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Original Research Article

Parametric System and Kriging Model Approach to Assess Land Potential Area for Development of Maize Production in Gowa Regency, South Sulawesi, Indonesia

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Abstract

Determination of potential land for maize development area is an important issue in providing land needed to increase production. The general aim of this research is: (1) basic considerations in choosing specific location on development of maize cultivation area and (2) developing the concept of sustainable agricultural production in effort to improve the welfare of the community, especially in the study area. The research was conducted using survey method in District Pattallassang and Bontomarannu of Gowa Regency, South Sulawesi. Representing of soil profile and collecting soil sample was done based on grid sampling with stratified random sampling as selected from the field work map. Combining of soil sample data, bio-physical land characteristics, and maize production is analyzed in Stepwise as parametric system and Kriging Model to determine potential land and distribution area for development of maize production. The results showed based on step wise analysis that bio-physical land characteristics variables as depth of soil (X_1), organic matter (X_8), and total potassium (X_9) had very significant effect (sig <0.01) and total nitrogen (X_{10}) had significant effect (sig <0.05). Analysis combination of four variables is found 69.5% with coefficient regression r = 0834 which means strong relationship between each variable in the study area. Land productivity models obtained in the study site was $Y = 0.0654X_1 + 0.021X_8 + 0.012X_9 + 0.008X_{10}$. Land suitability distribution based on Kriging Model is found that the range of land characteristics optimal for corn production is the depth of> 61 cm (S1), 25 -61 cm (S2), 16 - 25 cm (S3), and <16 cm (N). For organic matter> 2.92% (S1), 0.7- 2.92% (S2), 0.46 - 0.70% (S3), and <046% (S3). Nitrogen variable was > 0.32% (S1), 0.11-0.32% (S2), 0.07– 0.11% (S3), and <0.07% (N). Potassium variable was>0.75 cmol/kg (S1), 0.75 – 0.27 cmol/kg (S2), 0.27 – 0.17 cmol/kg (S3), and < 0.17 cmol/kg (S3). The level of land potential development for maize production is moderate to good. This results confirmed that parametric system using step wise and Kriging Model could be applied in determine land suitability class to provide maize development area.

Keywords

Kriging Model
Land suitability
Maize production
Parametric system

Introduction

Land suitability for plant growth is primer requirement for achieving maximum yield and highest quality product in crop production. In many cases it is not easy to found land with best characteristic to support plant needs. The differences of soil properties in each area was built an agro-ecological condition which must be adapted to plant characteristic. The interaction between agro-ecological conditions and plant growth would be determine plant productivity. The understanding of interaction pattern between plant growth requirement and soil characteristics could become useful tool in development of sustainability in agriculture production. So that formulation or creating model in combining both conditions is needed to be considered for optimalizing land capability in agriculture production (Doran et al., 2002). Agro-ecological conditions and bio-physical characteristics studies emphasize understanding of the diversity of land capability and suitability. The study is to determine the types of plants that can be developed or cultivated and be the deciding factor in land productivity level (Acquaah, 2002), including the development and management of land in particular area (Webb and Thiha, 2002). Biophysical conditions can reflect the values or characteristics of the land can be done with a parametric approach.

Parametric approach in land suitability evaluation is quantitative assessment with numeric indicator used in consideration of soil characteristics and plant growth as parameters in the assessment determination.Quantitative assessment of land suitability is given by numeric indicators. Many parameters of soil and plant growth, measurable at various scales of assessment, are used as numeric indicators of agricultural land suitability. For example, weighting factors related to water infiltration (aggregate stability, surface porosity), water absorption (porosity, total C, earthworms), degradation resistance (aggregate stability, microbial processes) and plant growth (parameters affecting rooting depth, water relations, nutrient relations and acidity) could be used (Karlen et al., 1997). Sys et al. (1991) used parametric method based on land evaluation framework for rainfed agriculture. The main step of this approach was matching land characteristics against crop needs, giving in that way suitability rating for each land characteristic. There has been a lot of research in the field of land-use assessment in order to determine the optimal distribution of land use/cover (Fontes et al., 2008). However, land suitability evaluation characteristics vary between regions, and to be practical, they must not become complicated. Thus, land evaluation for specific region and plant growth is needed to realize optimal land use and production.

