Vol. 15, No. 1 (2026): 470 - 477
http://dx.doi.org/10.23960/jtepl.v15i1.470-477

JURNAL TEKNIK PERTANIAN LAMPUNG

ISSN 2302-559X (print) / 2549-0818 (online)
Journal homepage : https://jurnal.fp.unila.ac.id/index.php/JTP

Analysis of Soil Quality Index in Several Land Use Units in the Manten Sub-Watershed

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Article History:

Received : 17 September 2025
Revised : 06 October 2025
Accepted : 13 December 2025

Keywords:

Land degradation,
Land use,
Soil management practices,
Soil physical properties,
Soil physical quality index.

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ABSTRACT

The Manten Sub-watershed faces land degradation problems due to improper land management. This study aims to identify the soil physical quality index across various land use types in the Manten Sub-watershed and to evaluate potential improvement alternatives. A descriptive quantitative method was applied by analyzing the Soil Physical Quality Index (SPQI) through the measurement of soil physical parameters such as bulk density, particle density, texture, structure, porosity, permeability, and soil organic carbon. Three land use types were evaluated in this research, including dryland or upland, rice field, and garden. Five sampling points were determined to score SPQI for each land use type. The results show that dryland farming and paddy fields can be classified as moderate to slightly good, with SPQI score values ranging from 0.57–0.73 and 0.63–0.70, respectively. Meanwhile, garden land use is classified as fairly good with SPQI score values of 0.70–0.73. Suggested improvement alternatives include the addition of organic matter and the implementation of soil conservation practices, such as proper tillage, cover cropping, and crop rotation.

1. INTRODUCTION

Soil quality in different regions varies depending on land use and how it is managed. Inappropriate soil management in the long term can cause a decline in quality, both physically, chemically and biologically. According to Herdiyantoro (2015), an intensive land cultivation system is indeed able to increase crop yields initially, but if it is carried out continuously without improvement it will actually reduce productivity. Excessive soil management can affect soil properties, especially physical properties, with impacts in the form of structural damage and reduced availability of organic material.

The physical properties of soil are an important factor in determining soil quality. Parameters such as unit weight, porosity, permeability and soil texture play a major role in the soil's ability to support plant growth (Suwarno *et al*., 2025). Differences in land use can produce variations in physical properties even though the soil is the same, due to differences in soil processing, addition of organic material, or other forms of management.

Soil quality is also a crucial component in sub-watershed management. Soil functions as the main medium in the hydrological cycle, especially in the process of infiltration, storage, and movement of water and air. A sub-watershed is a complete ecosystem from upstream to downstream consisting of land, vegetation, air and human activities that use it (Adhikari *et al*., 2016). Sub-watersheds play an important role in channeling rainwater through the surface, below the surface, and ultimately into river flows (Gultom *et al*., 2022).

The Manten sub-watershed has various forms of land use, such as drylands, gardens and rice fields, which influence the physical properties of the soil. Changes in land use in this region have caused a decrease in natural vegetation cover and increased potential for land degradation. The impact can be seen in the form of a decline in the physical quality of the land, an increase in critical land, and the emergence of the threat of environmental disasters such as floods, landslides and drought. Reducing vegetation cover also encourages increased rates of erosion and sedimentation which affect the stability of the sub-watershed's hydrological function. Therefore, this research was conducted to determine the quality of the physical properties of the soil in various land uses in the Manten Sub-watershed as well as to examine the most appropriate improvement alternatives to improve the physical quality of the soil in a sustainable manner.

2. RESEARCH MATERIALS AND METHODS

2.1. Research Location

This research was carried out in the Manten Sub-watershed (Figure 1) with an area of around 287.02 km^2 which is administratively located in Malang Regency and covers four sub-districts, namely Bululawang, Wajak, Tajinan and Poncokusumo. This research activity was carried out from November 2024 to February 2025.

2.2. Materials and Tools

The research was based on RBI maps as the basis for making land suitability maps, as well as soil samples from drylands, gardens, and rice fields at a depth of 0-30 cm. The tools included sample rings, support rings, soil drills, hoes, rulers, cameras, field knives, GPS, plastic bags, label paper and field stationery.

2.3. Research Methods

This research uses descriptive quantitative methods. This approach was chosen because it is able to provide a quantitative description of the condition of the physical properties of the soil which is then interpreted descriptively according to land use characteristics. The analysis was carried out by calculating a number of relevant physical soil parameters, including unit weight, soil texture, soil structure, porosity, permeability and organic C content. Each parameter was analyzed using standard laboratory methods.

