively better.

Land suitability based on rating minimum

The value based on the minimum index rating indicates that the lowest factor rating of 10 (Table 5) was obtained at soil pH and ESP, while the highest at 100 was found in the elevation factor rating, rainfall, clay, effective depth, and base saturation factor rating.

Table 5. Rating factors of land characteristics for porang.

LU	Rating factor																	Final RI
	RX_1	RX_2	RX_3	RX_4	RX_5	RX_6	RX_7	RX_8	RX_9	RX_{10}	RX_{11}	RX_{12}	RX_{13}	RX_{14}	RX_{15}	RX_{16}	RX_{17}	
1	39	79	80	82	44	45	89	98	99	76	72	74	100	94	46	63	100	44
2	38	82	80	82	70	65	88	93	92	65	77	78	100	100	58	63	93	100
3	38	73	80	82	100	78	95	100	92	67	77	80	100	100	49	63	100	100
4	41	87	80	82	100	70	90	96	92	94	75	76	100	100	54	63	86	100
5	40	85	80	82	70	59	90	99	96	72	77	76	100	100	54	63	100	100
6	43	88	80	88	44	55	92	100	100	90	74	78	100	96	56	63	100	100
7	45	91	80	72	17	64	91	100	100	94	74	79	100	99	58	63	10	10
8	42	90	80	100	17	58	89	96	96	100	73	76	100	97	57	63	100	36
9	45	93	80	82	17	59	91	100	94	60	73	77	100	95	57	63	100	28
10	43	94	80	82	100	86	92	98	100	79	72	73	100	97	52	63	100	100
11	100	91	80	88	97	76	92	99	100	100	75	78	100	100	52	63	100	100
12	48	93	80	72	44	77	94	100	100	34	74	78	100	98	45	63	100	51
13	41	95	80	100	70	85	94	100	100	10	71	80	100	95	52	63	100	25
14	42	96	80	100	70	65	91	99	100	10	72	77	100	96	49	63	100	21
15	100	96	80	88	70	55	88	94	100	95	70	77	100	91	57	63	100	100
16	39	82	80	82	100	46	90	99	100	88	74	77	100	99	57	63	100	100
17	40	87	80	108	17	74	92	99	100	92	77	78	100	100	58	63	100	44
18	40	90	80	88	44	74	95	100	100	68	69	76	100	93	56	63	100	100
19	63	96	80	82	70	55	93	100	100	75	75	77	100	100	52	63	100	100
20	53	94	80	72	44	83	98	100	100	99	69	78	100	93	59	63	100	100
21	60	96	80	84	70	63	91	100	96	72	71	78	100	95	55	63	100	100
22	40	79	80	82	70	72	92	99	100	80	77	80	100	99	57	63	100	100
23	44	88	80	82	17	61	90	99	92	62	76	74	82	100	63	63	100	23
24	100	91	80	88	44	61	91	100	100	11	68	81	100	92	62	63	100	35
25	40	82	80	88	100	74	92	99	100	25	76	78	100	99	56	63	100	61
26	39	87	80	100	17	74	92	100	100	100	74	77	100	97	50	63	100	38
27	47	95	80	82	44	62	92	100	100	10	68	78	100	91	49	63	63	9
28	43	96	80	82	70	64	91	100	100	93	78	77	100	100	54	63	100	100
29	43	93	80	72	100	79	93	100	100	88	74	78	100	98	44	63	100	100
30	44	94	80	100	44	90	93	99	100	100	73	79	100	98	62	63	96	100
31	46	92	80	88	100	51	89	98	100	100	76	73	98	100	61	63	100	100
32	38	95	80	84	44	63	90	99	100	63	72	77	100	96	59	63	100	100

Note: LU = land unit; X_1 = elevation; X_2 = temperature; X_3 = rainfall; X_4 = slope; X_5 = drainage; X_6 = sand; X_7 = silt; X_8 = clay; X_9 = by effective depth; X_{10} = pH; X_{11} = organic C; X_{12} = cation echange capacity; X_{13} = base saturation; X_{14} = total N; X_{15} = P_2O_5; X_{16} = K_2O; X_{17} = exchangeable sodium percentage; RI = rating index.