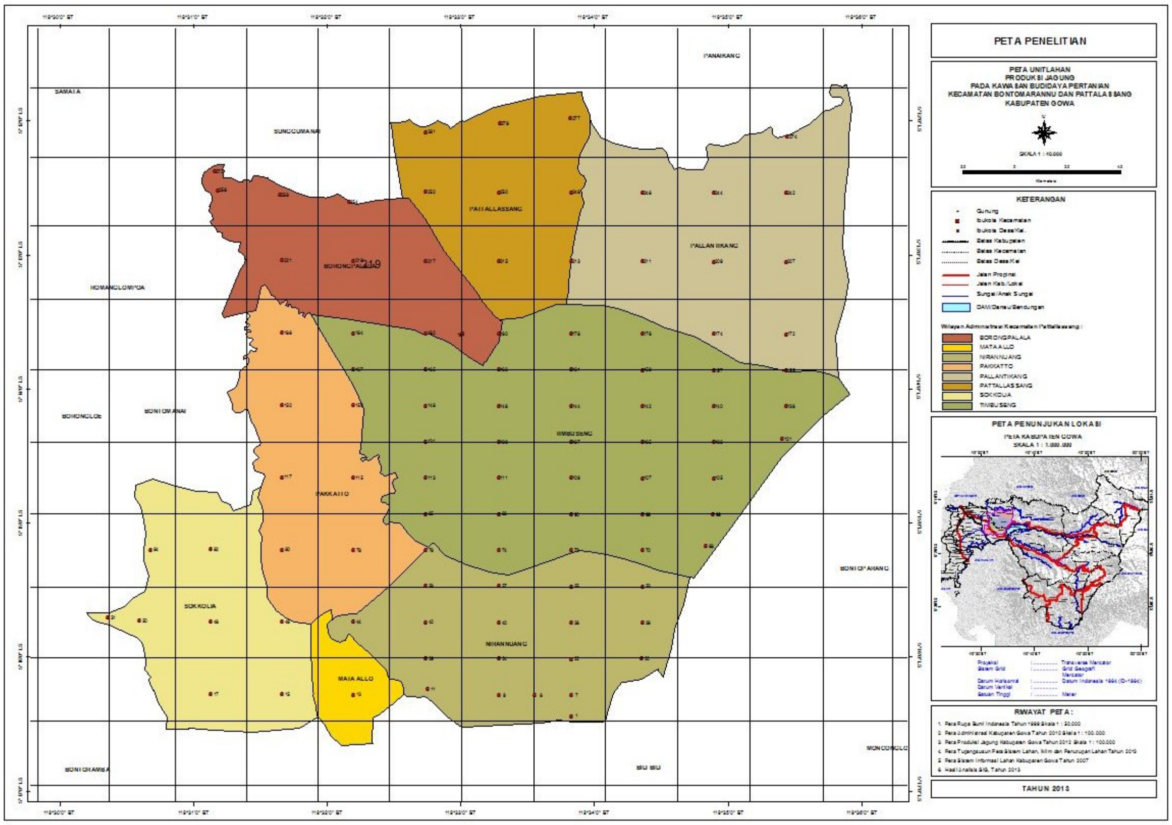
South Sulawesi is one of the center of maize production area in Indonesia with total potential development area approximately 392.648 ha, but maize plantation is only around 250.000 ha. In Gowa regency, there is 36.115 ha as potential area for maize cultivation with the productivity of about 4.56 to 6.16 tons ha^{-1} (Dept. of Agriculture Gowa Regency, 2011). Maize productivity in this area is still lower than national productivity capacity with 9.0-10.5 ton ha^{-1}. The low productivity of maize in this area could be caused by the utilization of land resources which are not appropriate due to soil biophysical constraint and plant production environment. According to Syaifuddin (2008), land in this area has good potention for maize development, but investigation of land productivity and land evaluation was done in general scale and there was no assessment in the specific area. Beside it, model assessment approach without different rating value of soil characteristics and plant growth parameters provide contributions in affecting assessment result. So, land evaluation for spesific area and quantified parameter would be needed to produce good result in development of plant production, in addition to the realization of optimum land use, increasing production, and economic benefits that can be obtained (Gabriel and Quemada, 2010; Salvati and Magherita, 2010). The main objectives of this research is to produce basic considerations in choosing specific location on development of maize cultivation area, and development concept of sustainable agricultural production in order to improve the welfare of the community, especially in the study area. In this study, parametric system was integrated with Kriging model and was applied to evaluate land suitability in the specific area for maize development. The evaluation was constructed using soil biophysical characteristics and maize growth requirement as parameters for scaling and rating in quantified value to introduce into calculation system.

