Soil Suitability Evaluation for Sawah in Sumani Watershed in West Sumatra Indonesia using Surfer Tool

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***Abstract*—This study characterized the soils of the Sumani watershed, West Sumatra Indonesia, for soil-suitability evaluation for sawah using Surfer tool-based multicriteria overlay analysis techniques combine with FAO 1976 procedure. The study showed that 78 samples at four soil orders including six groups, i.e. Oxic Hapuldant(OH), Andic Humitropept(AH), Typic Kandiudult(TK), Aeric Tropaquept(AT), Typic Distropept(TD) and Typic Eutropept(TE). Soil developed from fourth geological types. Soil chemical properties were anlysed using ICP and spectrofotemetry. The analysis revealed that the sawah soils number 1-2, 5, 16, 19, 25, 27, 38, 41-42, 44-45, 53-54, 64,68 and 78 were ''moderately suitable (S2)'' and sawah soils number 3-4, 6-14, 17-18, 20-24, 26, 28-32, 33-37, 39-40, 43, 46-48, 49-52, 55-63, 65-66, 67-75 and 76-78 were ''marginally suitable (S3)'' for sawah development. In Sumani watershed, the area analysis showed that for a sawah area about 9974.43 ha (17.1%) of total sawah is moderately suitable and classified as S2. An area about 48355.57 ha (82.9%) is marginal suitable (S3). However, a 0 ha (0%) area is not suitable (N) and 0 ha (0%) area is suitable (S1) for sawah because of uncorrectable factors commonly due to low available silicate(Si) and introduce silicate fertilizer to sawah soil that change sawah soil in criteria S2 (82.9%) . The study demonstrated that Surfer-based tool multicriteria overlay analysis of soil thematic parameters combine with FAO method will be of immense help in soil-suitability evaluation for present sawah condition.**

***Keywords*—sawah, silicon,watershed, suitability,Surfer tool**

I. Introduction

Knowledge of soil, soil characteristics and distribution of soil types is needed for the development of an area's agro-industry because it opens up opportunities for more logic land management[1,2]. Information on regional characteristics, landforms and soil quality is believed to be an important requirement when carrying out planning work to evaluate land suitability for certain plants and different crops

Evaluation of land using FAO scientific procedures is very important in assessing the potential and barriers of agricultural land with certain crops to increase production and profits of agricultural land [3,2]. Many methods of land evaluation approaches have been created or developed and each has specific methodological procedures in their use to achieve optimal benefits [4, 2]. The main objective of land suitability evaluation is to assess the potential of land whether it is suitable to be planted with existing crops or

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there are other alternative crops that are profitable to be planted by systematic comparison of the requirements for growing crops with the resources offered by the land [5,2]. Statistical and geospatial (such as: Surfer tools) are then used to assess the land units and to present the results as three dimension (3D) suitability maps. In the last decade, multicriteria evaluation has received renewed attention in the context of Surfer tool-based decision-making [2] has been used to resolve conflicts of interest for individuals or groups interested in spatial contexts, with the advancement of information and communication technology, computer-based decision support models have been developed for evaluation of land suitability to facilitate and accelerate appropriate decision making [6, 2]. The development of Surfer based thematic databases on soil is very important in its accuracy and accelerates land suitability analysis for optimally utilizing land resources and available information [7,8,9]. Topographic characteristics, climatic conditions, and soil quality of a farm are the most valuable blueprint parameter data in the land suitability evaluation process. Evaluation of the suitability of agricultural land with a three-dimensional map analysis technique can be done using a Surfer tool [10,2], developed a Surfer-based theoretical framework for soil erosion characteristic and recommended land use in Sumani watershed[7].

Agricultural practices vary widely under the different agro-ecological conditions. At present Indonesia lacks even emergency food production due to bio-physical and socio-economic limitations, and available land resources (climate and land) are not used according to their optimal potential [11] stated that evaluation of the physical environment and its impact on crop production is important for sustainable agriculture. This helps the government to determine the direction of potential effective and optimal land use benefits and ultimately optimize agricultural yields for the benefit of local farmers and preserve ecology

Sawah is paddy field with inlet and outlet for irrigation and drainase, respectively [12]. Sumani watershed has been used mainly for paddy production in west Sumatra, Indonesia for centuries. However, during the past decade it was observed that the yield of paddy was fluctuating and stagnant in 4.5 ton/ha not only in the Sumani watershed, but also at national levels in Indonesia. The low yield of Sawah has so far been caused by several factors, such as erratic rainfall distribution, poor soil and crop management practices, low use of inputs, unfavorable soil and site properties, soil mineralogy, $CaCO_3$ content, texture, structure, drainage [13] and available Silicon [15,14,8,9]. However, the factors related to the fluctuation in yield of sawah in different soils are not yet known. In order to find out the most sustainable soils and the factors influencing fluctuation and stagnant yield of paddy production even though all technologies adopted, the present study attempts to correlate the sawah yield with agro-environmental factors like soil physiographic condition, chemical properties in the Sumani Watershed.