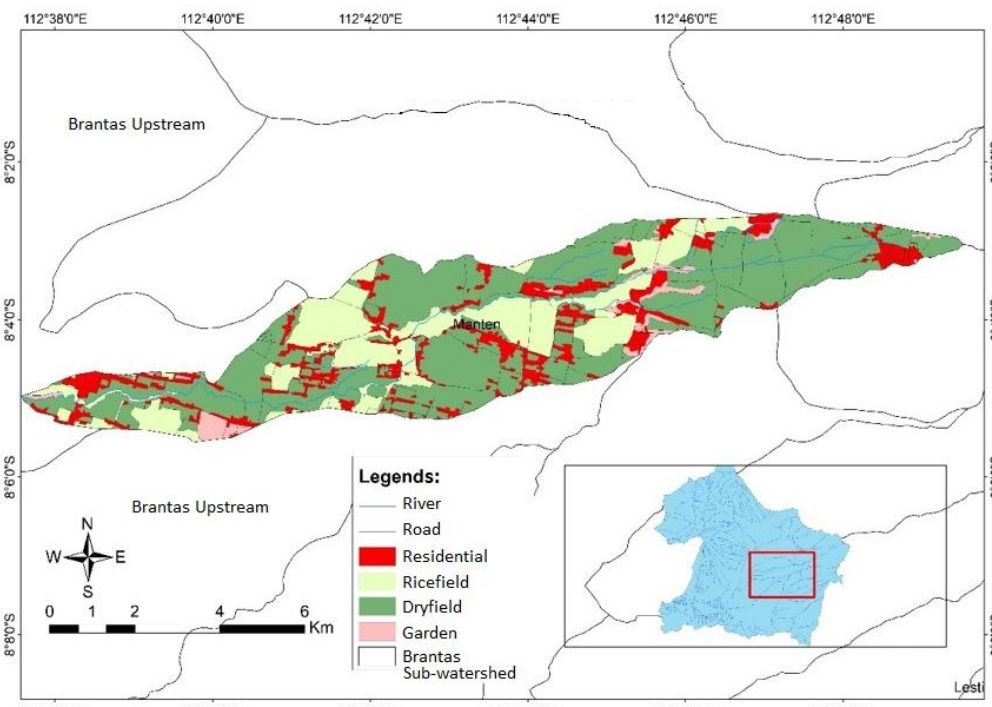

Figure 1. Land use map of the Manten Sub-Watershed, Malang Regency

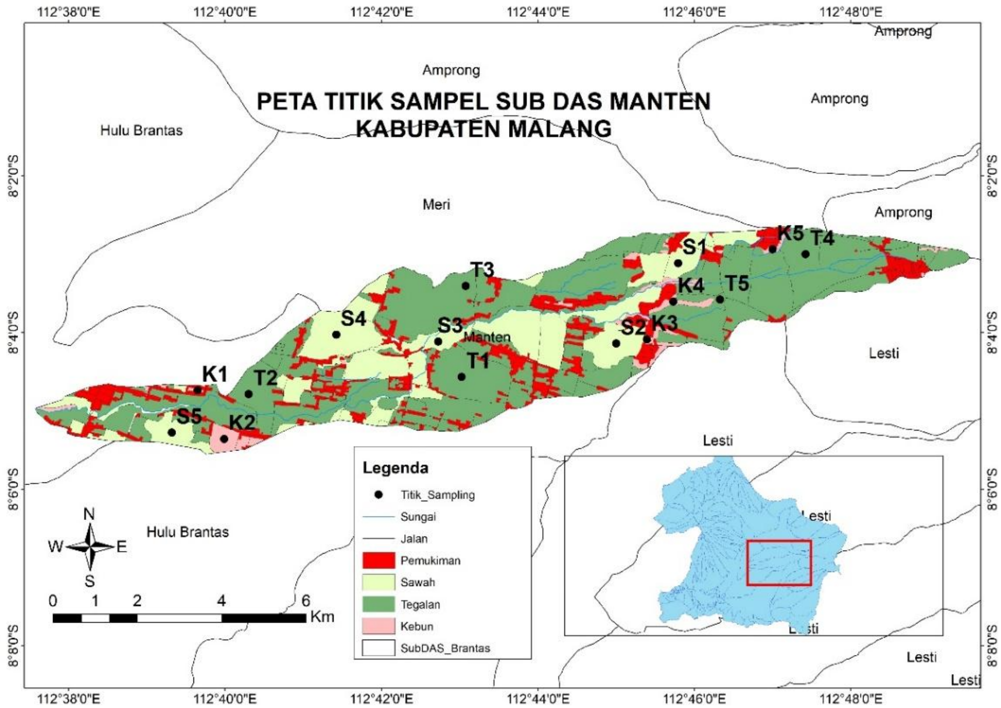

Figure 2. Sampling point map

2.4. Determination of Sample Points

The sample points were determined using the purposive random sampling method, namely the deliberate selection of locations on dryland, rice fields and gardens in the Manten Sub-watershed. Five replicate samples were taken for each type of land use to represent the existing land area with sampling point codes T1-T5 (Dryland or Upland or "Tegalan"), S1-S5 (Paddy Rice), and K1-K5 (Garden) (Figure 2). Soil samples were collected at a depth of 0-30 cm.

2.5. Soil Sampling

The sampling process is carried out in two ways. Whole soil samples were taken using a sample ring for analysis of bulk density, porosity and permeability. Meanwhile, disturbed soil samples were taken using a soil drill for texture and C-organic analysis. Each sample is labeled according to the collection point code, then taken to the laboratory for further analysis.

2.6. Data Analysis

Data analysis was carried out using the Soil Physical Quality Index (SPQI) method as the main approach for assessing the physical quality of soil in various land uses. This method combines several physical parameters into one quantitative

Table 1. Scores of soil physical quality for different parameters

Parameter	Unit	Score					
		0	1	2	3	4	5
Texture	-	Sa	LSa	SiC	SaL, Cl	SCl, Si, SiL, SiCl	L, SiClL, ClL, SaClL
Structure	-		Columnar	Pole	Blocky	Granular	Crumb
Content weight	(g/cm^3)	>1.6	1.4–1.6	1.2–1.4	1.0–1.2	0.8–1.0	<0.8
Porosity	(%)	<20	20–30	30–40	40–50	50–60	>60
Permability	(cm/hour)	<0.025	0.025–0.125	0.125–0.50	0.5–2.0	2.0–6.25	6.25–12.5
C-Organic	(%)		<1.0	1.0–2.0	2.1–3.0	3.1–5.0	>5.0

Note: Sa = Sand; LSa = Loamy Sand; SaL = Sandy Loam; L = Loam; SiL = Silty Loam; SiClL = Silty Clay Loam; SaClL = Sandy Clay Loam; ClL = Clay Loam; SaCl = Sandy Clay; Si = Silt; SiCl = Silty Clay; Cl = Clay; ClW = Heavy Clay (Clay >80%)