Materials and methods

The study area was located at Pattallassang district covering 84.96 km^2 and Bontomarannu district covering 52.63 km^2 of South Sulawesi Province, Indonesia extending from 5°11’0” to 5°17’0” S and 119°30’0” to 119°37’0” E. This area has D4-type climate based on climate classification of Oldeman (1974) with annual rainfall of 2989 to 3784 mm. The soil types within study area consisted of Dystrudepts, Haplustepts, Endoaquepts, Epiaquepts, Haplustults, Haplusdults and Endoaquults.

The research was conducted using survey method in two districts consisting 17 villages. Basic field work was started by preparation of field work map produced from overlaying of some thematic maps (regional administrative map, soil map of South Sulawesi review, geological map, topography and land use map), climate data, and maize production data. The main system product of field work map is delineating based on land unit system. Position and number of collecting soil samples was decided in the field work map. There were 98 point samples in 30 land units system spread on site of study area. Collecting soil sample was done based on grid sampling with stratified composite sampling (Fig. 1).

Fig. 1: Position point and collection of soil of stratified composite samples.



Soil samples were collected from different dept in each profiles and analyzed for physical and chemical characteristics using the standard analytical methods. Soil physical and chemical properties analyzed method such assoil texture was determined using hydrometer, water holding capacity was determined by pressure plate apparatus (Richards, 1965), sample core method was used to bulk density, and soil reaction (pH) was determined in 1:2 suspension using standard pH meter (Jackson, 1973).The method described by (Bower et al., 1952) was used for Cations Exchange Capacity (CEC) estimation. Total nitrogen (N-tot.) was estimated using Kjeldahl distillation method (Subbiah and Asija, 1956). Total potassium (K-tot.) was calculated using Ammonium Acetate saturation method. The soil organic carbon was estimated using the Walkley and Black wet oxidation method (Jackson, 1973). In addition, environmental conditions such as climate, land characteristics (soil depth, topography, slope, soil type and land use), maize production in each district and productivity index were used to compile data in developing analysis of the site.

Parametric evaluation was developed using sufficiency index/value adapted from the table prepared by Sys et al. (1991) which was constructed to soil characteristics in this study area. Sufficiency value class of soil characteristics related in this site was defined (Table 1).

Table 1. Sufficiency value class of soil characteristics in the study site.

Sl. No.	Variables	Sufficiency value			
		0.4	0.6	0.8	1.0
1.	Soil depth (cm)	< 25	25 – 50	41 – 60	> 60
2.	Texture	Coarse	Fine moderate coarse	Moderate fine	Medium
3.	WHC	< 0.25	0.25 – 0.28	0.28 - <30	≥ 30
4.	Bulk density	> 1.6 – 1.8	> 1.4 – 1.6	> 1.2 – 1.4	0.9 – 1.2
5.	pH (H_2O)	> 8.0	7.6 – 8.0	7.1 – 7.5	6.0 – 7.0
		<5.0	5.0 – 5.4	5.5 – 5.9	
6.	CEC (cmol kg^{-1})	< 5.0	5.0 – 17	18 – 25	> 25
7.	N total (%)	< 0.2	0.2 – 0.5	> 0.5 – 1.0	> 1.0
8.	K total ($mg.kg^{-1}$)	< 15	15 – 30	> 30 – 50	> 50
9.	Organic matter (%)	< 2.0	2.0 – 3.5	> 3.5 – 5.0	> 5.0

Soil characteristic in defined of study area then calculate into all soil samples of each land unit area. Calculated value in each soil characteristics is applied to statistical analysis using stepwise method. Correlation analysis is done to find out the interaction of each parameter in soil characteristics. Land suitability index calculation is the next step of the evaluation to compile the data into kriging method. The result of kriging method is determined land suitability class in the study area.

