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Land Use Change and Its Impact on Soil Quality Based on GIS and Soil Quality Index (SQI) in the Manten Sub-Watershed, Malang, Indonesia

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Abstract. This study aims to analyze land use change and its impact on soil quality in the Catchment Area of the Manten Sub-watershed, Malang Regency. Land use changes were assessed using satellite imagery data from 1998, 2008, 2018, and 2024, while soil physical and chemical properties were measured to develop the Soil Quality Index (SQI). The SQI was computed using the Minimum Data Set (MDS) approach based on principal component analysis, and each indicator was scored and integrated using a weighted additive formula. The results show a significant increase in built-up areas by 12% and a decrease in plantation land due to land conversion. These changes were driven by population growth and urbanization. The highest SQI value was recorded in plantation areas (0.70), while the lowest was found in dryland agriculture (0.58). The decline in soil quality was mainly caused by low organic matter content and unsustainable land management practices. This study emphasizes the significance of land use planning based on soil potential in promoting environmental sustainability.

Keywords: catchment area; GIS; land use change; soil quality index

INTRODUCTION

The increase in population and development intensity in recent decades has led to significant land use changes in various regions, including catchment areas, which are crucial zones in the hydrological cycle and water resource management (Nono Sutrisno & Adang Hamdani, 2019). In Malang Regency, the population grew from approximately 2.57 million in 2017 to 2.73 million in 2024. One of the areas experiencing the pressure of these changes is the Manten Sub-watershed, Malang Regency, East Java. This sub-watershed covers approximately 176 km² and spans four subdistricts: Bululawang, Wajak, Tajinan, and Poncokusumo, with elevations ranging from 406 to 685 m above sea level. It serves a strategic function as a clean water supply and an ecosystem buffer for surrounding areas, with its headwaters flowing into the Karangkates Dam, along with the Amprong and Bango Rivers. Based on Rupa Bumi Indonesia (RBI) maps, built-up land in the Manten Sub-watershed increased from 138.3 ha in 1998 to 701.2 ha in 2024, while plantation land declined from 2,014.1 ha to 160.6 ha. These rapid land conversions indicate increasing anthropogenic pressure and highlight the need to assess soil quality conditions to support sustainable watershed management.

The land conversion that occurs, especially from gardens and forests to settlements and industrial areas, causes various environmental impacts. Conversion of vegetative land cover causes disturbances in ecosystem balance, including a decrease in hydrological functions, an increase in erosion rates, land degradation, and the emergence of critical land (Taufikurrohman & Rahman, 2024). In addition, land change directly affects soil quality, both from physical and chemical aspects. A decrease in soil quality, which includes changes in pH, organic matter content, and availability of essential nutrients such as nitrogen (N), phosphorus (P), and potassium (K), ultimately impacts soil productivity and the ecological carrying capacity of the region (Juarti, 2016). While Juarti (2016) reported these effects in lowland agricultural systems, the extent and nature of degradation may differ under highland conditions such as the Manten Sub-watershed, which features steeper slopes, higher rainfall, and more intensive land conversion pressures. Thus, examining soil quality responses to land use change in this highland catchment provides a clearer understanding of site-specific degradation processes and helps develop more context-appropriate land management strategies.

Soil quality is a concept that describes the capacity of soil to perform its ecological functions, such as supporting plant growth, maintaining air and water quality, and serving as a habitat for microorganisms (Arifin *et al.*, 2017). According to Gulo *et al.* (2024), high-quality soil is directly related to the sustainability of agricultural systems and environmental balance.

Soil quality refers to the capacity of soil to function within natural or managed ecosystem boundaries, sustaining biological productivity, maintaining environmental quality, and promoting the health of plants and animals. The condition of soil quality is often evaluated through a composite indicator known as the Soil Quality Index (SQI), which integrates several key soil physical and chemical properties into a single quantitative value. One approach that can be used to assess the relationship between land use change and soil quality is to use Geographic Information Systems (GIS). GIS technology enables spatial and temporal analysis of land change and its relationship with other environmental variables. GIS also enables the visual and quantitative mapping of soil quality indices, allowing for the identification of the spatial relationship between land change intensity and soil degradation (Zaman, 2021).