In this study an attempt has been made to evaluate the soil resources of the present sawah in Sumani watershed, West Sumatra Indonesia, with soil-site suitability evaluation for sawah using multicriteria overlay analysis techniques in Surfer tool combine with FAO method. This involves landform analysis, characterization of physico-chemical properties of soil, creation of integrated database and information systems, and multicriteria based analysis of land suitability evaluation techniques in Surfer devices using modified FAO land suitability criteria for sawah.

II. MATERIAL AND METHODS

A. Study area

The Sumani watershed occupies 58,330 ha and is located in Solok regency (latitude 0º36'08" to 1º44'08"S, longitude 100º24'11"- 101º15'438" E) in West Sumatra, Indonesia (Fig. 1). The estuary of the watershed is Lake Singkarak. The Sumani watershed has annual rainfall of 1669 to 3230 mm and the range of altitude in the watershed is 300 m to 2500 m above sea level (asl) [7]. The annual temperature in the Sumani watershed ranges from 19 to 30 oC due to differences in height and topography. Annual air humidity is 78.1 to 89.4% (Table 3). Sumani watershed has many land uses, namely primary forest, tree plantations (mixed gardens, coconuts and tea gardens), vegetable gardens, rice fields, shrubs (shrubs, grasses and reeds [land dominated by Imperata cylindrica (Poaceae)]) and urban and rural settlements

B. Fields survey and analytical methods

To investigate the real data in Table 1, Soil surveys were carried out in 78 locations in the Sumani watershed and soil samples were taken based on uniformity and differences in geomorphic position, type of land use and soil type. Soil samples were taken with an auger drill at a depth of 0-20 cm and up to 110 cm. Air-dried and mashed soil samples with porcelain mortar were then sieved with a 2 mm mesh filter for physico-chemical analysis. Soil texture is determined by the feeling method in the field and corrected by the pipette method in the laboratory[16].

The bulk density (BD) is calculated by taking a soil sample with a 100 cm3 volume ring, after the sample has been heated at 105 ° C for about 72 hours, the soil weight per volume of the core sample (100 cm3) is measured. The percentage of pore space is calculated by the same method

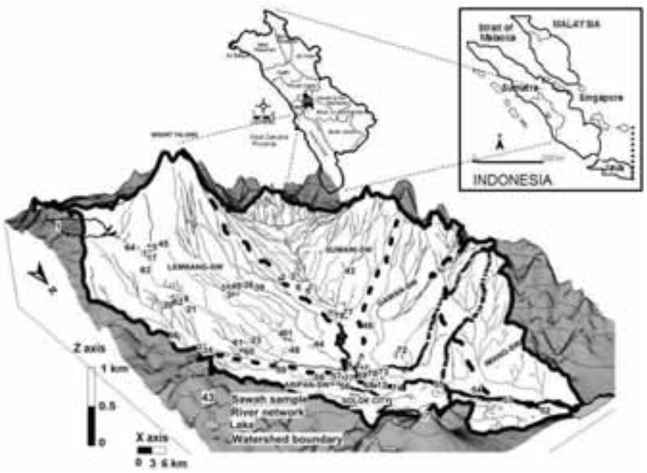

Fig. 1. Study site and distribution of sampling point in 3D map in Sumani, West Sumatra Indonesia.

To know the present physical condition of sawah soil, drainage, flooding, stones in soil surface coarse fragment, soil depth, peat soil depth, peat soil maturity and depth of sulfidic layer, field observation and farmers interview in the sampling time were carried out. We estimated soil erosion rates of sawah in Sumani watershed using USLE [17]as reported by [7,8,9] and percentage slope of sawah in the field were measured by abney level in the sampling time.

Climate (temperature and humidity) is measured by the climatology station in Solok. Soil chemistry is measured directly from soil samples. While the parameters analyzed are total carbon (TC).Total carbon was measured using the dry burning method with Yanaco CN-700 CN Corder equipment (Yanagimoto MFG. Co., Kyoto, Japan). Soil pH and soil EC (electric conductivity) were measured using the glass electrode method with a ratio of soil: water 1: 2.5. Exchange acidity is determined by the first extraction with 1 mol L^{-1} KCl and titration with NaOH. Exchangeable base cations (Ca, Mg, K and Na) were extracted from the soil using 1 mol L^{-1} neutral ammonium acetate and exchange of Ca and Mg measuring with Atomic Emission-Multiple Inductive Emission (Shimadzu ICPS 2000, Kyoto, Japan) equipment. and the exchange of K and Na was measured using Atomic Absorption Spectrophotometer (Shimadzu AS 680). Cation exchange capacity (CEC) is the sum of exchangeable amounts and acidity that can be exchanged. Base saturation (BS) calculates from the total base cation divided by CEC and multiply by 100%. Alkalinity (ESP) is calculated by the Exchangeable Na concentration divided by CEC and multiplied by 100%. Available Si was extracted by 1 mol L^{-1} acetate buffer (pH 4.0) at the mixing ratio of 1:10 for 5 h at 40ºC with occasional shaking. The concentration of Si in the filtrate was measured by Molybdenum-blue method at 810 nm. [14,15].

