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[Zulfikar,* 7(8): August 2020]
DOI: https://doi.org/10.29121/gjesr.v7.i8.2020.6

ISSN 2348 – 8034
Impact Factor- 5.070

GLOBAL JOURNAL OF ENGINEERING SCIENCE AND RESEARCHES

LAND SUITABILITY EVALUATION FOR A NUMBER OF ANNUAL CROPS IN THE TIWORO RIVER WATERSHED, MUNA, SOUTHEAST SULAWESI

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ABSTRACT

The Tiworo River Watershed, which covers a total area of 29,047.82 ha, has been a resource for agricultural development for the local people of Muna, Indonesia. The information regarding the land suitability for annual crops in this watershed was, however, still very limited. A survey-based study was, therefore, conducted to evaluate the land suitability in the watershed for six annual crops (i.e. paddy-rice, corn, peanut, soybean, cassava, and tomato). The evaluation was based on Djaenuddin's criteria, that was by matching the respective crop growth requirements against soil characteristics (e.g. soil pH, organic-C content, total-N, P_2O_5, K_2O, CEC, base saturation, soil texture and drainage, rock outcrops, effective soil depth, and slope) and climate (e.g. rainfall, and air temperature and humidity). Soil characteristics were collected from 87 land units. A ten-year climate data series was gathered from the Betoambari weather station. The results of the evaluation showed that the land in the watershed fell into class S3 (marginally suitable) and class N (not suitable) for all the six crops evaluated, and no land units belonged to S1 (highly suitable) and S2 (moderately suitable). The main limiting factors found were low water and nutrient availability, and high erosion hazard.

Key words: *Tiworo River watershed, land suitability, annual crops*.

I. INTRODUCTION

One of key factors that determine the ideal crop growth and optimal yields is land suitability [1, 2], and land suitability for agriculture is influenced by two main factors, i.e. climate and soil characteristics [3]. Climate characteristics (i.e. rainfall, air temperature, air humidity, number of dry months) generally affect crop water availability and ambient temperature, while soil characteristics affect nutrient and water availability, available phytotoxic elements (e.g. exchangeable Al and Fe), effective soil depth, topography (e.g. slope that contributes to erosion and flooding hazard) and rock outcrops (that contributes to workability or effectiveness in soil tillage and crop cultivation), and so forth [1]. The principle purpose of agriculture land suitability evaluation is to predict the potential and limitation of the land for crop production [3]. Therefore, land suitability assessment for agriculture is very essential in deciding present and future agricultural cropping pattern, planning and activities [4], and subsequently in achieving precision agriculture or site-specific crop management [5]. Land suitability evaluation provides information as to the main limiting factors for particular crop cultivation and enables decision makers (e.g. farmers, land use planners, or agricultural extension services) to choose and develop crop and land management that is suitable for or can ameliorate such constraints, thereby increasing crop yield [1, 4].

The Tiworo River Watershed, which covers a total area of 29,047.82 ha, has been a resource for agricultural development for the local people of Muna, Indonesia. The information regarding land suitability for agriculture in this watershed was, however, still very limited. The local farmers in the Tiworo River watershed, in particular, have cultivated crops without taking into account land suitability due to either lack of such information or lack of farming practice knowledge. A survey-based study was, therefore, conducted to evaluate the land suitability in the watershed for six annual crops (i.e. paddy rice, corn, peanut, soybean, cassava, and tomato), specially to overcome the former issue.

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II. METHODS

Study site

The study was conducted in the Tiworo River watershed, Muna, Southeast Sulawesi, Indonesia, from December 2017 to March 2019. The study area geographically stretches from 4º44'19.51"S to 4º59'21.53" S and from 22º49'53.60" E to 122º40'46.23" E, which covers a total area of 29,047.82 ha (Figure 1).

