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SOIL QUALITY INDEX: SEVERAL LAND USES IN DESA LUMUT TOBA WEST KALIMANTAN

INDEKS KUALITAS TANAH PADA BEBERAPA PENGGUNAAN LAHAN DI DESA LUMUT, TOBA, KALIMANTAN BARAT

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ABSTRACT

This study aims to analyze soil quality in several land uses using two different methods, namely Lal (1994) and Bajracharya (2006) in secondary forests, oil palm plantations, and open land. The research was conducted for 4 months, including soil sampling in Lumut Village, Toba Sub-district, Sanggau Regency, and laboratory analysis. Determination of soil sampling points using purposive sampling method. Each land use has 8 observation points of intact and disturbed soil sampling at a depth of 0-20 cm representing secondary forest (455,15 ha), oil palm plantation (516,44 ha) and open land (37,73 ha). The results of the soil quality index assessment using the Lal (1994) method in secondary forests, oil palm plantations and open land are in poor criteria with soil quality index values of 36, 34 and 32, respectively. In contrast to the soil quality index assessment using the Bajracharya (2006) method in secondary forests, oil palm plantations and open land all have good criteria with quality index values of 0,76, 0,76 and 0,74. Differences in soil quality classes can occur because the limiting factors and weights in each method are different.

ABSTRAK

Penelitian ini bertujuan untuk menganalisis kualitas tanah pada beberapa penggunaan lahan dengan menggunakan dua metode yang berbeda, yaitu Lal (1994) dan Bajracharya (2006) pada hutan sekunder, perkebunan kelapa sawit, dan lahan terbuka. Penelitian dilakukan selama 4 bulan, meliputi pengambilan sampel tanah di Desa Lumut, Kecamatan Toba, Kabupaten Sanggau, dan analisis laboratorium. Penentuan titik pengambilan sampel tanah menggunakan metode purposive sampling. Masing-masing penggunaan lahan memiliki 8 titik pengamatan pengambilan sampel tanah utuh dan terganggu pada kedalaman 0-20 cm yang mewakili hutan sekunder (455,15 ha), perkebunan kelapa sawit (516,44 ha), dan lahan terbuka (37,73 ha). Hasil penilaian indeks kualitas tanah dengan metode Lal (1994) pada hutan sekunder, perkebunan kelapa sawit dan lahan terbuka masuk dalam kriteria buruk dengan nilai indeks kualitas tanah masing-masing 36, 34 dan 32. Berbeda dengan penilaian indeks kualitas tanah menggunakan metode Bajracharya (2006) pada hutan sekunder, perkebunan kelapa sawit dan lahan terbuka semuanya memiliki kriteria baik dengan nilai indeks kualitas 0,76, 0,76 dan 0,74. Perbedaan kelas kualitas tanah dapat terjadi karena faktor pembatas dan bobot pada masing-masing metode berbeda.

KATA KUNCI:

Indeks kualitas tanah, Kualitas tanah, penggunaan lahan

1. INTRODUCTION

Soil is an important natural resource to support human life and environmental sustainability. Good soil quality supports plant growth and high production (Bedolla *et al*., 2020). Low soil quality will result in a decrease in the function of soil as a growing medium. Soil quality is broadly defined as the capacity of a soil to function within ecosystem and land-use boundaries to sustain biological productivity, maintain environmental quality, and promote plant, animal, and human health (Doran, 2002). Soil quality can also decline due to degradation (Arifin, 2011). Factors causing soil degradation are (1) unsustainable land use (2) improper soil management (3) environmental pollution and (4) uncontrolled land conversion.