C. Soil Sawah suitability evaluation procedure

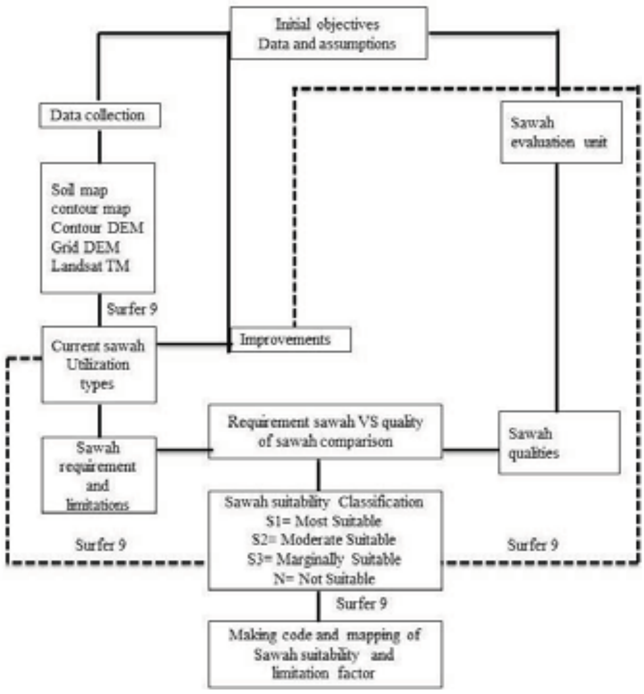

Fig. 2. The land evaluation procedure (FAO, 1976) and 3D mapping using Surfer Tool

This study adopted a land suitability evaluation method developed by the Food and Agriculture Organization (FAO) [3]. Finding the land and climate limiting factors for plants is the most important, this method compares the requirements of paddy fields and characteristics of land resources (Table 1; Table 2; Table 3). The process of analyzing data is briefly shown in schematic form in Figure. 2.

The process of assessing land suitability for sawah through requirements matching procedures grows sawah with certain soil unit characteristics. For sawah, land units are created from an overlay process from the specified theme layer or land quality that forms the basis of its suitability. Land classified as suitable (S1) is the best land for cultivating sawah; moderately suitable (S2) for sawah clearly suitable for use but has limitations, and is marginally suitable (S3) for sawah falling near (but above) the limit for suitability. Land that is not suitable (N) is clearly impractical to overcome or not as an acceptable or forested form. Sawah suitability maps have been generated from spatial overlays of factors in the study area. The quality of the soil is matched with the sawah requirements and classified into different suitability classes, and the suitability map for sawah becomes available where previously there was no.

Modified versions of climate suitability criteria and soil characteristics for sawah are based on parameters that are suitable between sawah requirements or certain land uses and soil parameters are followed (Table 1). Matching the soil parameters with the requirements for the growth of a particular sawah and the definition of the sawah suitability class are done first. sawah suitability analysis process is designed in a Surfer tool to integrate different thematic information. In the multi-criteria overlay analysis model in the Surfer tool [18], twenty effective parameters of soil are considered. Termination of sawah suitability classes according to procedural models in the surfer tool

D. Estimation soil erosion and 3D Mapping procedure

Soil erosion is estimated using the Universal Soil Loss Equation (USLE) model [17]. Required six erosion factors to be able to measure annual soil loss on a watershed scale:

$$E = R \times K \times L \times S \times C \times P \qquad (1)$$

Where: *A* is soil erosion in Mg/ha/y; *R* is Rainfall erosivity factor (dimensionless); *K* is inherent soil erodibility (dimensionless); *L* is length of the slope factor (dimensionless); *S* is slope factor (dimensionless); *C* is crop cover factor(dimensionless); and *P* is a factor that accounts for the effects of soil conservation practices(dimensionless).

The first step in making a map of 3 dimensions of soil erosion and distribution of evaluation suitability of sawah then after laboratory analysis is carried out and then dividing the watershed into 39312 grids measuring 125 mx 125 m. The basic data is then allocated and determined in each grid coordinate and filling in the basic data. Data was obtained by entering soil parameter data, reading maps, assessing Landsat imagery for type and height of land use, and for mapping the use of the kriging method in surfer tool [19].Quantitative distribution of soil physicochemical properties and the distribution of sawah suitability are mapped with the help of Surfer ® 9.

III. RESULTS AND DISCUSSION

A. *Landform characterization*

The Sumani watershed landforms identified were surrounding mount Talang as active volcano and Dibawah lake at upper position, hilly area at west side and Barisan hill areas at east side of watershed, flat area at lower elevation of Sumani watershed . The Sumani watershed consists of five sub-watersheds including Sumani, Lembang, Gawan ,Aripan and Imang (Fig.1). Based on field morphology and laboratory characterization, Sawah in the Sumani watershed cultivated on four soil orders including six groups, i.e. Oxic Hapuldant, Andic Humitropept, Typic Kandiudult, Aeric Tropaquept, Typic Distropept and Typic Eutropept [20]. Distribution of soil groups depends on the type of parent material and morphological position. (Figure 3 a, b; Table 2).