In designing development area for maize production, the interrelation parameter of soil characteristics must be considered. The effect of biophysical properties has direct to plant production, therefore calculation production is done continuously with soil characteristics. Statistical method was applied to understand the strong effect of biophysical parameters in support plant production. Stepwise method is used to determine correlation between estimation production and soil properties.

Results and discussion

Soil characteristics analysis result in each land unit followed with calculated weights of sufficiency is shown in Table 2. The results showed that sufficiency value has variation in range from low (0.4) to high (1.0). Variation of sufficiency value could be indicating the differences in land potential in supporting plant growth and development, and production according to soil characteristics. Developing analysis is followed following calculated weights of all parameters defined. This analysis is to produce quantitative analysis in designing correlation between the effects of biophysical characteristics and maize production. Statistical analysis has been done Step-wise following analytical hierarchy process which was applied to assign weights of parameters affecting land suitability analysis. The results of the analyses in pair wise comparison matrices are shown in Table 3.

The pair wise matrices result showed that each parameter has two types of correlation: positive and negative. By this correlation land characteristics has direct effect to maize production, and it could become single or multiple characteristic effects. The results showed that the soil depth had very significant effect to maize production as a single factor. Regression correlation analysis was done to determine correlation of each parameter of land characteristics which had significant effect on maize production. The regression analysis showed that there was one single parameter and three pairs had significant correlation to maize production. The regression correlation analysis results are shown in Table 4.

The distribution area of correlation between land characteristic parameters and maize production was analyzed using Kriging method of spatial model. The distribution of production area model and land productivity as a result of Kriging method of analyses are shown in Fig. 2.

Table 2. Defined soil characteristics data and sufficiency value in each land unit.