However, a factor rating of 100 still exists at pH and ESP, and the remaining factor rating values vary relatively from >10 – <100. A pH rating value of ≤10 in parametric land evaluation has been reported by Dengiz *et al.* (2010), while soil salinity and alkalinity often limit plant growth (Sulieman *et al.* 2018). Based on LU, the lowest rating factor distribution is at LU 27, while the remaining are relatively diverse. Based on the index rating, the land suitability class for porang with a minimum rating (R_{min}) was dominated by the very suitable class (S1) of 81.68% (Table 6 and Fig. 2). In this S1 class, the dominant R_{min} was elevation, followed by P_2O_5, drainage, and sand fraction. The class classified as marginal (S3) ranked second in terms of land area, accounting to 9.76%. This ranking is attributed to the sequential contribution of R_{min}, which includes factors such as drainage, pH, and elevation. The current unsuitable class (N1) ranked third at 7.34% with the contribution of R_{min} sequentially including drainage, pH, and ESP. The permanently unsuitable (N2) and moderately suitable classes (S2) ranked fourth and fifth at 0.70% and 0.52% with relatively the same R_{min} contribution of soil pH. The land elevation at several LUs < 50 m asl caused poor soil drainage for porang development, since it is often inundated during the rainy season. The elevation indicator has a sensitive value for increasing the sustainability status of farming (Riptanti *et al.* 2022). Meanwhile, poor soil drainage was a limiting land suitability class for porang (Apu *et al.* 2022). Rapid soil drainage is also not good for development due to the relatively high content of the sand fraction (Nimpuna *et al.* 2022).

Land suitability based on weight maximum

Based on the factor rating weighting, the highest maximum weight was indicated by elevation, while the lowest was K_2O and ESP (Table 7) with a pairwise comparison matrix ratio consistency of 0.06. A matrix with a ratio consistency value of less than 0.1 indicates a valid weight and can be used (Kau *et al.* 2023). Meanwhile, the value of the consistency ratio was greater than 0.1, and the assessment in the matrix needed to be revised (Chen *et al.* 2010; Bagherzadeh & Gholizadeh 2016). The results of this weighting will be used in the land suitability assessment with the maximum weight (Rabia & Terribile 2013). The factor rating values indicate that soil pH and

ESP obtain the lowest factor rating with a value of 10 and the remaining factor ratings vary relatively from >10 – <100 (Table 8). Based on the maximum weight rating, the lowest index rating weight is found at LU 23 which is only 37 and the remaining LUs vary relatively from 53 – 100. Dengiz *et al.* (2010) reported that the low pH factor rating was caused by low (acid) soil pH and the ideal value ranged from 6 – 7 (Indriyani *et al.* 2011).

Table 6. Land suitability classes for porang.

LSC	R_{min}	LU	Wide	
			Ha	%
	Elevation	2, 3, 4, 5, 6, 10, 16, 18, 22, 28, 29, 31, 32	47,062.21	79.06
S1	P_2O_5	11, 19, 21	1,253.31	2.11
	Drainage	20, 30	259.27	0.44
	Fraksi pasir	15	46.37	0.08
S2	pH	12, 25	308.38	0.52
	Elevation	1	508.48	0.85
S3	Drainage	8, 9, 17, 26	3,113.35	5.23
	pH	13, 24	2,189.80	3.68
	ESP	7	84.22	0.14
N1	pH	14	163.86	0.28
	Drainage	23	4,123.66	6.93
N2	pH	27	414.60	0.70
Total			**59,527.52**	**100**

LSC = land suitability class; Rmin = rating minimum; LU = land unit; ESP = exchangeable sodium percentage.