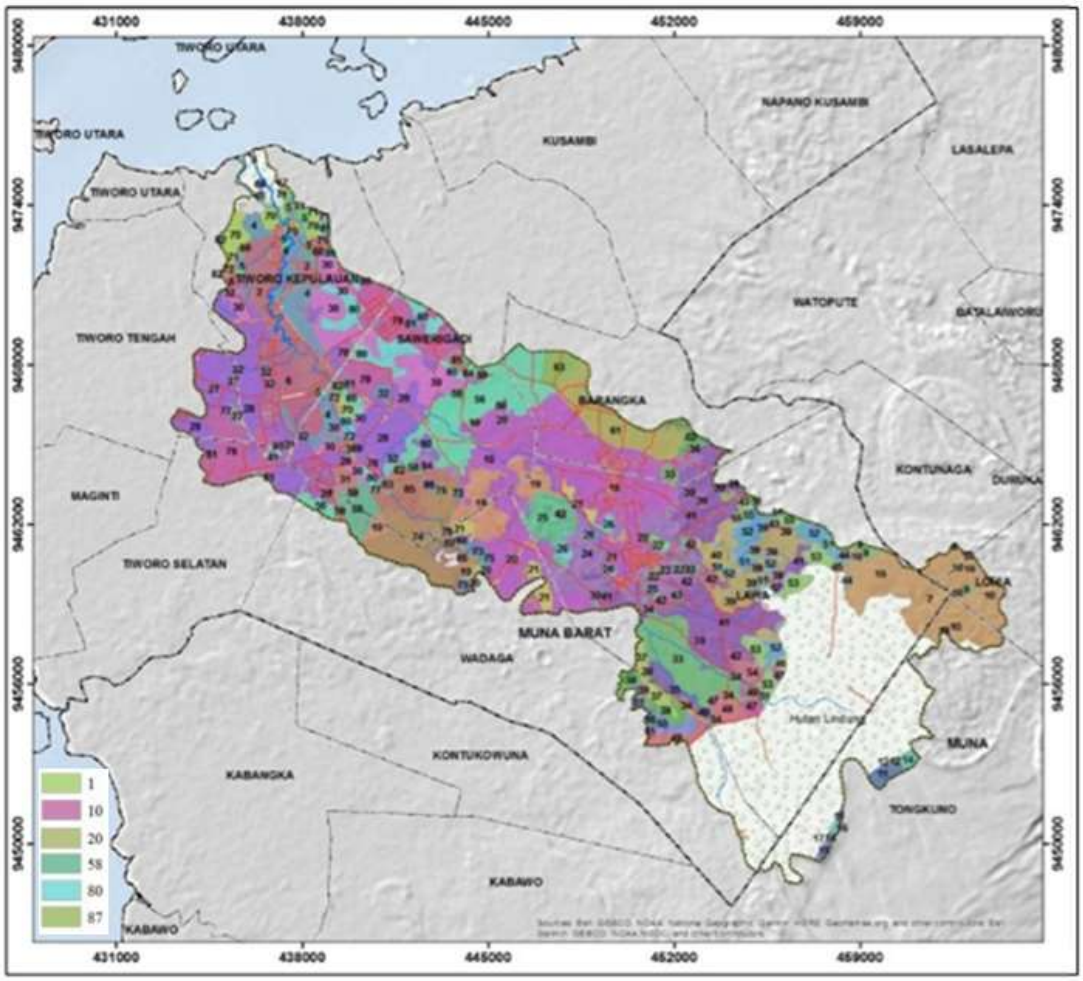

Figure 1. Land units in the study site of the Tiworo River watershed

Sampling and data collection

Land characteristics collected for the assessment were air temperature and relative humidity, rainfall, length of dry period, soil texture and drainage, soil pH_{H2O}, soil organic-C, total-N, P_2O_5 and K_2O content, cation exchange capacity (CEC), base saturation, soil coarse material content, effective soil depth, topographic slope, flood and erosion hazard, and outcrop rocks. They were collected from 87 land units via a direct survey. The 87 land units were produced by overlaying several thematic maps (e.g. map of geology, topography, soil types, and land uses), each of which had different characteristics from one another. Soil sampling was carried out using the stratified purposive sampling technique. Soil samples were compositely gathered from each land unit according to the Soil Observation Techniques proposed by the BPT [6], using the transect method in sloping areas and the free grid system in flat areas. Soil samples were taken up to soil depths of 60 cm using a soil auger. Meanwhile, to determine its corresponding effective soil depth, the drilling was continued to a depth of 150 cm. The physical soil properties were evaluated in the field, while

their chemical properties were analyzed at the Soil Laboratory of the Soil Science Department, Agricultural Faculty, Halu Oleo University-Kendari. In addition, a ten-year data series of climate conditions (i.e. from 2010 to 2019) was gathered from the Betoambari weather station, the closest weather station to the study area.

Land suitability evaluation.

The evaluation was conducted by matching the growth requirements of the six assessed crops (i.e. paddy rice, corn, peanut, soybean, cassava, and tomato) against the collected data of land characteristics based on the criteria proposed by Djaenuddin et al [1]. There are four classes of land suitability, i.e. highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N). The sub-class of each class was then determined based on the most limiting factors found. The distribution of the land suitability classes was mapped using Arc View 4.11.

III. RESULTS AND DISCUSSION

General overview of the study area

Geographical characteristics

The Tiworo River watershed geographically stretches from 4º44'19.51"S to 4º59'21.53" S and from 22º49'53.60" E to 122º40'46.23" E covering a total area of 29,047.82 ha, which is administratively located at 2 (two) regencies, namely Muna Regency with an area of 2,048 ha (7.05%) and West Muna Regency with an area of 26,999.82 ha (92.95%). The Tiworo River watershed consists of the Tiworo River with several tributaries, the Fotu River and the Laano Bhangka River. The Tiworo River watershed occupies 39 villages administratively within 6 districts in the Regency of West Muna and 8 villages within 3 districts in the Regency of Muna.

Climate

The Tiworo River watershed area has a tropical rain climate whose average monthly rainfall is considered wet (>60 mm). According to Oldeman's climate classification [7], the 10-year rainfall data series (collected from the Betoambari Weather Station, Bau-Bau City) in the Tiworo River watershed fell under the B2 climate type, which had 7-9 wet months and 2-3 dry months. The average annual rainfall, temperature, and relative humidity was 166.30 mm, 26.78ºC, and 79.24%, respectively (Table 1).

Table 1. Climate conditions in the Tiworo River watershed (2010-2019)

No	Month	Rainfall (mm)	Temperature (ºC)	Relative Humidity (%)
1	January	211.94	28.04	83.26
2	February	240.88	27.22	83.85
3	March	250.58	27.54	85.55
4	April	205.47	27.36	86.27
5	May	201.90	27.42	87.39
6	June	209.36	26.36	85.05
7	July	95.33	26.09	82.09
8	August	34.17	23.42	68.02
9	8eptember	51.72	29.49	66.57
10	October	51.82	28.25	75.55
11	November	103.30	25.64	71.14
12	December	339.15	24.51	76.14
	Average	166.30	26.78	79.24
	Minimum	34.17	23.42	66.57
	Maximum	339.15	29.49	87.39

Source: Betoambari weather station

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Topography

The Tiworo River watershed was dominated by low elevation areas whose topographic slopes varied and were classified into 7 classes. The distribution of topographic slope classes across the Tiworo River Watershed is presented in Figure 2.