B. *Soil morphological and soil physical properties*

The field survey reveals that sawah soils around mount Talang in upper position of Sumani watershed show dark brown (7.5 YR hues) colors, due to soil order Andisol (oxsic hapludant) characteristizeby black to dark brown colour (Fig. 3a). Climatic and soil-site suitability criteria for Sawah irrigation

Soil-Site Characteristic	Sawah suitability criteria			
	S1	***S2***	***S3***	***N***
Climatic characteristics • t=Mean temperature (^{0}C)	24-29	22-24	18-22	< 18
• h=Humidity (%)	33-90	30-33	<30; >90	-
Site characteristic • Slope (%) (S)	< 3	3-5	5-8	>8
• Erosion (ton/ha/y)	<14	14-28	28-56	>56
• Drainage (Fine&Moderate) (D)	I; MW	P, W	VP; RE	E
• Flood risk (Fh) (F)	F0-F23	F13-F43	F14-F44	F15-F45
• Stoniness in soil surface(%) (SS)	< 5	5-15	15-40	> 40
Soil characteristics • Texture (t) (PD)	cl,sicl,sc, sic	l,s, csi, scl, s	sl,ls,fs	s
• Coarse fragment within 50 cm (%) (CS)	<5	5-15	15-25	.25
• Soil Depth (cm) (SD)	>50	40-50	25-40	<25
• Peat soil depth(cm) (PS)	<60	60-140	140-200	>200
• Peat soil maturity	sapric	sapric, hemic	hemic,f ibric	fibric
• Depth of sulfidic layer founded (cm) (DS)	>100	75 - 100	40-75	<40
Soil fertility • CEC (cmol(+)/kg)	>16	< 16	-	-
• Base saturation(%) (BS)	>50	35-50	<35	-
• pH H_2O(p) (pH)	5.5-8.2	4.5-5.5 8.2-8.5	<4.5 > 8.5	
• Total Carbon (c) (%)(TC)	>1.5	0.8-1.5	<0.8	-
• ECe(e)(Salinity) (dS/m)	<2	2-4	4-6	>6
• ESP (Alkalinity)(a)(%) (A)	<20	20-30	30-40	>40
• Available Silicon (mg SiO2/kg) (Si)	>600**	300-600	86-300	< 86*

I=Imperfect; MW=Moderately well; P=Poor; W=Well; VP=Very Poor; RE=Rather excess; E=excess.cl=clay; sicl=silty clay loam; sc=sandy clay; sic=silty clay; l=loam; s=sandy; csi=clay silty; sl=silty loam; ls=loam sandy; fs=fine sand. *IRRI (2000), ** Sumida (1986); F=flooding

The sawah soil in flat area at lower position of Sumani watershed are brown to grayish brown (10 YR hues). The texture of the soils varies from silt loam to silt clay loam (Table 2) because of andesite basaltic and alluvial fans parent material. The soils on surrounding mount Talang have a silt loam and silt clay loam texture throughout the depth, while the soils developed on lower elevations where the finer particles are transported and deposited at stabilized slope result in a high silt loam content (Table 2). It is observed that no soil structures were found in surface soil sample at sawah. This may be due to paddling (mudding) practices in sawah soils. The physical characteristics of soils reveal that the soils developed in Sumani watershed have depth in range 50-110 cm and cover whole of watershed. Table 2shows that the coarse fragments and stoniness fragment are more (<5%) in soil surrounding mount Talang which are at a higher elevation than the soils formed on a lower elevation like soils at flat area, hilly at west side and Barrisan hill at east side of Sumani watershed. Based on field observation, the presence of coarse fragments is directly related to a topographic situation on a sequence.

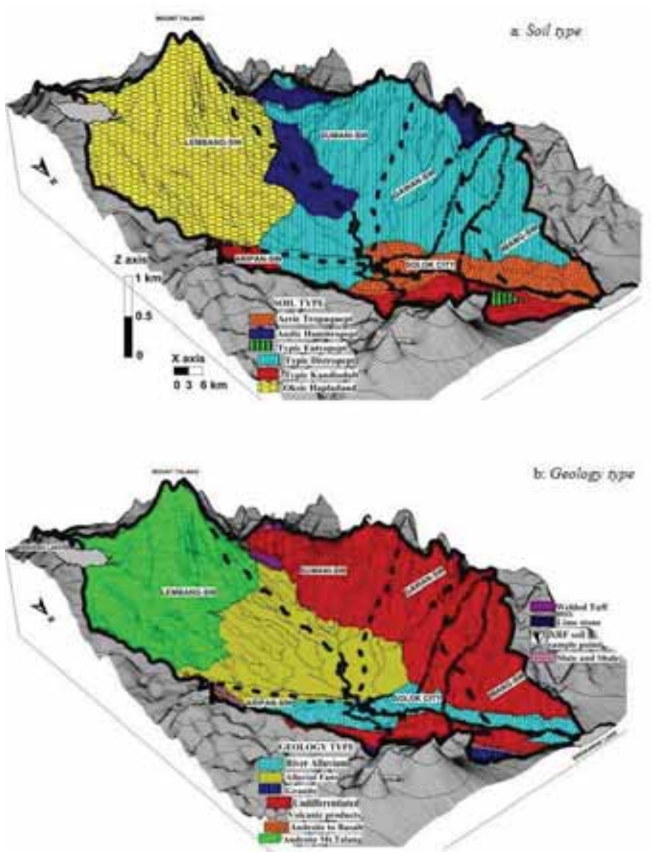

Fig. 3.3D Spatial distribution of geology and soil type in 3D map in Sumani watershed. a: *Soil type,* b: *Geology type.*

It is might be related to past eruption of mount Talang in year 2000. Average annual temperature ranges from 19-30 oC, which varies along an altitudinal gradient. Average annual humidity varies from 83.5% (Table 3). This climate suggests good condition for paddy production. Peat soil depth and depth of sulfides layer are not found in whole of Sumani watershed. Flat area with slope <3% at lower elevation used for sawah. At upland and middle position of sumani watershed farmer making a terrace before planting of paddy reducing percentage of slope by<3%.