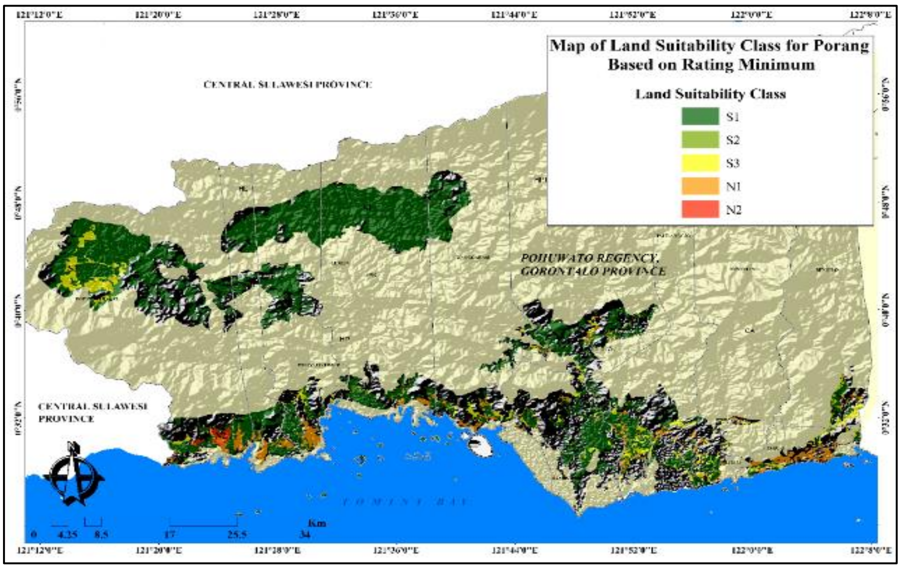


Fig. 2. Map of land suitability classes for porang based on the minimum rating.

Based on the index rating weight, the land suitability class for porang with the maximum rating weight (W_{max}) was dominated by the very suitable class (S1) of 86.26% (Table 9 and Fig. 3). The marginally suitable class (S3) ranked second based on the aspect of land area of 6.93% while the moderately suitable class (S2) was third at 6.82%, without unsuitable class (N). The cause of class S3 was poor soil drainage at LU 3, and according to Apu *et al.* (2022), the concept is often a limiting land suitability class. Soil drainage affects the growth of porang roots, since when the amount of water is excessive, root growth and land suitability class are affected (Nimpuna *et al.* 2022). Dengiz *et al.* (2010) stated that poor soil drainage caused land suitability classes S3 and even N on *Pinus pinaster* it using parametric methods.

Comparison of land suitability class and its consequences on land management priorities

Land suitability for porang with different parametric methods produced different classes. Based on the class, the use of the minimum rating (R_{min}) with the square root method (SRM) produced five classes, namely S1, S2, S3, N1, and N2 (Table 10 and Fig. 4).

Meanwhile, using the maximum weight (W_{max}) with the Rabia and Terribile method (RTM) only resulted in three classes, i.e., S1, S3, and S3 classes. Based on the land suitability class, the land management priorities of the two methods also show significant differences. Using R_{min} with SRM produced priorities I, II, III, and NP (not prioritized). Furthermore, priority I and II were the highest, while smallest at 81.68% and 0.52%, respectively. Using W_{max} with RTM only produced priorities I, II, and III, where priority I and II were the highest and smallest at 86.26% and 6.82% respectively.

Table 7. Pairwise comparison matrix between land characteristics and their weight.