Soil types and land use

The Tiworo River watershed consisted of 5 soil types including a) Eutrudepts (8,781.05 ha; 30.23%), b) Hapludalfs (10,216.24 ha; 35.17%), c) Rendolls (542.44 ha; 1.87%), d) Rendolls and Eutrudepts (933.28 ha; 32.13%), and e) Sulfaquents (174.81 ha; 0,60%). Around 44.37% of the area (12,888.32 ha) had been used for small-holder plantations (e.g. cashew), bushes 22.73%, forest 22.10%, and the remaining had been used for water-fed farms, paddy fields, fish ponds, etc.

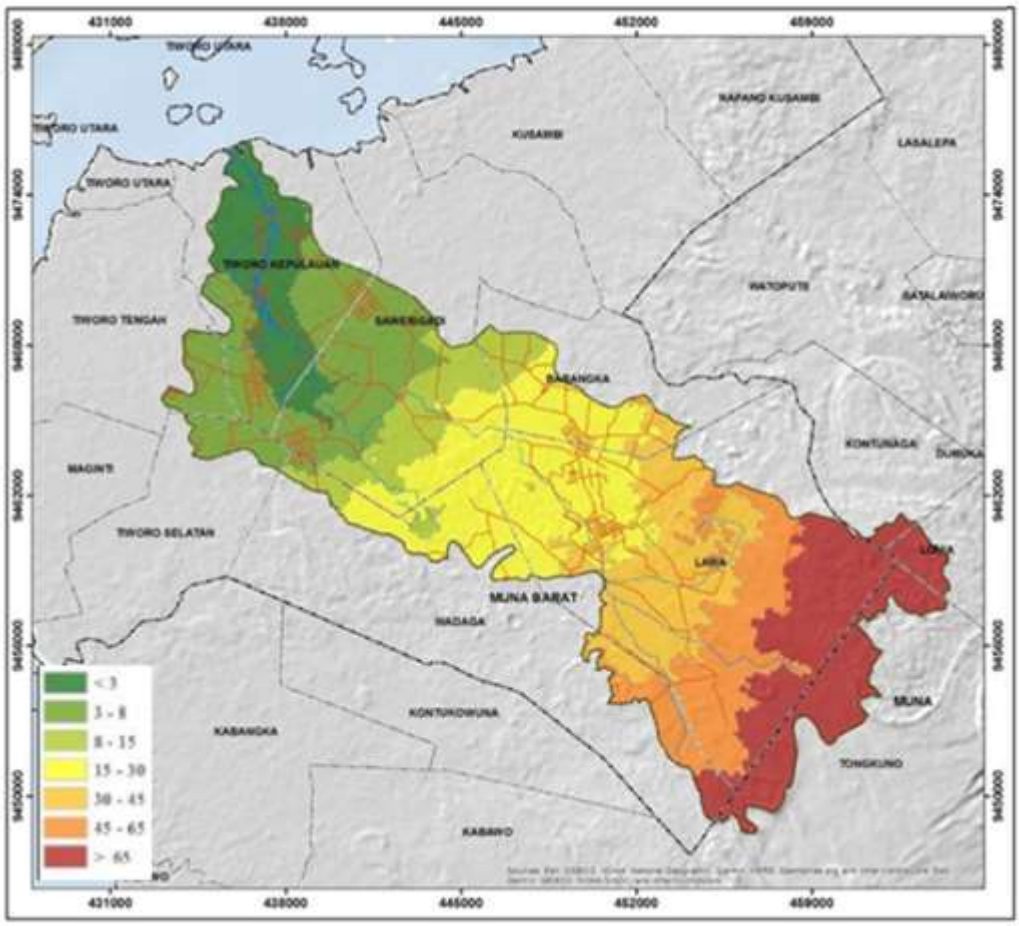

Figure 2. Topographic slope classes (in percent) across the Tiworo River Watershed

Land suitability for annual crop cultivations

Land suitability was determined using the matching technique proposed by Djaenuddin et al [1]. The land suitability has four classes, i.e. S1 (highly suitable), S2 (moderately suitable), S3 (marginally suitable), and N (not suitable). A land suitability class S1 indicates the absence of limiting factors for a crop growth and, therefore, does not require high inputs or expensive technologies to produce a desired yield. Class S2 and S3, on the other hand, have several limiting factors at varied levels and, therefore, require inputs and technologies from relatively low to high-level, thus from low to high cost to improve crop yield sustainably. A land with class S2 has fewer and/or less severe limiting factors than that with class S3. Whereas, a land with class N has highly severe limiting factors and is not recommended

for a sustainable agricultural development, unless high and intensive technologies are introduced. The results of the land suitability evaluation for each crop are, as follows:

Paddy-rice

Paddy rice crops are quite widely grown in the Tiworo River watershed. The results of the suitability evaluation showed that 40.83 % of the watershed (11,860.62 ha) can be used for paddy rice cultivation, but with some limiting factors, namely 1) water availability (wa), 2) oxygen availability (oa), 3) root zone medium (rc), 4) nutrient retention (nr), 5) nutrient availability (na), and 6) land preparation (lp) (Table 2). The distribution of land suitability for paddy-rice crops in the Tiworo River watershed is presented in Figure 3.