Therefore, this study aims to analyze the pattern of land use change in the Manten Sub-watershed from 1998, 2008, 2018, and 2024, identify the driving factors that influence land conversion in the area, and evaluate the impact of these changes on soil quality based on its physical and chemical properties. In this context, a study was conducted to assess land use change in the Manten Sub-watershed from 1998 to 2024, and evaluate its impact on soil quality through the soil quality index (SQI) approach. Satellite image data were used to analyze spatial changes in land use, while soil physical and chemical parameters were analyzed in the laboratory to calculate the SQI. The results of this study are expected to contribute to decision-making related to more sustainable land use management and soil conservation in the watershed and similar areas.

METHODS

This research was conducted in the catchment area of Manten Sub Watershed, Malang Regency, from November 2024 to February 2025. This study used spatial and laboratory analysis approaches to assess land use change and its impact on soil quality.

Spatial data in the form of Landsat 4-5, 7, and 8 satellite images in 1998, 2008, 2018, and 2024 were processed using ArcGIS and QGIS software. Processing included layer stacking, atmospheric correction, supervised classification using the Maximum Likelihood algorithm, and verification of classification results with field data.

The preprocessing steps consisted of radiometric calibration and atmospheric correction using the Dark Object Subtraction (DOS) method (Chaves, 1996), followed by the conversion of digital numbers (DN) to surface reflectance values to minimize the effects of atmospheric and illumination variations. This correction ensures spectral consistency among multi-temporal Landsat images, enabling more accurate land-use classification.

The accuracy of the land use classification was evaluated using a confusion matrix, which compared the classified results with reference data from high-resolution imagery and field observations. The classification showed a high overall accuracy and Kappa coefficient, indicating reliable differentiation of land use classes.

Soil sampling was conducted using a purposive sampling approach to ensure adequate representation of three dominant land use types: gardens, moorlands, and rice fields. This method was chosen because the study aimed to compare soil quality among predefined land use classes identified from classified imagery. A total of sampling points per class was determined based on common practice in tropical soil quality studies and practical field constraints, while maintaining broad spatial coverage across varying topographic conditions. Samples were collected at two depths, 0-30 cm and 30-60 cm, representing the active root zone and the subsurface layer that influences nutrient availability. All soil samples were analyzed at the Land Resources Laboratory, Faculty of Agriculture, UPN "Veteran" East Java.

The soil analysis included physical (bulk density, specific gravity, permeability, porosity, and texture) and chemical (pH, C-Organic, N-Total, P-available, K-available) parameters. To quantitatively assess soil quality, a Minimum Data Set (MDS)-based Soil Quality Index (QI) approach was used. The IKT was determined by combining four main parameters, namely soil texture, pH, organic carbon (C-organic) content, and soil fertility (NPK). Each parameter is given a score based on the value of the analysis results, then calculated using the formula from Ghimire et al. (2018) as presented in Equation 1.

$$\boldsymbol{SQI} = (\mathbf{0,2} \times \boldsymbol{RSTC}) + (\mathbf{0,1} \times \boldsymbol{RpH}) + (\mathbf{0,4} \times \boldsymbol{ROC}) + (\mathbf{0,3} \times \boldsymbol{RNPK}) \ \ldots\ldots\ldots \ \mathbf{1)}$$

Description:

R_{STC} = soil texture score
R_{pH} = soil pH score
R_{OC} = soil C-organic
R_{NPK} = fertility score (based on N, P and K content)

IKT values range from 0 to 1, with higher values indicating better soil quality. The score of each parameter was determined based on the classification of value ranges established by Ghimire *et al.*, (2018).

RESULTS AND DISCUSSION

General Conditions

The catchment area of Manten sub-watershed covers approximately ± 176 km^2 and extends across four sub-districts of Malang Regency, namely Bululawang, Wajak, Tajinan, and Poncokusumo, with elevations ranging from 406 to 658 meters above sea level. The headwaters river are located in the southern part of Poncokusumo and flow downstream into the Karangkates Dam, together with the Amprong and Bango Rivers. The dominant land use types in the area are gardens (plantation), rice fields, and drylands, with dryland agriculture being the most extensive.

Land Use Change

Land use change is an inevitable process accompanying regional development, including within the catchment area of the Manten Sub-watershed. Over the past two decades, this area has experienced substantial transformation, primarily through the conversion of vegetated lands such as gardens (plantations) into rice fields, drylands, and settlements. Such conversion alters the ecosystem's balance, affecting soil quality, hydrological function, and biodiversity (Suriadi *et al.*, 2024).