Desa Lumut is located in Kecamatan Toba, Kabupaten Sanggau, West Kalimantan. Land use that is not in accordance with its function will cause degradation and result in decreasing land carrying capacity. Determination of soil quality is done to determine the condition of the soil, identify possible problems, and evaluate the effectiveness of land management (Nusantara e*t al*., 2019). One commonly used way of determining soil quality is by calculating the soil quality index (SQI). The soil quality index is a value that describes the soil quality index value obtained from calculations based on several soil parameters, such as soil physical, chemical, and biological properties. Soil quality assessment in this study used two methods, namely Lal (1994) and Bajracharya (2006). Selection of Lal (1994) method considers various soil physical, chemical and biological parameters. These parameters include bulk density, soil texture, soil porosity, soil pH, cation exchange capacity (CEC), base saturation (BS), available phosphorus, total nitrogen, organic carbon, and microbial biomass carbon. Bajracharya's (2006) method emphasizes on parameters directly related to agricultural productivity, namely soil texture Soil pH, organic carbon, total nitrogen, available phosphorus, and available potassium. The use of two different methods can help to verify the research results and compare the advantages and disadvantages of each method.

The assessment of soil quality in this region focuses on three distinct land-use types, each playing a different role in the local ecosystem and soil health. Secondary forests act as critical conservation areas, providing natural biomass and root structures that maintain soil stability and organic matter. Assessing the soil quality index is essential for determining the extent of degradation in secondary forest areas (Rusvita, 2020). In contrast, oil palm plantations represent managed agricultural systems where soil quality is heavily influenced by anthropogenic inputs and intensive cultivation practices aimed at maximizing yield. Finally, open land serves as a baseline for soil vulnerability, often characterized by a lack of protective vegetation which leads to increased exposure to erosion and nutrient leaching. The open condition of the land causes higher surface erosion (Juarti, 2016). Understanding these functions is essential for evaluating how different management strategies impact the long term sustainability of the soil. The purpose of this study was to determine the soil quality index in the use of secondary forest, oil palm plantation and open land with two methods namely Lal (1994) and Bajracharya (2006) in Desa Lumut, Kecamatan Toba, Kabupaten Sanggau, West Kalimantan.

2. MATERIALS AND METHOD

This research was conducted in Desa Lumut, Kecamatan Toba, Kabupaten Sanggau, West Kalimantan. Soil analyses were conducted at the Soil analyses were conducted at the Soil Physics and Conservation Laboratory, the Soil Chemistry and Fertility Laboratory, and the Soil Biology Laboratory, Faculty of Agriculture, Tanjungpura University. The research was start from the preparation stage, determining the location of the sample point, profiling, soil sampling, laboratory analysis, data analysis and presentation of results. The method used in soil sampling is purposive sampling of 24 soil samples at a depth of 0-20 cm in accordance with the map of soil sampling points.

Determination of the soil quality index value using the Lal (1994) method is done by summing the value score of each indicator (Table 1). Based on the method established by Agustina *et al.*, (2020), the formula is defined as follows:

$$SQI = SF + SK + SB \quad (1)$$

Note: SQI = Soil Quality Index. SF = Soil Physical. SK = Soil Chemical. SB = Soil Biological.

Table 1. Factors and Relative Weights of Soil Quality Indicators Lal (1994)

Characteristic	Indicator	None (Very Good)	Slight (Good)	Moderate (Medium)	Severe (Poor)	Extreme (Very Poor)
		1	2	3	4	5
Physic	Bulk density (g/cm3)	<1.19	1.2 - 1.29	1.3 - 1.39	1.4 - 1.49	>1.5
	Soil Texture (%)	Loam	Silt loam, silty clay loam	Clay loam, sandy loam	Silty clay, loamy sand, sandy clay loam,	Clay, sand, sandy clay
	Available Water Capacity(%)	>30	20 – 29	8 – 19	3 – 7	<2
	Soil Porosity (%)	>20	18 - 19	15 - 17	11 - 14	<10
Chemical	Soil pH	6.0 - 7.0	5.8 - 5.9	5.4 - 5.7	5.1 - 5.3	<5
	CEC ($cmol_{(+)}kg^{-1}$)	>40	25-39	17-24	6 - 16	<5
	Base Saturation (%)	>70	51 - 69	31 - 50	21 - 30	<20
	Nutrition (N, P and K)					
	Total Nitrogen (%)	>0.75	0.51 - 0.74	0.21 - 0.50	0.11 - 0.20	<0.10
	Available Phosphorus (ppm)	>35	26 - 34	16 - 25	11 - 15	<10
	Available Potassium ($cmol_{(+)}kg^{-1}$)	>1.0	0.6 – 0.9	0.3 – 0.5	0.11 – 0.2	<0.1
	Organic Carbon (%)	>5	3 - 4	1 - 2	0.6 - 0.9	<0.5
Biology	Microbial Biomass Carbon (mg CO_2/g)	>25	20-24	10 - 19	5-10	<5