Currently, paddy fields have covered an area of 3,241 ha located in five districts, i.e. the District of Tiworo Kepulauan (1,465 ha), Maginti (347 ha), Central Tiworo (169 ha), South Tiworo (670 ha), and Sawerigadi (690 ha). However, only has 34.34% of the total paddy fields (1,113 ha) produced rice grains, mainly located in four districts, i.e Tiworo Kepulauan (279 ha), Maginti (128 ha), South Tiworo (258 ha), and Sawerigadi (378 ha) [8].

Table 2. Land suitability for paddy rice crops

Land suitability for paddy rice crops	Limiting factors	Land units	Area	
			(ha)	(%)
S3 (marginally suitable)	na	43	66.21	0.56
	nr,	31,56,59,65,81,82	1,319.51	11.13
	n, lp	70	326.28	2.75
	nr, na	30	822.60	6.94
	nr, na	2,3,18,19,21,28,38, 58, 60,62,71,72,80	7,703.57	64.95
	oa, nr, na	4,5,6,32	1,266.43	10.68
	oa, nr, na, lp	53	277.30	2.34
	oa, nr, na, lp	49	30.22	0.26
	rc, nr, na, eh	16	3.86	0.03
	wa, nr	79	4.13	0.04
	wa, nr, na	15,68	40.15	0.34
Total		**32**	**11,860.62**	**100**

Note: 55 land units (17,187.20 ha or 59.17% of the watershed) fell under suitability class N; No class S1 and S2 were found

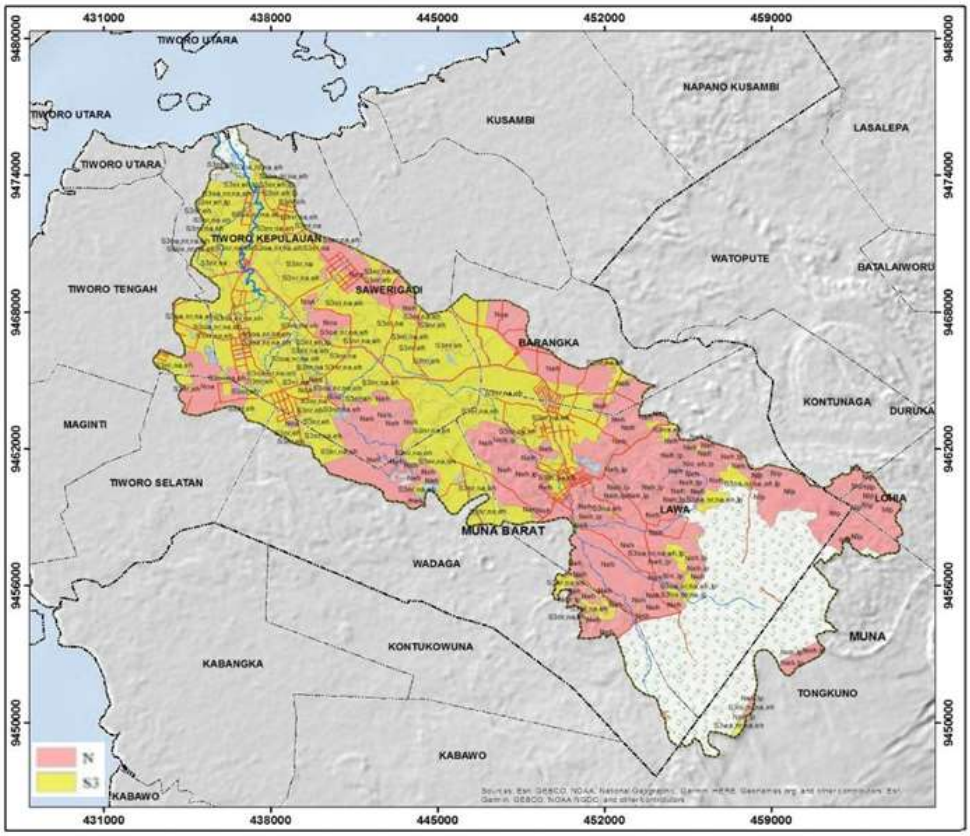

Figure 3. Distribution of land suitability for paddy-rice crops in the Tiworo River watershed

Corn

Corn are cultivated in almost all areas of the Tiworo River watershed. It was reported that the total area for corn cultivation was around 6,779 ha, with a total production of 20,221 tons in 2019 [8]. This also shows that although corn crops have been grown widely and producing, the low productivity (2.98 tons ha^{-1}) indicates the presence of limiting factors. The results of land suitability evaluation showed that only is 22.31 % of the total area (6,479.24 ha) marginally suitable (S3) for corn cultivation. The limiting factors found were 1) water availability (due to low rainfall), 2) oxygen availability (due to poor soil drainage), 3) root media (due to shallow effective soil depth and soil texture), 4) nutrient retention (due to low soil organic content), 5) nutrient availability (due to very low P and K availability), and 6) erosion hazard (due to high topographic slopes) (Table 3). Therefore, improvements should be based on the existing limiting factors that inhibit the ideal corn crop growth. The distribution of land suitability for corn crops in the Tiworo River watershed is presented in Figure 4.