quantitative index value so that it is easier to compare between land uses. With its application, each soil physical parameter is given a score between 0 and 5 according to the SPQI criteria according to Andrews *et al*. (2004). The total SPQI value is calculated using the equation:

2.7. Data Analysis

Data analysis was carried out using the Soil Physical Quality Index (SPQI) method as the main approach for assessing the physical quality of soil in various land uses. This method combines several physical parameters into one quantitative index value so that it is easier to compare between land uses. With its application, each soil physical parameter is given a score between 0 and 5 according to the SPQI criteria according to Andrews *et al*. (2004). The total SPQI value is calculated using the equation:

$$SPQI = \frac{\Sigma S}{n \times i} \quad (1)$$

where S is soil parameter score, n is number of parameters, and i is maximum index (range 0 to 5). The SPQI values obtained were then classified into seven soil quality index criteria according to Putri *et al*. (2021).

Table 2. Soil quality index criteria and category (Putri *et al*., 2021)

Class	Value	Category
1	< 0.20	Very bad
2	0.20 – 0.39	Bad
3	0.40 – 0.54	Slightly Bad
4	0.55 – 0.69	Medium or moderate
5	0.70 – 0.79	Slightly Good
6	0.80 – 0.89	Good
7	0.90 – 1.00	Very good

3. RESULTS AND DISCUSSION

Analysis of soil physical properties was carried out on three main types of land use in the Manten Sub-watershed, namely dryland, paddy fields and garden land. Evaluation is carried out based on six parameters, namely bulk density (BI), porosity, permeability, texture, structure and C-organic content, which are then processed into SPQI (Soil Physical Quality Index) index values to determine soil quality classification.