Table 2. Soil Quality Criteria Based on 10 Parameters Lal (1994)

Soil Quality Criteria	Relative Weighting	Cumulative Weight (SQI)
Very Good	1	< 20
Good	2	20 – 24
Medium	3	25 – 29
Poor	4	30 – 39
Very Poor	5	> 40

Table 3. Bajracharya (2006) Soil Quality Index Determination Parameter Score

Characteristic	Indicator	Ranking Values				
		0,2	0,4	0,6	0,8	1,0
Physic	Soil Texture	Clay, Sand	Sandy clay loam, silty clay, loamy sand	Sandy loam, silty clay	Loam, silt loam, clay loam	Silty clay loam, sandy clay
Chemical	Soil pH	<4.0	4.0 – 4.9	5.0 – 5.9	6.0 – 6.4	6.5 – 7.5
	Carbon Organic (%)	<0.5	0.5 – 1.0	1.1 – 2.0	2.1 – 4	>4
	Nutrition (N, P and K)*	Very Poor	Poor	Moderate	Good	Very Good
	Total Nitrogen (%)	<0.10	0.10 - 0.20	0.21 - 0.50	0.51 - 0.75	>0.75
	Available Phosphorus (ppm)	<10	10 - 15	16 - 25	26 - 35	>35
	Available Potassium ($cmol_{(+)}kg^{-1}$)	<0.1	0.1 - 0.2	0.3 - 0.5	0.6 - 1.0	>1.0

Table 4. Soil Quality Criteria Based on Soil Quality Index (SQI) Values

Soil Quality Criteria	SQI Value
Very Good	0,80 – 1,00
Good	0,60 – 0,79
Medium	0,40 – 0,59
Poor	0,20 – 0,39
Very Poor	0,00 – 0,19

Source: Partoyo (2005).

The soil quality index value is determined by summing the assigned weights of each predetermined parameter, which are then categorized according to the cumulative weight criteria presented in Table 2. According to Ghimire, *Et al.*, (2018), the following equation is used to calculate the Soil Quality Index (SQI) value:

$$SQI = [(a \times R_{STC}) + (b \times R_{pH}) + (c \times R_{OC}) + (d \times R_{NPK})] \quad (2)$$

Note: SQI = Soil Quality Index. R_{STC} = Score value assigned to soil texture class. R_{pH} = Score value assigned to soil pH. R_{OC} = Score value assigned to soil organic carbon. R_{NPK} = Score value assigned to nitrogen, phosphor and potasium.

The weights on each parameter were assigned by Ghimire *Et al.*, (2018) namely a = 0.2; b = 0.1; c = 0.4; and d = 0.3. The soil quality index assessment using the Bajracharya (2006) method is conducted through a scoring and weighting process. A higher soil quality index value indicates superior soil conditions within a specific land area. The specific criteria and classes for soil quality are detailed in Table 4.

3. RESULT AND DISCUSSION

3.1 Lal (1994)

The Soil Quality Index (SQI) according to Lal (1994) is divided into three soil properties, namely soil physical properties consisting of several parameters including content weight, soil texture, field capacity moisture content and porosity. Chemical properties with several parameters namely bulk density, soil texture, soil porosity, soil pH, cation exchange capacity (CEC), base saturation (BS), available phosphorus, total nitrogen, organic carbon, and microbial biomass carbon.