	X_1	**X_2**	**X_3**	**X_4**	**X_5**	**X_6**	**X_7**	**X_8**	**X_9**	**X_{10}**	**X_{11}**	**X_{12}**	**X_{13}**	**X_{14}**	**X_{15}**	**X_{16}**	**X_{17}**	**W**
X_1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	**0.13**
X_2	0.50	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	**0.12**
X_3	0.33	0.50	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	**0.11**
X_4	0.25	0.33	0.50	1	2	3	4	5	6	7	8	9	10	11	12	13	14	**0.10**
X_5	0.20	0.25	0.33	0.50	1	2	3	4	5	6	7	8	9	10	11	12	13	**0.10**
X_6	0.17	0.20	0.25	0.33	0.50	1	2	3	4	5	6	7	8	9	10	11	12	**0.09**
X_7	0.14	0.17	0.20	0.25	0.33	0.50	1	2	3	4	5	6	7	8	9	10	11	**0.08**
X_8	0.13	0.14	0.17	0.20	0.25	0.33	0.50	1	2	3	4	5	6	7	8	9	10	**0.07**
X_9	0.11	0.13	0.14	0.17	0.20	0.25	0.33	0.50	1	2	3	4	5	6	7	8	9	**0.07**
X_{10}	0.10	0.11	0.13	0.14	0.17	0.20	0.25	0.33	0.50	1	2	3	4	5	6	7	8	**0.06**
X_{11}	0.09	0.10	0.11	0.13	0.14	0.17	0.20	0.25	0.33	0.50	1	2	3	4	5	6	7	**0.05**
X_{12}	0.08	0.09	0.10	0.11	0.13	0.14	0.17	0.20	0.25	0.33	0.50	1	2	3	4	5	6	**0.04**
X_{13}	0.08	0.08	0.09	0.10	0.11	0.13	0.14	0.17	0.20	0.25	0.33	0.50	1	2	3	4	5	**0.04**
X_{14}	0.07	0.08	0.08	0.09	0.10	0.11	0.13	0.14	0.17	0.20	0.25	0.33	0.50	1	2	3	4	**0.03**
X_{15}	0.07	0.07	0.08	0.08	0.09	0.10	0.11	0.13	0.14	0.17	0.20	0.25	0.33	0.50	1	2	3	**0.02**
X_{16}	0.06	0.07	0.07	0.08	0.08	0.09	0.10	0.11	0.13	0.14	0.17	0.20	0.25	0.33	0.50	1	2	**0.01**
X_{17}	0.06	0.06	0.07	0.07	0.08	0.08	0.09	0.10	0.11	0.13	0.14	0.17	0.20	0.25	0.33	0.50	1	**0.01**

X_1 = elevation; X_2 = temperature; X_3 = rainfall; X_4 = slope; X_5 = drainage; X_6 = sand; X_7 = silt; X_8 = clay; X_9 = by effective depth; X_{10} = pH; X_{11} = organic C; X_{12} = cation echange capacity; X_{13} = base saturation; X_{14} = total N; X_{15} = P_2O_5; X_{16} = K_2O; X_{17} = exchangeable sodium percentage; W = weight.

A comparison of the two methods can be presented following the SRM series pattern as follow: S1 > S3 > N1 > N2 > S2 and I > III > NP > II. Additionally, when considering the RTM series pattern, the order is as follow: S1 > S3 > S2 and I > III > II. RTM is better used in assessing land suitability is in line with Bagherzadeh and Gholizadeh (2016), where using the parametric method is preferred, since it has a high correlation coefficient of 0.94 on the land suitability assessment for wheat in Iran. Using parametric methods integrated with GIS is a more accurate, reliable, and efficient land suitability assessment tool (Dengiz *et al.* 2010).

The employment of the rabia method in assessing land suitability is better and more realistic than the SRM and the Storie method (Rabia & Terribile 2013). However, when compared to the Storie method, the SRM is more reliable and realistic (Shiri & Farbodi 2022).

Table 8. Rating factor of land characteristic for porang.