The particle size distribution shows that majority of the soils have a fairly high amount of silt compared to clay and sand fractions. Soils at surrounding mount Talang areas, which represent the upper and middle sectors of sawah have a higher silt content amounting to 50%, 70%, and 80%, respectively (Table 2). In general, increasing trend of clay is observed at flat areas on lower elevation which is situated at a upper and middle position with clay percentage at lower position as deposition due to the severe erosion that occurred at upland areas in relation to land use change and intensive agricultural activity at upland area, dominated by vegetables production, as reported by [8,9].

The bulk density values of soils vary from 0.6 to 1 Mg/m3 (Table 2). The variation in bulk density of these soils varies with soil type and may be due to high silt content, organic matter content present in soil andsoil tillage in sawah. As stated by [21], The soil surface is less compact due to the high organic matter and many plant roots. The percentage of pore space values in the study area varied from 64.20% to 75.90% and related to bulk density, clay content and organic matter (Table 2). [22] states that for an ideal medium-textured, well-granulated surface is a good condition for plant growth, about 50% of the soil volume will consist of pore space, and that the pore space will be half full of air and half full with water. The total porosity varies for soil because each of the soil bulk density(BD) also varies. BD values range from a loss of 25% in compacted soils to more than 60% in surface soils which have high organic matter content. Bulk density and soil management can affect the soil pore space.

C. Soil chemical properties in Sumani watershed

Soil chemical characteristics from laboratory analysis found the overall pH value of the soil in the Sumani watershed studied ranged from 4.18 to 7.3,

TABLE I. PHYSICAL PROPERTIES AND SITE CHARACTERISTIC OF SAWAH SOILS IN DEPTH (0-20 CM)

Soil type	Geology type	SD cm	CS %	SS %	PS cm
OH	AMT (n=14)	61.4	7.5	8.1	0
	AF (n=16)	69.4	5.9	5.4	0
AH	AF(n=9)	60.0	5.2	5.3	0
	RA(n=1)	60	5	4.8	0
TD	RA (n=7)	56.1	5.4	4.7	0
	AF(n=10)	60.0	4.9	4.8	0
TE	UVP (n=1)	60	5	5	0
TK	UVP (n=1)	60	4.9	4.7	0
AT	AF(n=3)	60.0	5.3	5	0
	RA (n=10)	60.0	5.5	4.8	0
	UVP (n=6)	60.0	3.8	4.3	0

SD=soil depth(cm); CS=Coarse fragment(%); SS= Stoniness in soil surface (%); PS=peat soil depth(cm); OH=Oxsic Hapludant;AH=Andic Humitropept;TD=Typic Distropept; TE=Typic Eutropept;TK=Typic Kandiudult; AT=Aeric Tropaquept; AMT=Andesit Mt. Talang; AF=Alluvial fans; RA=River alluvium; UVP=Undifferentiated volcanic product;

TABLE II. CONTINUED

Geology type	F	S %	DS cm	PD		
				C%	*Si%*	*S %*
AMT (n=14)	F0	3.6	0	31.6	58.3	10.1
AF (n=16)	F0	5.2	0	29.8	59.3	10.9
AF(n=9)	F0	3.3	0	39.0	47.3	13.7
RA(n=1)	F0	3	0	20.0	69.8	10.2
RA (n=7)	F0	3.3	0	25.0	65.0	10.0
AF(n=10)	F0	3.1	0	25.9	53.7	20.4
UVP (n=1)	F0	3.2	0	10.43	70.25	19.32
UVP (n=1)	F0	3	0	37.80	56.70	5.50
AF(n=3)	F0	3.3	0	20.7	51.1	28.2
RA (n=10)	F0	3.1	0	21.5	55.7	22.8
UVP (n=6)	F0	2.9	0	18.8	63.8	17.4

F=flooding; S=Slope(%); DS=Depth of sulfides layers(cm); PD=particle size distribution; C=clay(%); Si(silt(%); S=sand(%)

TABLE II. CONTINUED

Geology type	USDA NS	BD	PS %
AMT (n=14)	Scl ; 1, 14,15,16,17,18, 19,20,21,45,46,62,63,64	0.67	74.9
AF (n=16)	Scl; 22,23,24,35,36,37,38 ,39,40,60,61,65,66	0.7	73.6
AF(n=9)	Scl;2,3,4,5,6,75,76,77,78	0.8	68.5
RA(n=1)	Scl; 74	0.8	71.7
RA (n=7)	Sl ; 25,26,27,55,57,58,59	0.8	69.9
AF(n=10)	Sl; 41,42,43,44,48,49,51,59,72	0.9	65.9
UVP (n=1)	Sl; 67	0.6	75.9
UVP (n=1)	Scl;47	1.0	64.2
AF(n=3)	Sl; 1,2,3	0.9	66.3
RA (n=10)	Sl; 10,11,12,13,50,52,54,68,70,73	0.8	71.6
UVP (n=6)	Sl;28,29,30,31,53,55	0.8	69.4

USDA NS=USDA Texture class and No. sample; BD= Bulk density(Mg/cm3); PS=Pore space (%); Scl=silt clay loam; SL=silty loam

suggesting that soils are extremely acid to neutral.