3.1. Dryland

Analysis of the physical quality of soil on upland land was carried out on six parameters, namely bulk density, texture, porosity, permeability, soil structure and organic C. The results of calculating SPQI values on dryland are shown in Table 3. The dryland in the Manten sub-watershed shows SPQI values ranging from 0.57 to 0.73 with a moderate to rather good classification. Soil characteristics at observation points T1–T5 show quite significant variations. The unit weight is in the range of values 1 to 3, which indicates differences in the level of soil compaction, from relatively loose to moderate conditions. This condition is similar to the research results of Ardiansyah *et al*. (2015) who reported that intensive soil cultivation on dry land can increase soil density, thereby affecting the availability of pore space. Soil texture received a high score of 4-5, indicating the dominance of the fine clay fraction which plays an important role in water retention. Porosity shows an increasing trend from 2 to 4, so there is an indication of improvement in soil pore space between particles. Permeability is relatively stable with a value of 3–4, indicating quite good water infiltration capabilities, in line with research by Alista & Soemarno (2021) which states that soil permeability is closely related to the combination of texture and organic matter content. The soil structure is at a consistent value of 4, which indicates that the soil aggregate has quite high stability. However, the C-organic content only ranges from 1–2, which reflects the low level of soil fertility. This low content is thought to be due to minimal input of organic matter, as explained by Tian *et al.* (2022) that organic matter plays an important role in improving soil fertility and maintaining aggregate stability. Overall, this condition indicates that some upland areas, especially T1–T3, require the addition of organic material and improved porosity management to improve the physical quality of the soil.

Meanwhile, points T4 and T5 show relatively better quality so they can be used as a reference in more sustainable management of drylands.

Table 3. Results of calculation of dryland land use

Point Name	Soil Content Weight	Soil Texture	Porosity Point Name	Soil Permeability	Soil Structure	C-Organic Soil	SPQI value	Classification
T1	1	5	2	4	4	1	0.57	Medium
T2	2	4	3	3	4	2	0.60	Medium
T3	2	5	3	3	4	2	0.63	Medium
T4	3	5	4	4	4	2	0.73	Slightly good
T5	3	5	4	4	4	2	0.73	Slightly good

3.2. Rice Fields

The use of rice fields in the Manten Sub-watershed shows a variety of distinctive physical characteristics compared to dry land and gardens. This variation is reflected in the SPQI calculation results which are summarized in Table 4. Rice fields in the Manten sub-watershed have SPQI values between 0.63 and 0.70 with a moderate to rather good classification (Table 2). The bulk density of the soil is at a value of 2-3, which is still within the ideal limit to support root development while maintaining water retention. This condition is in accordance with the findings of Ethan (2015) who reported that paddy fields generally have moderate density due to flooding, but are still able to support rice growth. Soil texture got high score (4–5), indicating the dominance of fine clay which effectively retains moisture, as explained by Zega (2024) that fine texture plays an important role in increasing water holding capacity. Porosity is classified as quite good (3–4), which indicates that the soil pore space is adequate to support air and water circulation.

Table 4. Results of calculation of paddy land use

Point Name	Soil Content Weight	Soil Texture	Soil Porosity	Soil Permeability	Soil Structure	C-Organic Soil	SPQI Value	Classification
S1	2	5	4	3	4	2	0.67	Medium
S2	2	5	3	3	4	2	0.63	Medium
S3	3	5	4	3	4	2	0.70	Slightly good
S4	2	4	4	4	4	2	0.67	Medium
S5	2	5	4	4	4	2	0.70	Slightly good

The permeability of rice fields is at a value of 3-4, indicating that infiltration is relatively stable. These results are in line with research by Bwire *et al*. (2024) which states that periodic flooding of rice fields can slow down infiltration, but still maintain soil moisture. The soil structure is consistent at a value of 4, indicating stable aggregates, in line with Arsyad's (2018) statement that granular structures in rice fields tend to form due to repeated processing and flooding systems. The C-organic content is uniform at 2, which indicates that the fertility level is sufficient, but still needs to be increased. According to Marta & Gulo (2024), organic material input plays an important role in improving fertility and increasing soil aggregate stability. In general, points S1, S2, and S4 are moderate, while S3 and S5 are rather good. This shows that the rice fields in the Manten sub-watershed have quite good physical soil quality, but still require improvement efforts through the addition of organic material and sustainable porosity management.