Table 3. Land suitability for corn crops

Land suitability for corn crops	Limiting factors	Land units	Area	
			(ha)	(%)
S3 (marginally suitable)	nr, na	87	11.21	0.17
	wa	43	66.21	1.02
	wa, na, eh	26	106.64	1.65
	wa, nr, eh,	2,30	1,528.17	23.59
	wa, nr, na	31,37,38	355.12	5.48
	wa, nr, na, eh	15,19,28,49,53,58, 59,62,65,68,71,72, 75,76,79,80,81,84	4,329.95	66.83

	wa, nr, na, eh	5	81.94	1.27
Total		**27**	**6,479.24**	**100**

Note: 60 land units (22,568.58 ha or 77.69 % of the watershed) fell under suitability class N; No class S1 and S2 were found

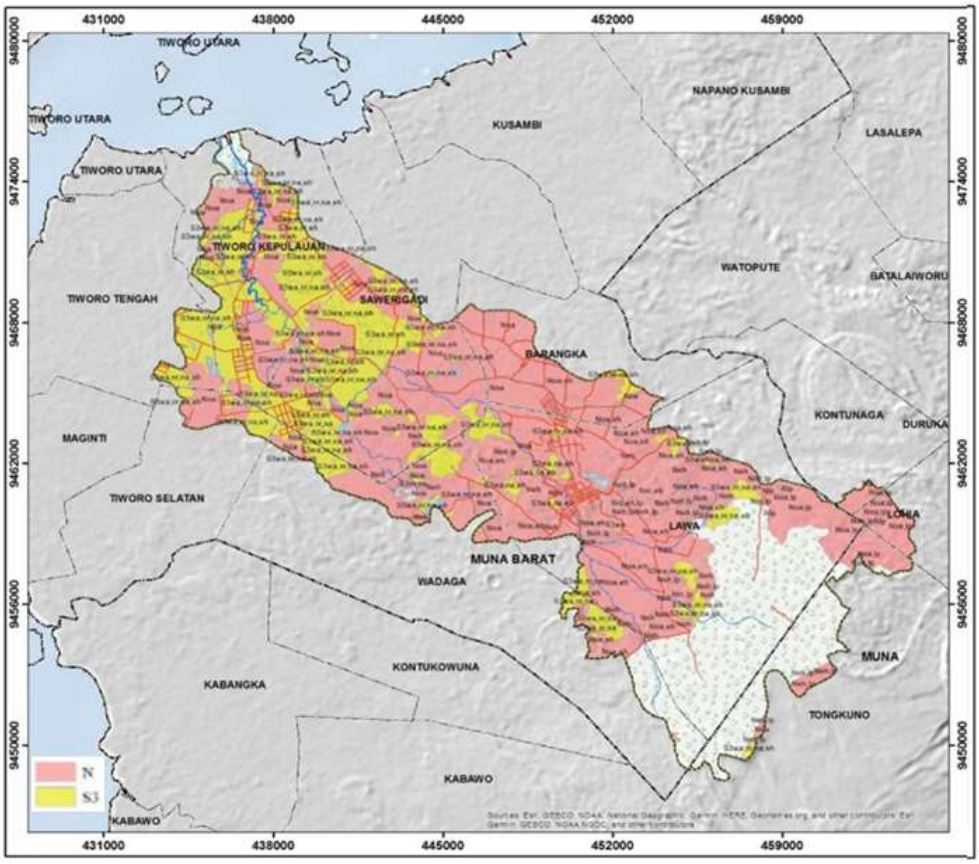

Figure 4. Distribution of land suitability for corn crops in the Tiworo River watershed

Peanut

Peanut crop is another commodity cultivated by farmers in the Tiworo River watershed, either using monoculture or intercropping systems (especially with corn) [8]. The land suitability evaluation showed that 22.06 % of the total area (6,408.6 ha) fell under class marginally suitable (S3) for peanut cultivation. Several limiting factors that need to be addressed in order to improve peanut yield were 1) water availability (due to low rainfall), 2) nutrient retention (due to low soil organic content), 3) nutrient availability (due to very low P and K availability), and 4) erosion hazard (due to high topographic slopes) (Table 4). The existing conditions indicated that the total area of peanut cultivation in the Tiworo River watershed was around 1,596 ha, with a total production of 748 tons in 2019 only, indicating that the productivity of peanut crops in the Tiworo River watershed was still very low (0.46 tons ha^{-1}) [8]. The distribution of land suitability for peanut crops in the Tiworo River watershed is presented in Figure 5.

Table 4. Land suitability for peanut crops

Land suitability for peanut crops	Limiting factors	Land units	Area	
			(ha)	(%)
S3 (marginally suitable)	na, eh	28	2,124.17	33.15
	nr, na	81,87	73.65	1.15

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wa, na, eh	26	106.64	1.67
wa, nr, na	2	705.57	11.01
wa, nr, na, eh	5,15,19,22,30,31,37,38,49,53,59,62, 65,68,71,72,75,79,80,84	3,398.53	53.03
Total	**26**	**6,408.6**	**100**

Note: 61 land units (22,639.22 ha or 77.94 % of the watershed) fell under suitability class N; No class S1 and S2 were found