Analysis of soil electrical conductivity showed that soil from the study area was very low in dissolved salt concentrations with electrical conductivity ranging between low (0.18 and 2 dS/m), middle (2 and 4 dS/m), high (4 and 4.2 dS/m) (Table 3). Low EC means the soil has no danger of salinity. This shows that the soil in the Sumani watershed is free of salt so the land is responsive and responds well to fertilizer practices and management.

However, Moderate and high value of EC are indicates that the soil has a salinity hazards and hence the soil is not responsive to the given fertilizer and management practices [23]. The total carbon content in the soil from the study area ranges from 1.84 to 3.20 %. Soil in surrounding mount Talang contains more organic carbon than other soils because of soil types is Andisol and crop cover on the surface (Fig. 3).

Silicon available in soil is an important macro element for rice production [24]. However, this has not been noticed from the beginning and almost no silicone fertilization has been applied in the sawah in Indonesia. In the field, blast diseases occurred in local rice varieties, which might be due to deficiency of available Si. Some studies on Si concerning rice production has been published in Indonesia.[25] reported that about 11-20% of available Si decreased in sawah soil due to intensive rice cultivation for the last three decades. In addition, [14] reported that in West Java, supply of Si in lowland sawah through decreased irrigation due to dissolution Si is trapped by diatoms (phyto-plankton) in the dam. However, there is still little research that examines the effect of Si availability on rice production and better Si management in Indonesia. Based on this reason, we add available silicon to FAO guideline as a modification. Available Silicon at 78 sawah soil sample shows mean soil properties and soil erosion rates in respective land use types. According to[26], available Si levels less than 600 and 300 mg SiO_2/kg were considered to be"low" (S2) and "deficient (S3)" for rice plant growth (Table 3). Based on these criteria, most of the sites were grouped into the categories of "low" (S2)or"deficient"(S3), indicating that soils in Sumani watershed arelow in available Si in the range of 127.3-299.79 mg SiO2/kg (Table 3).This might be a reason for blast dieses frequently observed in this watershed.

Cation exchange capacity (CEC) of soils varies from 614.71 to 28.43 cmol(+)/kg and they are related to clay and organic matter content (Table 3). These high values of CEC are attributed to the volcanic glass (25%) and labradorite of minerals [28] and high amounts of silt and clay content (Table 2). Soil exhibits a slight variation in its soil alkalinity (ESP) percentage (3.67-7.46%). Low alkalinity suggests that soils have no sodium hazards (Table 3). Soil exhibits a moderate variation in its base saturation percentage (51.04–83.75%). High base saturation > 50% and low alkalinity (<20%) suggests that soils are suitable for sawah cultivation.

D. Soil Sawah suitability evaluation in Sumani watershed

In order to evaluate sawah suitability, the results obtained on climate and soil physicochemical properties in the study area are summarized in Table 2 and Table 3. The class and parameters needed for multicriteria overlay in the Surfer tool for input parameters in evaluating the suitability of sawah where the data are shown in Table 2 and Table 3.

Based on the data, sawah suitability classes for association were S1-S2 (17.1% of total sawah area) and S1-S3(82.9% of total sawah area) in Sumani watershed (Fig. 4). The Surfer tool-based analysis reveals that sawah soil numbers 1-2, 5, 16, 19, 25, 27, 38, 41-42, 44-45, 53-54, 64,68 and 76 with moderate limitations in soil texture, CEC, available Si, EC salinity and base saturation were ranked moderately suitable (S2) for Sawah. Sawah soil numbers 3-4, 6-14, 17-18, 20-24, 26, 28-32, 33-37, 39-40, 43, 46-48, 49-52, 55-63, 65-66, 67-75 and 77-78 with severe to moderate limitations in available silicon are marginally suitable (S3). However, sawah soil in Sumani watershed are not found in suitable (S1) class and not suitable class (N) for cultivation of sawah (Fig. 5). The limitations of available silicon are uncorrectable while those pertaining to fertility can be corrected by the application of amendments and introduction of improved silicon fertilizer such as coal fly ash, abundance in Indonesia. The area analysis reveals that for a sawah, an area about 9974.43 ha (17.1%) of total sawah in Sumani watershed is moderately suitable and classified as S2.