This method also analyzes soil biological properties for soil C-biomass parameters. Research shows a strong correlation between biomass C potential and soil quality index in various types of land use (Hidayat, *et al*., 2023).

Based on the data in Table 5, the physical properties of soil in Desa Lumut, Kecamatan Toba, Kabupaten Sanggau, West Kalimantan in the three land uses, namely secondary forest, oil palm plantation and open land, are generally in good condition. This is indicated by the score of soil physical properties parameters that are at 1 and 2. Fill weight values for the three land types (HS, LK, LT) are around 1.17-1.18 g/cm^3. This value indicates a relatively low soil density. A low specific gravity indicates a less dense soil, which is good for root penetration and water movement. Manurung *et al*., (2021) in their research on soil quality index also found that it is influenced by bulk density. This is supported by the soil texture class in the three land uses for HS and LK being SiCL (Silty Clay Loamy), while for LT it is L (Loamy). In addition, the physical properties of porosity and field capacity moisture content also have a score of 1 (without limitation) and are closely related indicating that the soil's ability to retain water is very good. Based on the results of a study by Triadiawarman *et al*., (2022), the water content will affect the bulk density of the soil. Porosity provides space and field capacity moisture content determines how much of that space can be filled with water.

Chemical properties are one of the determinants of soil quality index assessment. pH value ranges from 5.21-5.43, which is classified as acidic. Soil low acidity levels have low base saturation, while soils with high acidity levels have high base saturation. Low base saturation also indicates high levels of aluminum (Al), iron (Fe), and other acidic cations (Hardjowigeno, 2015). The pH value correlates with a relatively low CEC value (14.55-18.97 cmol$_{(+)}$kg^{-1}), especially on LK and LT lands with a score of 4. Based on the results of research conducted by Lestari *et al*., (2022) Acidic soil (low pH) ion hydrogen dominates the exchange sites, reducing the soil's ability to retain important cations such as calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^{+}). Soil with low CEC are unable to release potassium effectively, resulting in low or very low potassium content (Harahap, 2018). Low CEC limits the soil's ability to retain and provide nutrients. CEC values vary across different soil types and are influenced by factors such as pH and organic C (Sahfiitra, 2023). This has an impact on the availability of N, P, and K. A score of 3 for Total N indicates moderate nitrogen availability, but scores of 4 and 5 for Available P and Available K indicate low to very low phosphorus and potassium availability. In addition, acidic pH also reduces the base saturation (BS) score of 5 in all three land uses (7.96-10.45%) indicating very low base saturation, which correlates with acidic pH conditions. H^{+} ions displace base cations from exchange sites, reducing the percentage of available base cations. Low base saturation (BS) indicates a deficiency of base cations, which are essential for plant growth (Soekamto, 2015). This can affect the availability of other nutrients. Phosphorus (P) availability is greatly influenced by pH. At acidic pH, phosphorus tends to be bound by iron and aluminum, making it unavailable to plants. The availability of potassium (K) is also influenced by CEC and base saturation (BS) (Martunis *et al*., 2015). Organic C plays an important role in increasing soil fertility (Arifin, 2017).

Organic matter can increase CEC, base saturation and nutrient availability, as well as improve soil pH. Light to moderate Organic C values(scores 2 and 3) indicate the potential for improving soil chemical properties through increasing organic matter. Parameters in soil chemical properties are closely related, this is supported by the results of Soekamto's (2015) research on the value of organic C 0.99% (Very Low), N-total 0.10% (Very Low), P2O5 5.1 ppm (Very Low), K 6.81 mg/100g (Low), CEC 19.06 me/100g (Medium), base saturation 57.06% (High) and pH 5.5 (acid).