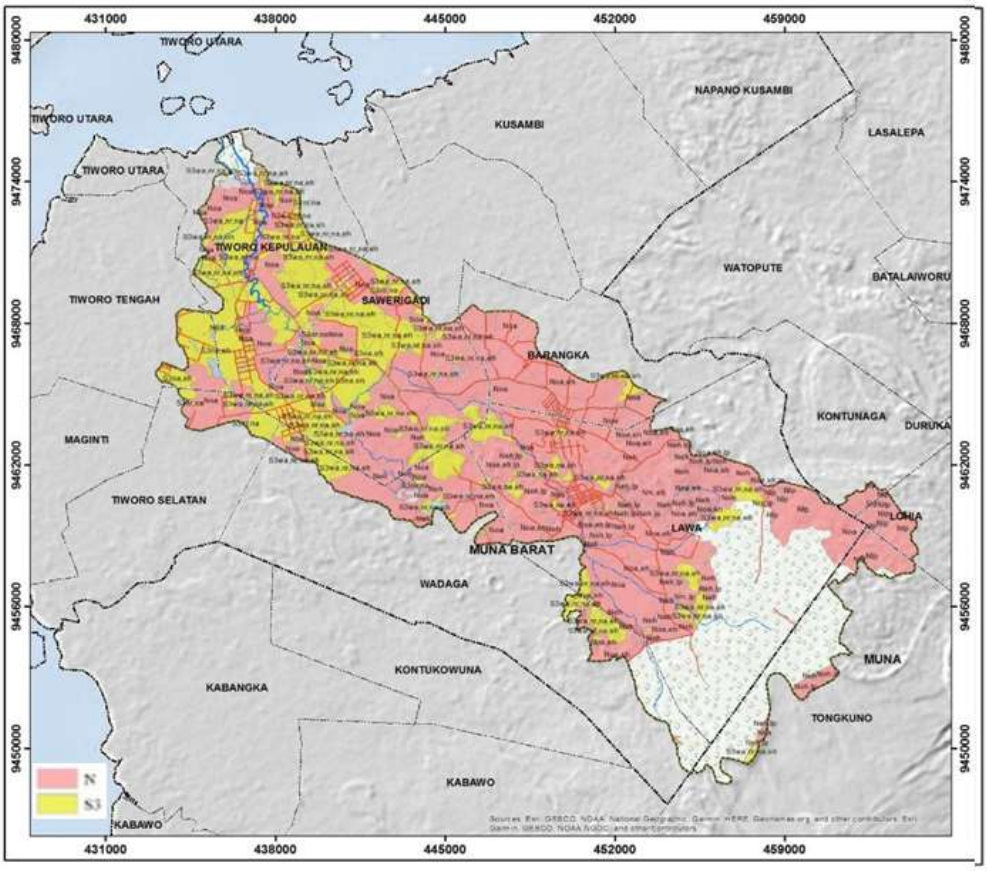

Figure 5. Distribution of land suitability for peanut crops in the Tiworo River watershed

Soybean

Demands for soy beans in Indonesia is high. However, various constraints exist in increasing soybean production, particularly sue high soil acidity [9]. Similar constraints are also found in the Tiworo River watershed. Of the 93 ha of soybean cultivation, its total production was only 115 tons (1.24 tons ha^{-1}), which was also very low compared to our nation-wide soybean productivity [8]. The results of the land suitability evaluation indicated that only can 22.54% of the total area (6,546,8 ha) be sustainably cultivated for soybean crops, under suitability class S3 and with inhibiting factors of 1) water availability, 2) nutrient retention, 3) available nutrients and 4) erosion hazard (Table 5). The distribution of land suitability for cassava crops in the Tiworo River watershed is presented in Figure 6.

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Table 5. Land suitability for soybean crops

Land suitability for soybean crops	Limiting factors	Land units	Area	
			(ha)	(%)
S3 (marginally suitable)	nr, na	87	11.21	0.17
	nr, na, eh	19	626.37	9.57
	wa	5	81.94	1.25
	wa, na, eh	30,31,37,38,43	1,243.93	19.00
	wa, nr, na	2	705.57	10.58
	wa, nr, na, eh	15,16,17,22,26,28,49,53,58,59,60,62, 65,68,71,72,75,79,80,81,84	3,877.82	59.23
Total		**30**	**6,546.6**	**100**

Note: 57 land units (22,501.02 ha or 77.46 % of the watershed) fell under suitability class N; No class S1 and S2 were found

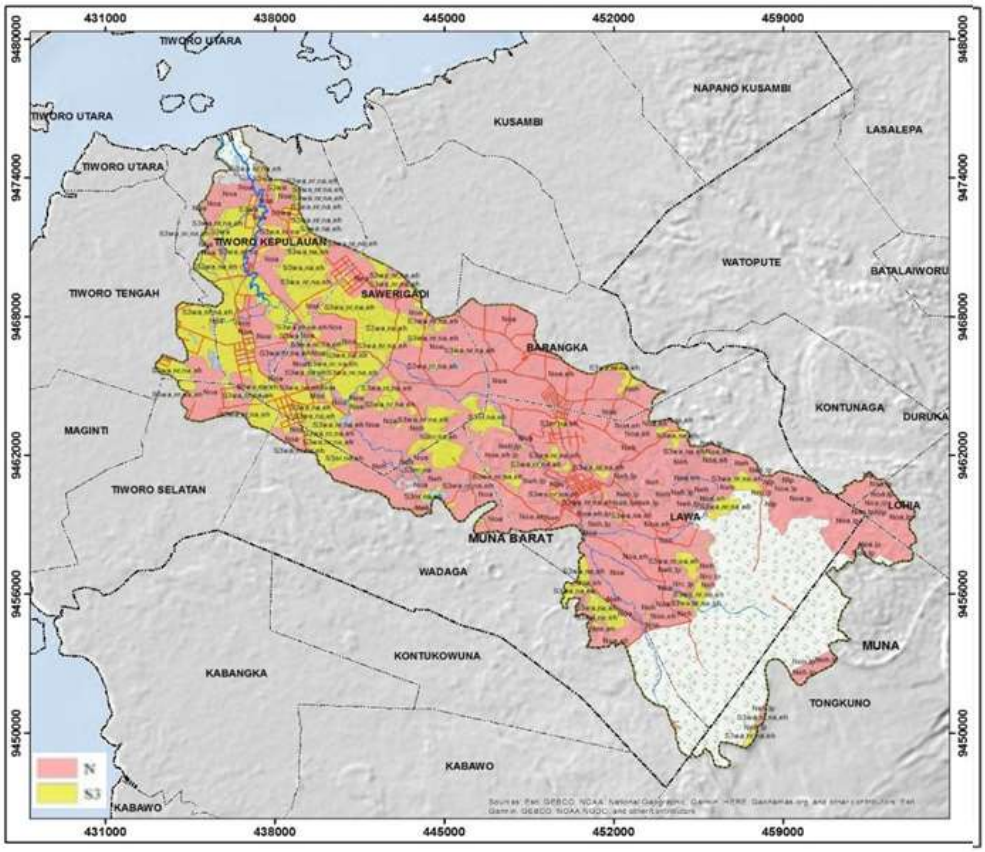

Figure 6. Distribution of land suitability for soybean crops in the Tiworo River watershed