Land Unit	Soil depth	Texture	Available Water	WHC	BD	pH	CEC	N Total	KTotal	OM
	(cm)		cm cm^{-1}	cm cm^{-1}	g cm^{-3}	(H2O)	(cmol kg^{-1})	(persen)	(mg kg^{-1})	(%)
1	45 (0.8)	ah (0.8)	0.14 (0.7)	0.26 (0.6)	1.30 (0.8)	4.9 (0.4)	28.52 (1.0)	0.19 (0.4)	35 (0.8)	2.92 (0.6)
2	89 (1.0)	ah (0.8)	0.18 (0.9)	0.26 (0.6)	1.10 (1.0)	4.73 (0.4)	30.09 (1.0)	0.16 (0.4)	38 (0.8)	2.16 (0.6)
3	37 (0.6)	ah (0.8)	0.16 (0.8)	0.41 (1.0)	1.10 (1.0)	4.0 (0.4)	32.93 (1.0)	0.26 (0.6)	62 (1.0)	3.40 (0.6)
4	69 (1.0)	h (0.6)	0.16 (0.8)	0.27 (0.6)	1.12 (1.0)	5.0 (0.6)	24.97 (0.8)	0.11 (0.4)	26 (0.6)	1.90 (0.4)
5	72 (1.0)	h (0.6)	0.20 (1.0)	0.33 (1.0)	1.05 (1.0)	4.8 (0.4)	33.27 (1.0)	0.15 (0.4)	47 (0.8)	1.91 (0.4)
6	18 (0.4)	s (1.0)	0.17 (0.85)	0.34 (1.0)	1.18 (1.0)	5.45 (0.6)	38.95 (1.0)	0.21 (0.6)	77 (1.0)	3.89 (0.8)
7	29 (0.6)	s (1.0)	0.16 (0.8)	0.20 (0.4)	1.23 (0.8)	5.9 (0.8)	30.79 (1.0)	0.15 (0.4)	48 (0.8)	3.31 (0.6)
8	62 (1.0)	ah (0.8)	0.10 (0.5)	0.22 (0.4)	1.31 (0.8)	4.5 (0.4)	20.28 (0.8)	0.19 (0.4)	22 (0.6)	2.31 (0.6)
9	24 (0.4)	ak (0.4)	0.18 (0.9)	0.37 (1.0)	1.24 (0.8)	5.9 (0.8)	40.88 (1.0)	0.11 (0.4)	66 (1.0)	1.40 (0.4)
10	65 (1.0)	h (0.6)	0.16 (0.8)	0.33 (1.0)	1.11 (1.0)	5.5 (0.8)	28.65 (1.0)	0.14 (0.4)	49 (0.8)	2.61 (0.6)
11	48 (0.8)	s (1.0)	0.19 (0.95)	0.29 (0.8)	1.15 (1.0)	4.7 (0.4)	28.28 (1.0)	0.22 (0.6)	37 (0.8)	2.54 (0.6)
12	89 (1.0)	h (0.6)	0.17 (0.85)	0.29 (0.8)	1.08 (1.0)	5.0 (0.6)	27.36 (1.0)	0.16 (0.4)	40 (0.8)	2.29 (0.6)
13	105 (1.0)	ah (0.8)	0.16 (0.8)	0.30 (1.0)	1.00 (1.0)	5.7 (0.8)	31.34 (1.0)	0.15 (0.4)	35 (0.8)	1.76 (0.4)
14	24 (0.4)	ah (0.8)	0.14 (0.7)	0.25 (0.6)	1.18 (1.0)	5.5 (0.8)	28.68 (1.0)	0.14 (0.4)	61 (1.0)	3.15 (0.6)
15	40 (0.6)	h (0.6)	0.08 (0.4)	0.18 (0.4)	1.43 (0.6)	5.3 (0.6)	23.96 (0.8)	0.13 (0.4)	24 (0.6)	2.93 (0.6)
16	71 (1.0)	ah (0.8)	0.16 (0.8)	0.26 (0.6)	1.15 (1.0)	6.0 (1.0)	24.83 (0.8)	0.12 (0.4)	34 (0.8)	1.93 (0.4)
17	50 (0.8)	h (0.6)	0.11 (0.6)	0.22 (0.4)	1.20 (1.0)	5.7 (0.8)	27.55 (1.0)	0.11 (0.4)	35 (0.8)	1.88 (0.4)
18	68 (1.0)	ah (0.8)	0.12 (0.6)	0.29 (0.8)	1.32 (0.8)	5.3 (0.6)	27.54 (1.0)	0.13 (0.4)	44 (0.8)	2.53 (0.6)
19	19 (0.4)	s (1.0)	0.13 (0.7)	0.28 (0.8)	1.12 (1.0)	5.0 (0.6)	21.91 (0.8)	0.17 (0.4)	47 (0.8)	1.86 (0.4)
20	46 (0.8)	h (0.6)	0.17 (0.9)	0.20 (0.4)	1.21 (0.8)	4.9 (0.4)	22.63 (0.8)	0.42 (0.6)	19 (0.6)	2.96 (0.6)
21	51 (0.8)	s (1.0)	0.14 (0.7)	0.28 (0.8)	1.17 (1.0)	5.9 (0.8)	27.08 (1.0)	0.16 (0.4)	48 (0.8)	3.06 (0.6)
22	44 (0.8)	s (1.0)	0.21 (1.0)	0.30 (1.0)	1.18 (1.0)	6.0 (1.0)	33.94 (1.0)	0.17 (0.4)	93 (1.0)	2.61 (0.6)
23	98 (1.0)	h (0.6)	0.12 (0.6)	0.24 (0.4)	1.19 (1.0)	4.7 (0.4)	53.66 (1.0)	0.08 (0.4)	56 (1.0)	0.51 (0.4)
24	50 (0.8)	ah (0.8)	0.16 (0.8)	0.25 (0.6)	1.25 (0.8)	5.0 (0.6)	26.01 (1.0)	0.18 (0.4)	40 (0.8)	1.58 (0.4)
25	94 (1.0)	ah (0.8)	0.17 (0.9)	0.28 (0.8)	1.21 (0.8)	5.0 (0.6)	29.64 (1.0)	0.16 (0.4)	31 (0.8)	2.07 (0.6)
26	107 (1.0)	ah (0.8)	0.17 (0.9)	0.28 (0.8)	1.16 (1.0)	5.2 (0.6)	21.92 (0.8)	0.13 (0.4)	29 (0.6)	2.04 (0.6)
27	21 (0.4)	ah (0.8)	0.18 (0.9)	0.33 (1.0)	0.96 (1.0)	5.0 (0.6)	23.25 (0.8)	0.19 (0.4)	33 (0.8)	2.03 (0.6)
28	81 (1.0)	h (0.6)	0.21 (1.0)	0.30 (1.0)	1.07 (1.0)	6.1 (1.0)	28.62 (1.0)	0.21 (0.6)	33 (0.8)	2.17 (0.6)
29	86 (1.0)	h (0.6)	0.18 (0.9)	0.29 (0.8)	1.14 (1.0)	4.0 (0.4)	23.63 (0.8)	0.13 (0.4)	22 (0.6)	1.83 (0.4)
30	71 (1.0)	h (0.6)	0.13 (0.7)	0.29 (0.8)	1.10 (1.0)	5.5 (0.8)	39.49 (1.0)	0.13 (0.4)	44 (0.8)	1.54 (0.4)