Based on field observations and satellite imagery analysis (Table 1), significant changes in land use have occurred between 1998 and 2024. Built-up areas increased sharply from 138.3 ha to 701.2 ha (+12.4%), while plantation areas decreased from 2,014.1 ha to 160.6 ha (−8.6%). Rice fields and drylands also showed notable fluctuations due to agricultural expansion and crop rotation patterns. These conversions are primarily driven by population growth, infrastructure development, changing consumption patterns, and local economic pressures. Given the overall classification accuracy exceeding 85%, the detected changes are considered reliable within an estimated uncertainty margin of ±5%. More intensive cultivation and unplanned land use have further accelerated soil degradation. Consequently, sustainable management practices such as organic matter addition, contour planting, and vegetation buffers are often overlooked. This has led to a decline in organic matter content, soil compaction, and structural disruption, ultimately reducing soil productivity and the land's ecological carrying capacity (Journal *et al.*, 2025).

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Table 1. Extent of Land Use

No	Land Use	1998		2008		2018		2024	
1.	Settlement	138 ha	3%	477 ha	10%	701 ha	15%	701 ha	15%
2.	Farm	2014 ha	42%	786 ha	21%	161 ha	3%	161 ha	3%
3.	Rice Fields	1161 ha	24%	1577 ha	33%	1121 ha	23%	1121 ha	23%
4.	Farmland	1469 ha	31%	1942 ha	36%	2799 ha	59%	2799 ha	59%

Table 1 presents the extent and percentage of each land-use type in the Manten Sub-watershed from 1998 to 2024. Over the 26-year period, built-up areas expanded markedly from 138 ha (3%) in 1998 to 701 ha (15%) in 2024, reflecting rapid settlement growth. Conversely, garden (plantation) areas decreased drastically from 2,014 ha (42%) to 161 ha (3%), indicating extensive land conversion driven by development pressure. Meanwhile, rice fields fluctuated slightly, decreasing from 1,161 ha (24%) in 1998 to 1,121 ha (23%) in 2024, while dryland farmland increased substantially from 1,469 ha (31%) to 2,799 ha (59%). These results illustrate a clear shift from vegetated and agricultural land toward more intensive land uses, particularly residential and dryland expansion, consistent with urbanization and population growth trends in Malang Regency.

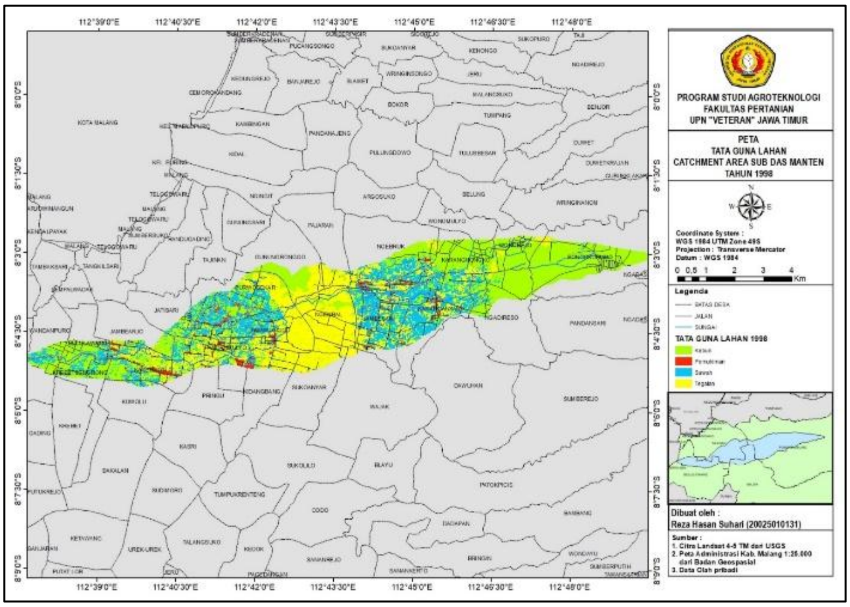


Figure 1. Map of Land Use Changes in 1998

Period 1998-2008

In 1998, land use in the Manten Sub-watershed was dominated by gardens (plantations), covering 2,014 ha (42%), followed by drylands (1,469 ha; 31%), rice fields (1,161 ha; 24%), and settlements (138 ha; 3%). By 2008, the area of gardens had declined sharply to 786 ha (21%), while rice fields expanded to 1,577 ha (33%) and drylands increased to 1,942 ha (36%). Settlement areas also grew more than threefold, reaching 477 ha (10%) (Figure 1.)