Cassava

Cassava has been another important staple food in Indonesia, after rice and corn. In the Tiworo River watershed, cassava crop is mainly grown only to meet the daily farmers need, and some farmers grow it as a complementary crop (not as main crops) because it is considered economically inferior to other crops. If grown properly, it can be a means of improving farmers' income. Of the 252 ha of cassava cultivation, its total production was 8.076 tons (32.04 tons ha^{-1}), which was considered quite high [8]. The result of land suitability evaluation showed that cassava crops can be

cultivated in 18.80 % of the Tiworo River watershed (5,459.35 ha), but under land suitability class S3, with limiting factors of 1) water availability, 2) root media, 3) nutrient retention, 4) available nutrients, and 5) erosion hazard (Table 6). The distribution of land suitability for cassava crops in the Tiworo River watershed is presented in Figure 7.

Table 6. Land suitability for cassava crops

Land suitability for cassava crops	Limiting factors	Land units	Area	
			(ha)	(%)
S3 (marginally suitable)	na	30	822.60	15.07
	na, eh	26,43	172.85	3.17
	nr, eh	5,59,65,70,72,74,75,79,81,84,85	1,791.94	32.82
	nr, na	37,38	256.02	4.69
	nr, na, eh	2,19,49,58,71,80,87	2,276.34	41.70
	rc, nr, eh	31	99.09	1.82
	wa, nr, na, eh	15,68	40.51	0.74
Total		**26**	**5,459.35**	**100**

Note: 61 land units (23,588.47 ha or 81.21 % of the watershed) fell under suitability class N; No class S1 and S2 were found

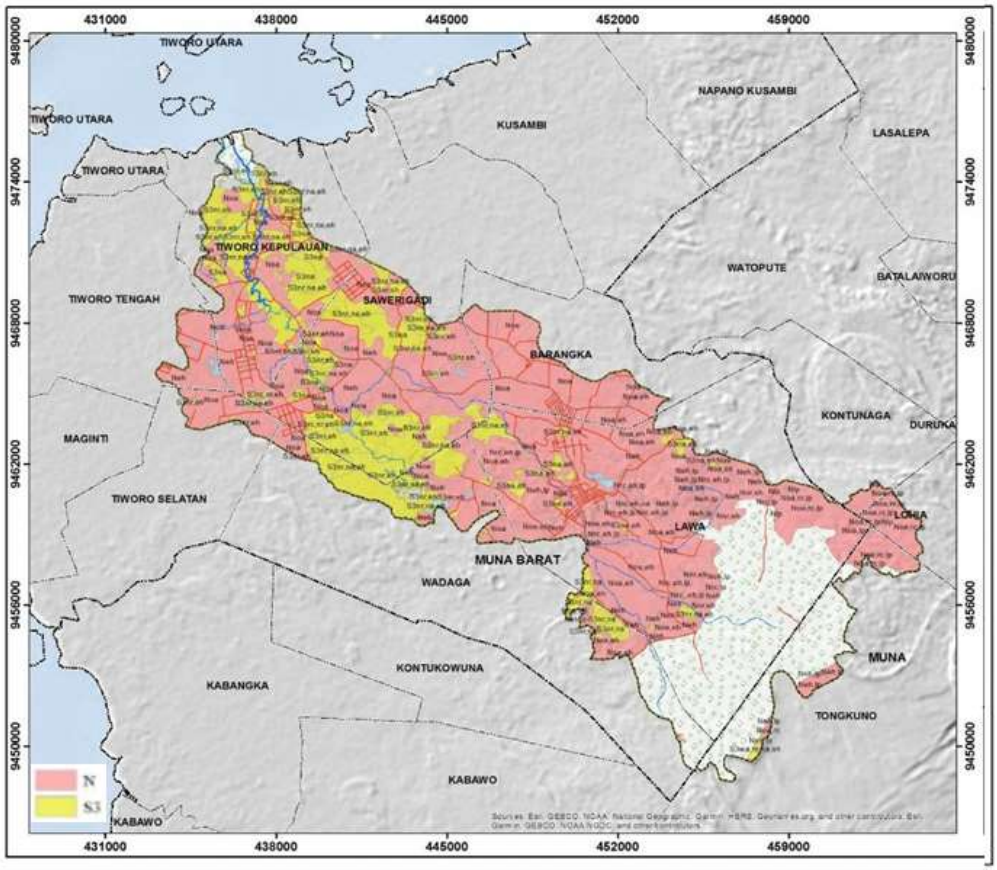

Figure 7. Distribution of land suitability for cassava crops in the Tiworo River watershed

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Tomato

Apart from being used as vegetable, tomatoes are also widely used as raw materials for medicines, cosmetics, and food industries such as ketchup, fruit juices, and others. Therefore, tomatoes have a high economic value [10]. Farmers in the Tiworo River watershed also frequently grow the crop, but only to meet their daily needs (small scales). In 2019, a total of 77 ha across the watershed was cultivated with tomato crops, particularly in the District of South Tiworo (16 ha). The total tomato production only reached 373.10 tons (4.84 tons ha^{-1}), which was below the nation-wide productivity [8]. However, the potential for tomato cultivation in the Tiworo River watershed is quite high, as indicated by the result of land suitability evaluation that tomato crops can be grown in 42.82% of the area (12,437.68 ha). The limiting factors for tomato crops were 1) water availability, 2) oxygen availability, 3) nutrient retention, 4) available nutrients, and 5) erosion hazard (Table 7). The distribution of land suitability for tomato crops in the Tiworo River watershed is presented in Figure 8.