Note: Value of x (y) ------------ x = soil characteristics data; y = sufficiency value

Table 3. Pair-wise comparison matrices between land characteristics with maize production.

Parameters		Prod	Soil depth	Texture	Av. Water	WHC	BD	pH	CEC	N	K	OM
Prod	Pearson Correlation	1	0.762**	-0.152	0.134	0.036	0.194	0.039	-0.033	-0.188	-0.277	-0.215
	Sig. (2-tailed)		0.000	0.423	0.479	0.851	0.304	0.840	0.863	0.319	0.139	0.254
	N	30	30	30	30	30	30	30	30	30	30	30
Soil Depth	Pearson Correlation	0.762**	1	-0.235	0.068	-0.064	0.147	-0.134	0.039	-0.186	-0.422*	-0.239
	Sig. (2-tailed)	0.000		0.211	0.722	0.735	0.438	0.480	0.839	0.326	0.020	0.203
	N	30	30	30	30	30	30	30	30	30	30	30
Text.	Pearson Correlation	-0.152	-0.235	1	0.330	0.379*	0.345	0.224	0.286	0.050	0.387*	0.262
	Sig. (2-tailed)	0.423	0.211		0.075	0.039	0.062	0.234	0.125	0.794	0.035	0.162
	N	30	30	30	30	30	30	30	30	30	30	30
Av. Wt	Pearson Correlation	0.134	0.068	0.330	1	0.624**	0.449*	0.109	0.190	0.329	0.197	0.091
	Sig. (2-tailed)	0.479	0.722	0.075		0.000	0.013	0.565	0.315	0.076	0.298	0.632
	N	30	30	30	30	30	30	30	30	30	30	30
WHC	Pearson Correlation	0.036	-0.064	0.379*	0.624**	1	0.442*	0.293	0.271	0.139	0.343	0.096
	Sig. (2-tailed)	0.851	0.735	0.039	0.000		0.014	0.117	0.148	0.465	0.063	0.613
	N	30	30	30	30	30	30	30	30	30	30	30
BD	Pearson Correlation	0.194	0.147	0.345	0.449*	0.442*	1	0.146	0.135	0.111	0.098	-0.154
	Sig. (2-tailed)	0.304	0.438	0.062	0.013	0.014		0.441	0.476	0.559	0.606	0.417
	N	30	30	30	30	30	30	30	30	30	30	30
pH	Pearson Correlation	0.039	-0.134	0.224	0.109	0.293	0.146	1	0.228	-0.105	0.320	-0.042
	Sig. (2-tailed)	0.840	0.480	0.234	0.565	0.117	0.441		0.226	0.579	0.085	0.826
	N	30	30	30	30	30	30	30	30	30	30	30
CEC	Pearson Correlation	-0.033	0.039	0.286	0.190	0.271	0.135	0.228	1	0.098	0.690**	0.135
	Sig. (2-tailed)	0.863	0.839	0.125	0.315	0.148	0.476	0.226		0.608	0.000	0.476
	N	30	30	30	30	30	30	30	30	30	30	30
N	Pearson Correlation	-0.188	-0.186	0.050	0.329	0.139	0.111	-0.105	0.098	1	0.141	0.444*
	Sig. (2-tailed)	0.319	0.326	0.794	0.076	0.465	0.559	0.579	0.608		0.456	0.014
	N	30	30	30	30	30	30	30	30	30	30	30
K	Pearson Correlation	-0.277	-0.422*	0.387*	0.197	0.343	0.098	0.320	0.690**	0.141	1	0.098
	Sig. (2-tailed)	0.139	0.020	0.035	0.298	0.063	0.606	0.085	0.000	0.456		0.606
	N	30	30	30	30	30	30	30	30	30	30	30
OM	Pearson Correlation	-0.215	-0.239	0.262	0.091	0.096	-0.154	-0.042	0.135	0.444*	0.098	1
	Sig. (2-tailed)	0.254	0.203	0.162	0.632	0.613	0.417	0.826	0.476	0.014	0.606	
	N	30	30	30	30	30	30	30	30	30	30	30