This period marks the onset of a structural shift from predominantly vegetated and agricultural land toward more intensive land use. The increasing demand for land driven by population growth and physical development was the main driver of this transformation (Setiawan & Rudiarto, 2016). Early signs of soil degradation also began to emerge, particularly in areas converted without proper conservation measures, as indicated by reduced organic matter and visible surface compaction.

Period 2008-2018

As shown in Figure 2, the following decade was characterized by a continued expansion of settlement areas, increasing from 477 ha to 701 ha. A substantial increase also occurred in drylands, which expanded from 1,429 ha to 2,374 ha, while garden (plantation) areas continued to decline. This trend was largely driven by rapid population growth and uncontrolled local urbanization.

The growing demand for residential areas, public facilities, and commercial space led to the conversion of productive agricultural land into settlements and open drylands. According to (Wicaksono, 2021), the expansion of dryland areas also reflects spatial flexibility for informal economic activities and small-scale subsistence agriculture. However, intensive land use and cultivation during this period were often not accompanied by proper soil management, potentially leading to soil degradation, nutrient imbalance, and reduced organic matter content (Hizrian *et al.*, 2024).

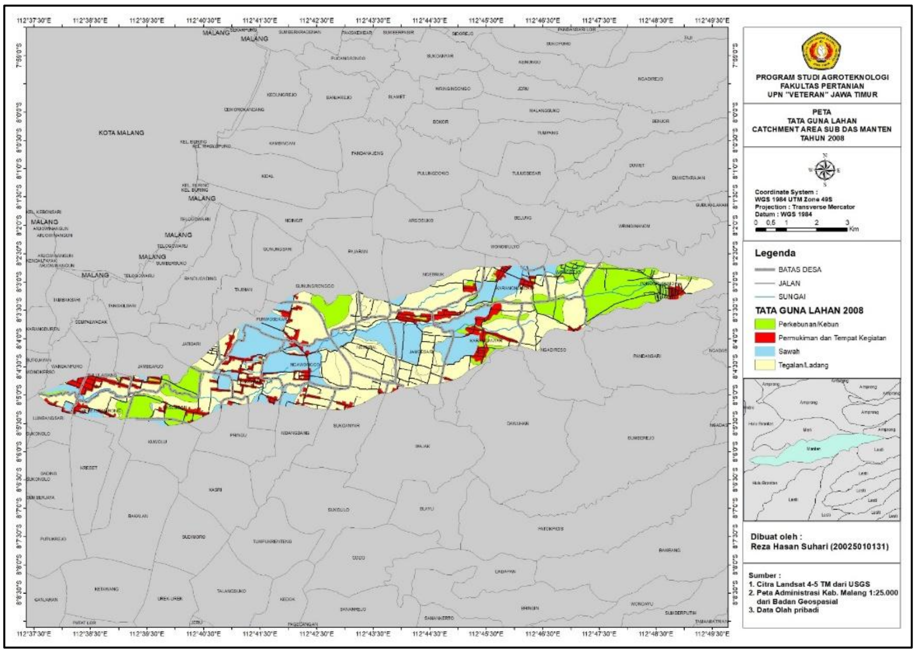
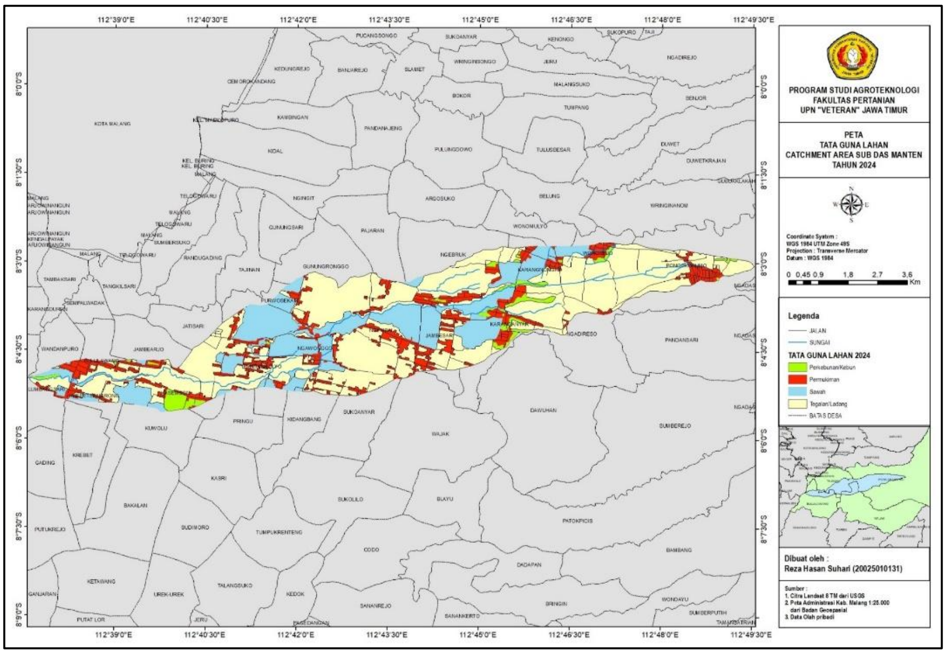