Table 5. Soil Quality Index for Several Land Uses Desa Lumut, Kecamatan Toba, Kabupaten Sanggau, West Kalimantan Based on the Lal Method (1994)

Characteristic	Indicator	HS Value	Score	LK Value	Score	LT Value	Score
Physics	Weight Content (g/cm^3)	1.18	1	1.17	1	1.17	1
	Soil Texture (%)	SiCL	2	SiCL	2	L	1
	Available Water Capacity (%)	48.77	1	50.82	1	50.85	1
	Porosity(%)	54.39	1	54.64	1	54.88	1
Chemistry	pH	5.21	4	5.43	3	5.28	4
	CEC (cmol$^{(+)kg-1}$)	18.97	3	14.55	4	15.02	4
	Base Saturation (%)	7.96	5	8.90	5	10.45	5
	Nutrition (N, P and K)						
	Total Nitrogen (%)	0.31	3	0.27	3	0.30	3
	P-Available (ppm)	14.70	4	32.06	2	41.08	1
	K-Available (cmol$_{(+)}$kg^{-1})	0.13	4	0.08	5	0.12	4
	C-Organic(%)	2.93	3	3.05	2	3.83	2
Biology	C-Biomass (mg CO_2/g)	3.57	5	0.70	5	1.23	5
Criteria		Poor	36	Poor	34	Poor	32

Note: HS = Secondary Forest. LK = Oil Palm Plantation. LT = Open Land.

The biological properties of the soil analyzed are soil biomass carbon. The C-value biomass in the three land uses, namely 3.57 mg CO_2/g (HS), 0.70 mg CO_2/g (LK), and 1.23 mg CO_2/g (LT) including a score of 5 (extreme) indicating very poor conditions. Low C-biomass values indicate low microorganism activity, which can be caused by various factors such as lack of organic matter and extreme pH. Organic matter is a source of energy for soil microorganisms (Widodo e*t al*., 2016). The more organic matter, the higher the activity of microorganisms and the higher the C-Biomass. According to research by Sagala et al. (2021), one of the main causes of low microbial biomass is an inadequate soil drainage system. Based on Table 5, the C-organic value is at a light-moderate level (scores 2 and 3). However, the C-biomass value is very low, indicating that even though there is organic matter, microorganism activity is very limited. Low C-biomass values can occur due to several factors, such as the amount of organic matter content as a food source for microorganisms (Fang *et al*., 2014). This can be caused by several factors, one of which is high soil acidity. Low microorganism activity can disrupt the carbon cycle in the soil. Under normal conditions, microorganisms decompose organic matter and release carbon dioxide (CO_2) into the atmosphere (Suzana, 2019). However, if the activity of microorganisms is very low, the decomposition of organic matter slows down, and carbon can be trapped in the soil or lost through other processes . In addition, soil conditions that are too moist, or too dry, can affect carbon volatilization. Carbon volatilization can also occur as a result of human activities, such as land burning.

The three lands HS, LK and LT have poor quality index values land respectively 36, 34 and 32. The lowest soil quality index value in the three lands is open land. Open land based on direct observation results has a lot of grass vegetation and there is still a lot of litter left over from tree felling. Ultisol soil types have low acidity potential (Angreni *et al*., 2015). To improve its quality, it is often treated by adding organic materials or liming.

3.2 Bajracharya (2006)

Soil Quality Index (SQI) according to Bajracharya (2006) is seen based on the analysis of six key parameters, namely soil texture, pH, total N, available P, available K and organic C. Determination of the soil quality index with this method focuses on several physical and chemical properties and there are no soil biological parameters.