3.3. Garden Land

Garden land use generally has a more stable physical soil condition than rice fields and dryland due to the presence of annual vegetation cover. This can also be seen in the results of the SPQI analysis in the Manten Sub-watershed, which are summarized in Table 5. Garden land in the Manten Sub-watershed shows SPQI values ranging from 0.70 to 0.73 with a rather good classification at all observation points (Table 3). This condition indicates that the physical quality of the soil on the garden land is relatively stable and supports land productivity. The bulk density is at a value of 2–3, which indicates that the soil density is still ideal for root growth and water circulation. This is in line with research by Alfiyah *et al*. (2024) which states that soil with medium density tends to be optimal for the roots of plantation crops. Soil texture scores 4–5, indicating the dominance of fine clay to sandy loam which is good for water and nutrient retention. This condition is in accordance with the findings of Alghamdi *et al*. (2024) that the combination of clay and sand fractions can improve the balance between water holding capacity and drainage. Porosity is consistent at a value of 4, which reflects that the space between soil particles is sufficient for air and water circulation. According to Zhang *et al*. (2025), stable porosity is very important in maintaining soil aeration and microbial activity in plantation fields.

Table 5. Calculation results of garden land use

Point Name	Soil Content Weight	Soil Texture	Soil Porosity	Soil Permeability	Soil Structure	C-Organic Soil	SPQI Value	Classification
K1	3	4	4	5	4	2	0.73	Slightly Good
K2	3	4	4	5	4	2	0.73	Slightly Good
K3	2	5	4	4	4	2	0.70	Slightly Good
K4	2	5	4	5	4	2	0.73	Slightly Good
K5	3	4	4	4	4	2	0.70	Slightly Good

The permeability of garden land is in the range of 4–5, which indicates optimal infiltration capacity, especially at points K1, K2, and K4. These results are supported by research by Zebua & Gea, (2024) who reported that soil management on plantation land with organic inputs was able to increase permeability and water infiltration capacity. The soil structure is uniform at a value of 4, indicating stable aggregates and supporting aeration and microorganism activity. The C-organic content is at a value of 2 at all points, which indicates that soil fertility is quite good although it can still be improved. According to Farrasati *et al*. (2019), additional organic material input can increase fertility and support nutrient cycles in plantation soil. Overall, plantation land shows the most consistent physical soil quality compared to dryland and rice fields, so it can be used as a more sustainable land management model in the Manten Sub-watershed.

3.4. Improvement Alternatives

Improvements to the quality of the physical properties of the soil in the Manten Sub-watershed area need to be carried out considering that the soil classification is still in the "medium" to "somewhat good" category, which is not fully optimal in supporting overall soil function. One of the recommended strategies is the addition of organic materials, considering that the C-organic content at the observation location is relatively low. Organic matter plays an important role in the formation of soil aggregates, which directly influences structure and porosity. The addition of organic matter can also increase the efficiency of soil drainage and aeration through a balanced pore distribution (Wood *et al*., 2018), and contribute to improving overall soil quality (Iqbal *et al*., 2023).

Strategic application of soil management practices, such as sage tillage, use of cover crops, and crop rotation, can support synergistic improvements in soil physical properties. One effective approach is the application of compost, which has been proven to increase soil aggregation and organic matter content. Research by Mulyani *et al*. (2024) shows that the addition of organic fertilizer can increase soil porosity from 51.09% to 56.14%, C-organic content from 2.26% to 2.73%, and reduce bulk density from 1.05 g/cm³ to 0.94 g/cm³. However, the effectiveness of each method is highly dependent on soil characteristics and previous management conditions, so an adaptive, local conditions-based approach is necessary.

4. CONCLUSION

The conclusion of this research shows that the quality of the physical properties of soil in the Manten Sub-watershed varies based on the land use unit. On upland or dryland, soil quality is classified as moderate to slightly good with Soil Physical Quality Index (SPQI) values ranging from 0.57–0.73. The use of paddy fields also shows the same classification, namely moderate to rather good, with an SPQI value range of 0.63–0.70. Meanwhile, on garden land, the soil quality classification is only in one class, namely rather good, with an SPQI value between 0.70–0.73. The recommended improvement alternative to improve the quality of soil physical properties in the Manten Sub-watershed area is the addition of organic material and conservative soil management, such as wise tillage, use of cover crops, and regular crop rotation.

AUTHOR CONTRIBUTION STATEMENT

Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
PFG	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓		✓	
Mar	✓			✓								✓	✓	
BWW	✓	✓		✓	✓					✓		✓		

C: Conceptualization
M: Methodology
So: Software
Va: Validation
Fo: Formal Analysis
I: Investigation
D: Data Curation
R: Resources
O: Writing - Original Draft
E: Writing - Review & Editing
Vi: Visualization
Su: Supervision
Fu: Funding Acquisition
P: Project Administration

ACKNOWLEDGEMENT

The author would like to thank all parties who were willing to help carry out this research, especially the supervisors and the Environmental Resources Laboratory of the Faculty of Agriculture who have provided facilities to the author.

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