LU	Rating factor																	Final WRI
	RX_1	RX_2	RX_3	RX_4	RX_5	RX_6	RX_7	RX_8	RX_9	RX_{10}	RX_{11}	RX_{12}	RX_{13}	RX_{14}	RX_{15}	RX_{16}	RX_{17}	
1	39	79	80	82	44	45	89	98	99	76	72	74	100	94	46	63	100	58
2	38	82	80	82	70	65	88	93	92	65	77	78	100	100	58	63	93	100
3	38	73	80	82	100	78	95	100	92	67	77	80	100	100	49	63	100	100
4	41	87	80	82	100	70	90	96	92	94	75	76	100	100	54	63	86	100
5	40	85	80	82	70	59	90	99	96	72	77	76	100	100	54	63	100	100
6	43	88	80	88	44	55	92	100	100	90	74	78	100	96	56	63	100	100
7	45	91	80	72	17	64	91	100	100	94	74	79	100	99	58	63	10	60
8	42	90	80	100	17	58	89	96	96	100	73	76	100	97	57	63	100	87
9	45	93	80	82	17	59	91	100	94	60	73	77	100	95	57	63	100	61
10	43	94	80	82	100	86	92	98	100	79	72	73	100	97	52	63	100	100
11	100	91	80	88	97	76	92	99	100	100	75	78	100	100	52	63	100	100
12	48	93	80	72	44	77	94	100	100	34	74	78	100	98	45	63	100	100
13	41	95	80	100	70	85	94	100	100	10	71	80	100	95	52	63	100	90
14	42	96	80	100	70	65	91	99	100	10	72	77	100	96	49	63	100	59
15	100	96	80	88	70	55	88	94	100	95	70	77	100	91	57	63	100	100
16	39	82	80	82	100	46	90	99	100	88	74	77	100	99	57	63	100	100
17	40	87	80	108	17	74	92	99	100	92	77	78	100	100	58	63	100	100
18	40	90	80	88	44	74	95	100	100	68	69	76	100	93	56	63	100	100
19	63	96	80	82	70	55	93	100	100	75	75	77	100	100	52	63	100	100
20	53	94	80	72	44	83	98	100	100	99	69	78	100	93	59	63	100	100
21	60	96	80	84	70	63	91	100	96	72	71	78	100	95	55	63	100	100
22	40	79	80	82	70	72	92	99	100	80	77	80	100	99	57	63	100	100
23	44	88	80	82	17	61	90	99	92	62	76	74	82	100	63	63	100	37
24	100	91	80	88	44	61	91	100	100	11	68	81	100	92	62	63	100	100
25	40	82	80	88	100	74	92	99	100	25	76	78	100	99	56	63	100	100
26	39	87	80	100	17	74	92	100	100	100	74	77	100	97	50	63	100	99
27	47	95	80	82	44	62	92	100	100	10	68	78	100	91	49	63	63	53
28	43	96	80	82	70	64	91	100	100	93	78	77	100	100	54	63	100	100
29	43	93	80	72	100	79	93	100	100	88	74	78	100	98	44	63	100	100
30	44	94	80	100	44	90	93	99	100	100	73	79	100	98	62	63	96	100
31	46	92	80	88	100	51	89	98	100	100	76	73	98	100	61	63	100	100
32	38	95	80	84	44	63	90	99	100	63	72	77	100	96	59	63	100	100

LU = land unit; X_1 = elevation; X_2 = temperature; X_3 = rainfall; X_4 = slope; X_5 = drainage; X_6 = sand; X_7 = silt; X_8 = clay; X_9 = by effective depth; X_{10} = pH; X_{11} = organic C; X_{12} = cation echange capacity; X_{13} = base saturation; X_{14} = total N; X_{15} = P_2O_5; X_{16} = K_2O; X_{17} = exchangeable sodium percentage; WRI = weight of rating index.

Table 9. Land suitability class for porang.

LSC	LU	Wide	
		Ha	%
S1	2, 3, 4, 5, 6, 8, 10, 11, 12, 13, 15, 16, 17, 18, 19, 20, 21, 22, 24, 25, 26, 28, 29, 30, 31, 32, 33	51,346.20	86.26
S2	1, 7, 9, 14, 27	4,057.66	6.82
S3	23	4,123.66	6.93
N1	-	0.00	0.00
N2	-	0.00	0.00
Total		59,527.52	100

Note: LSC = land suitability class; LU = land unit.

Table 10. Comparison of land suitability classes and land management priorities for porang.

LSC	R_{min} (Square Root Method)				W_{max} (Rabia and Terribile Method)			
	LU	Priority	Ha	%	LU	Priority	Ha	%
S1	2, 3, 4, 5, 6, 10, 11, 15, 16, 18, 19, 20, 21, 22, 28, 29, 30, 31, 32	I	48,621.16	81.68	2, 3, 4, 5, 6, 8, 10, 11, 12, 13, 15, 16, 17, 18, 19, 20, 21, 22, 24, 25, 26, 28, 29, 30, 31, 32, 33	I	51,346.20	86.26
S2	12, 25	II	308.38	0.52	1, 7, 9, 14, 27	II	4,057.66	6.82
S3	1, 8, 9, 13, 17, 24, 26	III	5,811.63	9.76	23	III	4,123.66	6.93
N1	7, 14, 23	NP	4,371.74	7.34	-		0.00	0.00
N2	27	NP	414.60	0.70	-		0.00	0.00
Total			**59,727.61**	**100**			**59,527.52**	**100**

Note: LSC = land suitability class; LU = land unit; R_{min} = rating minimum; W_{max} = weight maximum.