Table 6. Soil Quality Index for Several Land Uses in Desa Lumut, Kecamatan Desa, Kabupaten Sanggau, West Kaliamtan Based on Bajracharya Method (2006)

Indicator	HS Value	Score	LK Value	Score	LT Value	Score
Soil Texture (%)	SiCL	0.2	SiCL	0.2	L	0.16
pH	5.21	0.06	5.43	0.06	5.28	0.06
C-Organic (%)	2.93	0.32	3.05	0.32	3.83	0.32
N-Total (%)*	0.31(S)	0.06	0.27 (S)	0.06	0.30 (S)	0.06
P-Available (ppm)*	14.7 (AR)	0.08	32.06 (AT)	0.1	41.08 (T)	0.1
K-Available (%)*	0.18 (AR)	0.04	0.08 (AR)	0.02	0.12 (AR)	0.04
Criteria	Good	0.76	Good	0.76	Good	0.74

Based on Table 6, the assessment of the soil quality index has good criteria for HS, LK and LT with sequential values of 0.76, 0.76 and 0.74. Texture parameters are physical properties used in determining SQI in the Bajracharya method (2006) with a soil texture class of silty clay loam in HS and a soil texture class of clay for LT. Soil texture is a basic physical property that affects many other soil properties. Soil texture is a relatively stable and difficult to change property, thus providing an overview of the physical condition of the soil. Soil texture greatly determines the ability of the soil to retain water and nutrients, aeration and drainage and soil structure which are very important for plant growth. Soil texture affects the formation of soil structure, which is the arrangement of soil particles into aggregates. Good soil structure improves aeration, drainage, and water infiltration. Soil texture can differ in various land uses, influenced by vegetation, human activities, and environmental conditions (Solekhah, *Et al*., 2024).

The chemical properties of the soil in the three land uses were also analyzed to determine the SQI alue. The pH values in the three locations (HS, LK, LT) were in the range of 5.21 to 5.43. This indicates that the soil in the area tends to be acidic. Acidic pH can affect the availability of nutrients for plants such as phosphorus (P) becoming less available in acidic conditions. The results showed that the soil pH in the oil palm plantations studied tended to be acidic, with a pH value of 4.32 at a depth of 0-30 cm (Damara, 2021). Total nitrogen, available phosphorus, and available potassium score assessments were adjusted according to PPT (1983). The N-total criteria for the three land uses were moderate. Total N was consistently found to be in the moderate range for various types of land, including oil palm (Dewanti, *Et al*., 2024). The C/N ratio of organic matter affects the total N content, the greater the C/N, the greater the total N produced.

The levels of available P in the three types of land showed differences. HS land had the lowest levels of Available P, which was 14.7 ppm, LK 32.06 ppm and LT 41.08 ppm indicating very high phosphorus availability among the three types of land. This difference is caused by differences in soil type, land use and land management. In addition, one of the factors for the low P content is the low organic content at the location (Jumiun, *Et al*., 2024).

Available potassium is a form of potassium that can be absorbed by plants, with soil potassium in equilibrium, namely mineral, fixed, exchangeable, and dissolved in water. The results of the analysis of Table 6 show that the K content in the three land uses has a rather low criterion. The low K content is influenced by the leaching of K by water and absorption by plants (transported) without any return by fertilization methods. This is supported by the results of research by Baihaki *Et al*., (2020) the amount of K in the soil that can be absorbed by plants is only a little. In addition to the low availability of K, the availability of K in the soil can also be reduced due to three things, namely the uptake of K by plants (permanent), leaching of K by water, and soil erosion.

The assessment of soil quality index using both has different results. Soil quality in the three land uses has poor criteria seen from the analysis of the Lal method (1994), while the assessment of soil quality using the Bajracharya method (2006) has good criteria. This can occur because of differences in the parameters that determine the value of the soil quality index, resulting in interpretations that can also be different. Each method has a different threshold or criteria for classifying soil quality.

4. CONCLUSIONS

The results of the research that Based on Lal method (1994), the three types of land use, Secondary Forest, Oil Palm Plantation Land, and Open Land, have soil quality that is classified as Poor (36, 34, and 32). Based on the Bajracharya (2006) method, the soil quality category for the three types of land use is Good (0.76, 0.76 and 0.74). Several parameters provide a greater contribution to determining the IKT value in each method, so that in the Lal Method (1994) the parameters are pH, CEC and C-biomass and in the Bajracharya Method (2006) the parameters are C-Organic, N-Total, P-Available, and K-Available.

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