Table 7. Land suitability for tomato crops

Land suitability for tomato crops	Limiting factors	Land units	Area	
			(ha)	(%)
S3 (marginally suitable)	wa, na, eh	26,43	172.85	1.39
	wa, nr, eh	3,5,31,65,75,79, 81,82	293.96	2.36
	wa, nr, na	30	822.60	6.61
	wa, nr, na, eh	2,15,18,19,21,28,36,37,38,49,53,56,58,59,60, 62,68,70,71,72,80,84,85,86,87	10,109.85	81.28
	wa, oa, nr, na, eh	4,6	1,034.56	8.32
	wa, rc, nr, na, eh	16	3.86	0.03
Total		**39**	**12,437.68**	**100**

Note: 48 land units (16,610.14 ha or 57.18 %) fell under suitability class N; No class S1 and S2 were found

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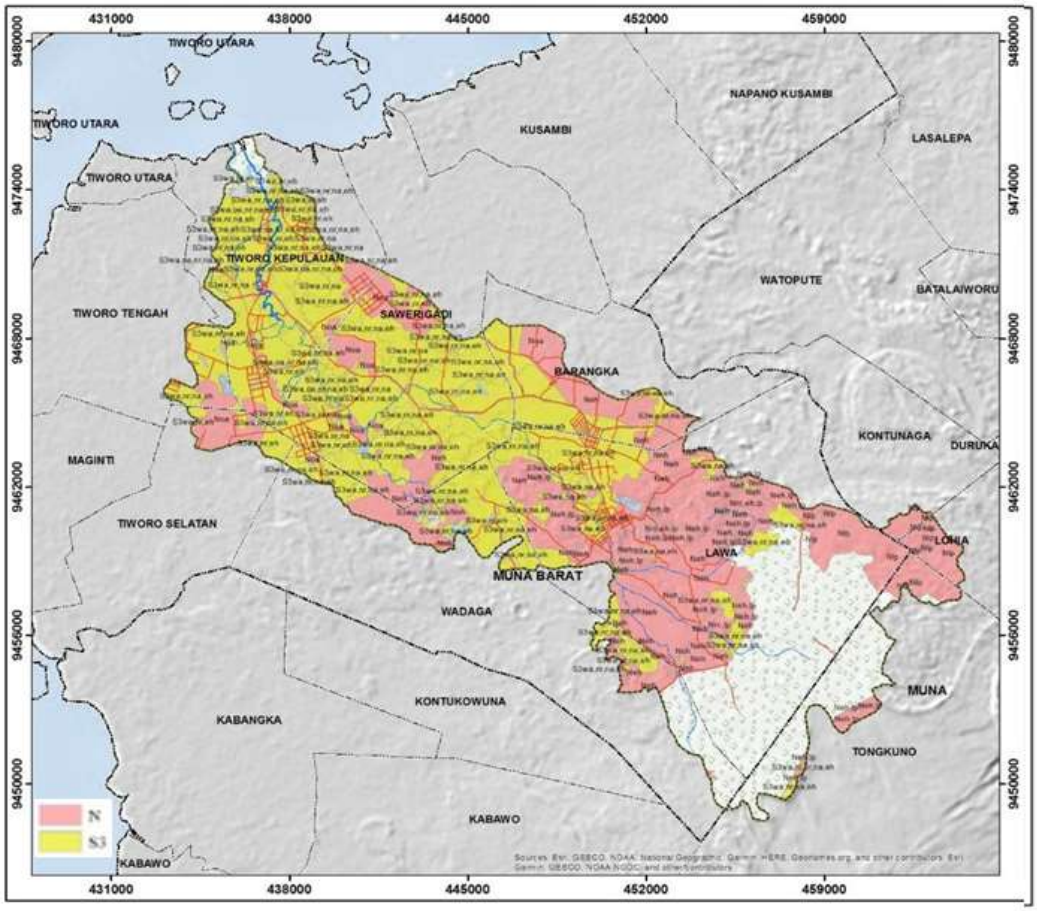

Figure 8. Distribution of land suitability for tomato crops in Tiworo River watershed

IV. CONCLUSION

The results of the study showed that the majority of the land units in the Tiworo River watershed was not suitable for cultivation of paddy-rice (63.22%), corn (68.97%), peanut (70.11%), soybean (65.52%), cassava (70.11%), and tomato (55.17%). The remaining respective land units only fell into class S3 (marginally suitable) for all crops evaluated. No class S1 and S2 were found. The limiting factors for ideal crop growth were low water availability, low nutrient availability, and high erosion hazard. Therefore, this study recommends that: (i) sustainable corresponding crop cultivation be carried in areas categorized as suitable; (ii) mitigating the respective limiting factors be conducted appropriately, for instance, through the application of N and P fertilizers or by increasing the soil organic matter through effective crop residue management and increased use of leguminous crops, through irrigation, and through creation of suitable terraces.

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