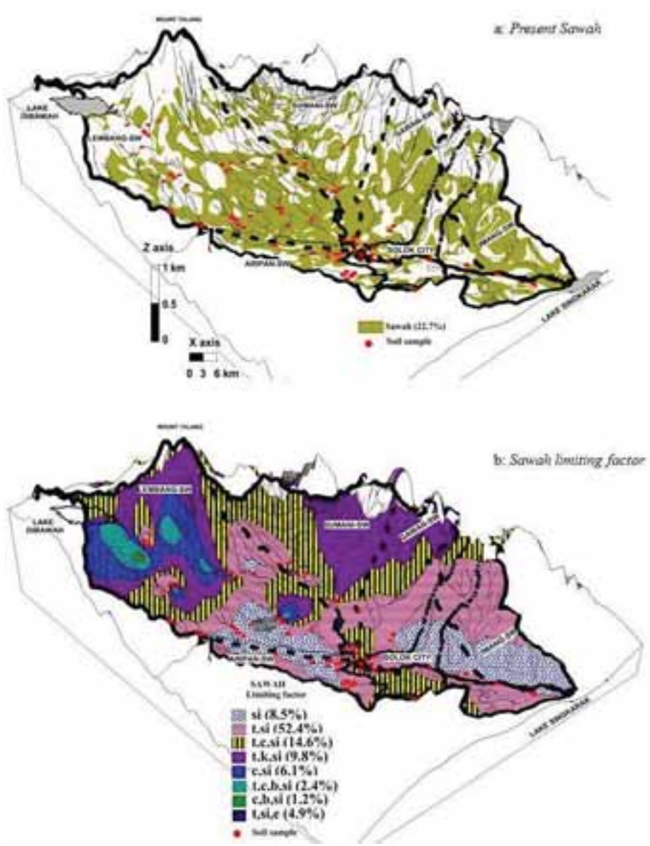

Fig. 4. Spatial distribution of present sawh and sawah suitability class association in Sumani watershed. a: *Present sawah,* b: *Sawah limiting factor.Si: available silicon, t: soil texture, c: CEC, k:total carbon, b: base saturation, e: Ec/salinity.*

TABLE II. CHEMICAL PROPERTIES OF SAWAH SOILS (0-20 CM) AND CLIMATIC CHARACTERISTIC

Soil type	Geology type	pH	EC	TC %	A (%)
OH	AMT (n=14)	5.25	1.46	3.20	5.35
	AF (n=16)	5.35	1.94	3.10	4.54
AH	AF(n=9)	5.57	1.98	2.16	7.01
	RA(n=1)	5.85	0.41	0.91	3.94
TD	RA (n=7)	5.66	1.07	2.13	4.85
	AF(n=10)	5.58	1.75	2.33	3.99
TE	UVP (n=1)	4.90	0.29	3.06	3.67
TK	UVP (n=1)	5.80	0.50	1.99	6.36
AT	AF(n=3)	5.56	0.32	1.84	7.46
	RA (n=10)	5.73	0.77	2.36	5.65
	UVP (n=6)	6.08	0.84	2.45	7.27

pH= soil acidity 1:2.5; EC=electric conductivity1:2.5(dS/ m); TC= Total Carbon(%); A=Alkalinity(ESP)(%)

TABLE III. CONTINUED

Geology type	BS	CEC	Si	Climatic characteristic	
				t	h
AMT (n=14)	65.65	18.95	264.32	19-30	78-89
AF (n=16)	66.67	19.56	207.70	19-30	78-89
AF(n=9)	70.76	20.18	299.79	19-30	78-89
RA(n=1)	83.75	26.05	127.3	19-30	78-89
RA (n=7)	79.98	28.43	275.14	19-30	78-89
AF(n=10)	74.65	21.41	290.51	19-30	78-89
UVP (n=1)	51.04	15.32	189.43	19-30	78-89
UVP (n=1)	74.01	16.56	261.0	19-30	78-89
AF(n=3)	64.79	14.71	178.92	19-30	78-89
RA (n=10)	80.25	25.63	254.92	19-30	78-89
UVP (n=6)	79.57	27.02	219.82	19-30	78-89

BS= base saturation (%); Si=Available Silicon(mg SiO2/kg); t= Mean Tempe-rature(oC); h =Humidity(%); CEC = Cation exchange capacity(cmol(+)/kg)

The marginally suitable soils for sawah are classified as S3 and cover an area about 48355.57 ha (82.9%) of total sawah in Sumani watershed. However, 0 ha (0%) area is not suitable (N) because there were no severe limitation factors and 0 ha (0%) area is suitable (S1) for sawah in present condition because of uncorrectable factors such as available silicon (Fig. 5).