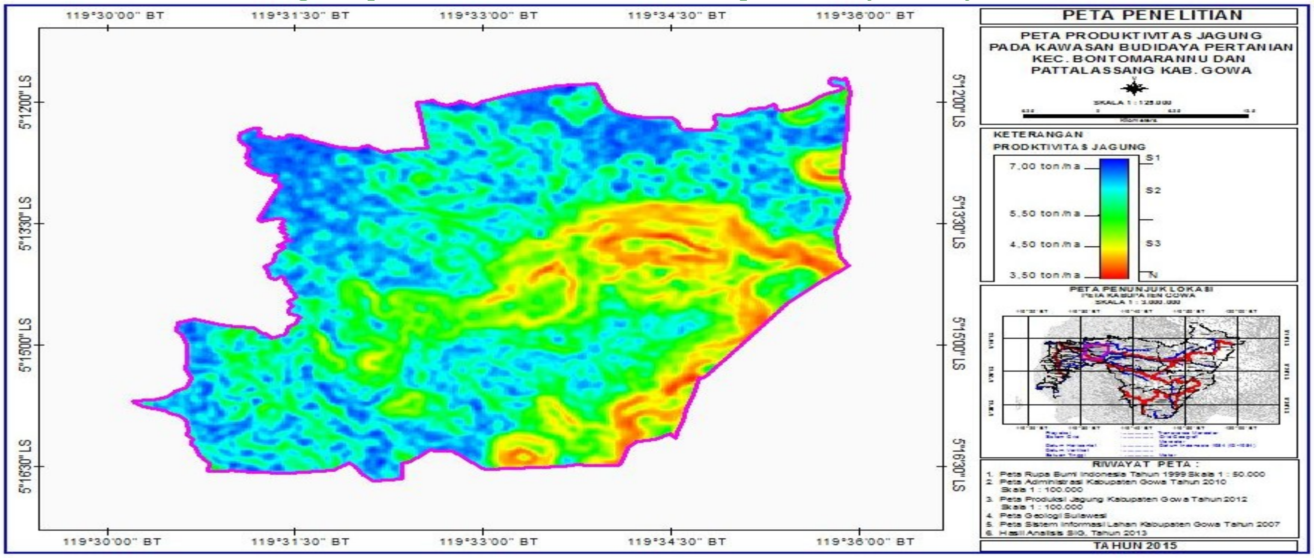
** Correlation is very significant at the 0.01 level (2-tailed); * Correlation is significant at the 0.05 level (2-tailed).

Table 4. Regression correlation analysis of land characteristics to maize production.

Sl. No.	Land characteristics	R	R^2	Regression equation
1.	Soil depth, organic matter, nitrogen and potassium	0.834**	0.695	$Y= 5.157+ 0.021X_1 - 0.147X_{10} - 1.650 X_8 - 0.800 X_9$
2.	Soil depth, nitrogen and potassium	0.820 **	0.687	$Y=4.828+0.023 X_1 - 2.266 X_8 - 0.799 X_9$
3.	Soil depth and potassium	0.816 **	0.666	$Y=4.215+0.025 X_1 - 0.553 X_9$
4.	Soil depth	0.809 **	0.654	$Y=3.872 + 0.027 X_1$

Note: ** = very significant; X_1 = sufficiency value of soil depth; X_9 = sufficiency value of potassium; X_8 = sufficiency value of nitrogen; X_{10} = sufficiency value of organic matter.

Fig. 2: Spatial distribution area of maize productivity in study area.



Conclusion

The land assessment to determine distribution area for maize production development is an important process in sustainable land resources utilization. The accurate and reliable method is needed to find real area with correct land characteristics which supports plant growth. As parametric procedure, the analysis result could be calculated precisely introducing all parameters with exact value. Combining parametric and Kriging method approach could be used in defined strong impact of land characteristics to maize growth.

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