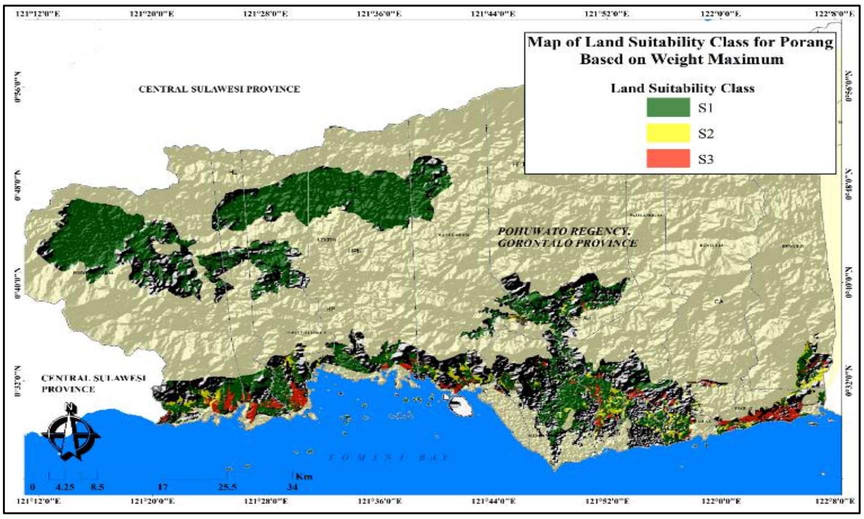


Fig. 3. Land suitability class map for porang based on the maximum weight.

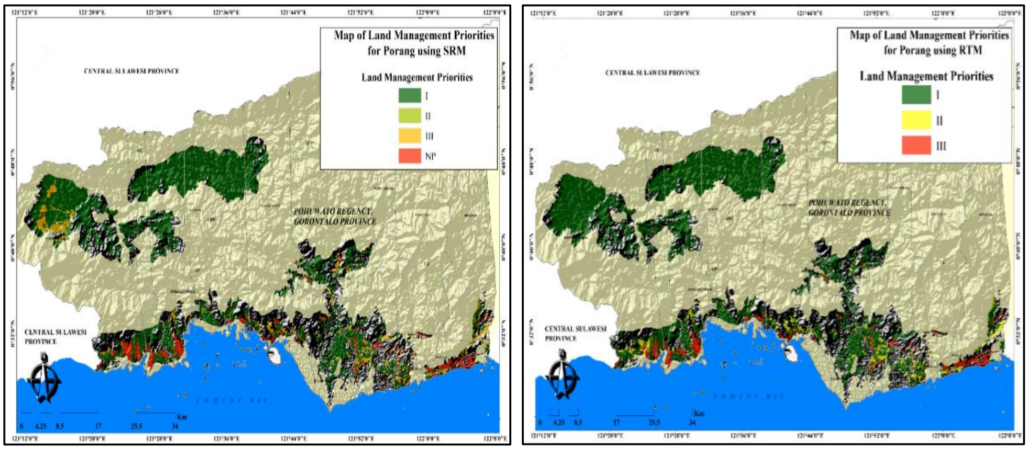


Fig. 4. Map of comparison of management priorities for porang.

CONCLUSION

In conclusion, land suitability for porang plants with the square root method (SRM) and the Rabia and Terribile method (RTM) was dominated by the very suitable class (S1), however, the distribution of S1 was wider with the RTM. The remaining classes using the SRM consisted of moderately suitable (S2), marginally suitable (S3), currently not suitable (N1), and permanently inappropriate (N2), while the remaining classes using the RTM only consisted of classes S1, S2, and S3 without class N. Land management priority for these two parametric methods was dominated by priority I. In the SRM, there were priorities II, III and not prioritized (NP), while in the RTM other than priority I there were only II and III. Based on land suitability classes and land management priorities, the RTM was better and more realistic in its assessment results for porang compared to the SRM.

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