E. Sawah suitability potential with silicate fertilizer

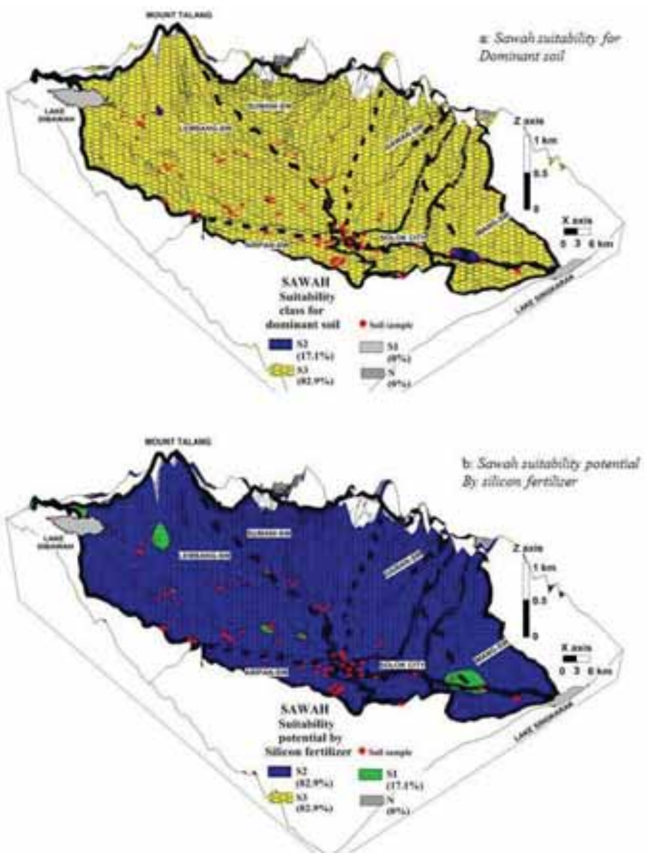

Fig. 5. Spatial distribution of sawah suitability. *a.Sawah suitability actual for dominant soil. b:Sawah suitability potential by silicon fertilizer.*

The analysis of morphological, geological and soil physicochemical properties showed that they are strongly linked not only to the climate but also to soil type, geology and their position in the landscape. The sawah soils are necessarily the most suitable soils (S1). However, sawah soil in Sumani watershed is marginally suitable (S3) due to deficiences of available Si,due to intensive cultivation of sawah in 2-3 productions in a year and resulting in transportation of silicon in rice and straw from the field, without replenishing through silicon fertilizer. The present sawah soil is potentially e suitable (S1-S2) (Fig. 5) when available silicon increases to > 600 mg SiO_2/kg through addition of silicon fertilizer.

In sawah soils even with application of silicon fertilizer, manure, compost and lime, the maximum yield could, however, be obtained with irrigation t. In Sumani watershed during dry season, with shortage of water, farmersresult to vegetable production. However, in middle topographical positions, irrigation water is enough for sawah through out the years. This study found out that the main factor causing stagnated sawah yield of 4.5 – 5 ton/ha/y in Sumani watershed to be due to to low concentration of available Si in sawah soils.

Surfer tool-based sawah-suitability analysis indicates that in the present study, the area is mostly marginally suitable (S3) for cultivation of sawah and the suitability of sawah can be improved by adopting technology such as use of silicon fertilizer. The study revealed that about 9974.43 ha (17.1%) of sawah in Sumani watershed is moderately suitable and classified as S2 for sawah. However, 48355.57 ha (82.9%) area is marginally (S3) for sawah cultivation in present condition (Fig. 4). The sawah soils, which are ‘‘moderately suitable’’(S2) and ‘‘marginally suitable,’’(S3) are due to low level of available silicon 100% (Fig. 4). Sawah productivity can be improved with better management practices such as addition of silicon fertilizer that will change sawah suitability to S2 (82.9%) (Fig 5). The integrated Surfer tool-based model provides site-specific and spatially explicit maps of site suitability for sawah in the Sumani watershed

IV. CONCLUSIONS

Surfer tool-based soil-suitability analysis for sawah reveals that an area of about 9974.43 ha (17.1%) is moderately suitable (S2), 48355.57 ha (82.9%) is marginally suitable (S3), 0 ha (0%) is not suitable (N), and 0 ha (0%) suitable (S1) for sawah in the Sumani watershed as a result of factors such as available silicon, soil texture, CEC, total carbon, base saturation and salinity. The sawah soils number 1-2, 5, 16, 19, 25, 27, 38, 41-42, 44-45, 53-54, 64,68 and 78 are ‘‘moderately suitable’’ while Sawah soils number 3-4, 6-14, 17-18, 20-24, 26, 28-32, 33-37, 39-40, 43, 46-48, 49-52, 55-63, 65-67, 69-77 and 79-80 are ‘‘marginal. The study indicates that about (17.1%) and (82.9%) of total sawah in Sumani watershed is moderately suitable (S2) and marginally suitable (S3) respectively, where sawah productivity can be improved with better management practices such as addition of silicon fertilizer that will change sawah suitability to S2 (82.9%). The soils, which are ‘‘moderately suitable’’ and ‘‘marginally suitable,’’ are due to the low level of available silicon. This study shows that the creation of a database of sawah soil parameters in the Surfer tool and multicriteria overlay analysis is a data blueprint for success in evaluating the land suitability for sawah. Potential and limiting factors of the soil are very important to be assessed in order to optimally manage natural resources and find alternative land uses, especially where sawah is not feasible in the watershed. Three Dimension (3D) maps of sawah suitability can be enriched with village administrative boundaries and can be used to indicate specific locations or sub-locations, where sawah are suitable. Product of 3D map based on the Surfer tool can be used by scientists and extension farmers to select sawah that will be given appropriate treatment to increase the productivity of rice fields.

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