Figure 2. Map of Land Use Changes in 2008

Period 2018-2024

By 2024, drylands dominated the Manten Sub-watershed, covering 2,799 ha (59%), followed by rice fields (1,121 ha; 23%), settlements (701 ha; 15%), and gardens (plantations) with only 161 ha (3%) remaining (Figure 3). This pattern indicates extensive land conversion, particularly from productive agricultural and vegetated areas into non-irrigated drylands and settlements.

The continued population growth in Malang Regency, reaching approximately 3.2 million people (Desmawan *et al.*, 2024), has intensified pressure on spatial and land resources. Without effective spatial planning and land-use regulation, this process will likely accelerate the loss of agricultural land and increase the risk of environmental degradation such as erosion, declining soil fertility, and disruption of hydrological balance (Chalise *et al.*, 2019)



.**Figure 3.** Map of Land Use Changes in 2024

Soil Quality Index

Soil Quality Index (QI) assessment is conducted based on the Minimum Data Set (MDS) approach by considering relevant but efficient soil physical and chemical parameters (Jumiun *et al.*, 2024). The parameters used include pH, C-Organic, N, P, K, and soil texture, representing the physical, chemical, and biological functions of soil (Salamah *et al.*, 2024). The SQI value is calculated from the score of each parameter and the weight of its function on soil quality.

This approach enables comprehensive and objective evaluation of soil quality, as well as identifying potential soil degradation due to changes in land use and different management practices (Abd-Elazem *et al.*, 2024). In this context, IKT is not only used to compare locations but also to evaluate the extent to which its constituent parameters contribute to overall soil conditions (Awoonor *et al.*, 2025).

This assessment was conducted on three types of land use: gardens, fields, and rice fields, to examine the variation in soil parameters that contribute to the IKT value, as well as to identify potential differences in soil quality based on land use.

Garden Soil Quality Index

The calculation of the Soil Quality Index (SQI) on garden land was based on six key parameters: soil texture, pH, organic carbon (C-organic), total nitrogen (N), available phosphorus (P), and available potassium (K). As shown in Table 2, the soil texture was classified as silty clay loam, which contributed a high score to the index, indicating good physical conditions for plant growth (de Paul Obade & Lal, 2016). Both phosphorus and potassium levels were in the high category, which significantly enhanced the overall SQI value for this land type (Ellur *et al.*, 2024).

The soil pH was classified as slightly acidic (5.67), while total nitrogen content was moderate, each providing a medium contribution to the final score. On the other hand, the C-organic content was low, and since this parameter carries a high weight in the SQI calculation, it served as a limiting factor in improving the overall index score.

Overall, the garden land had an SQI value of 0.68, which falls under the "good" category. This indicates that the soil generally provides adequate support for plant growth, although it has not yet reached optimal

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quality. The low levels of organic carbon and nitrogen should be considered as primary concerns in future efforts to improve soil quality. Therefore, land management strategies should prioritize the addition of organic matter such as compost or manure and the application of targeted nitrogen fertilizers to maintain and enhance the soil's long-term productivity and health (Panhwar *et al.*, 2018).

Table 2. Garden Soil Quality Index Results

No.	Soil Parameters	Garden			
		Analysis Result	Weight (1)	Score (2)	Value (1 x 2)
1.	Texture	Dusty Loam	0,2	0,8	0,16
2.	pH	5,67 (SA)	0,1	0,6	0,06
3.	C-organic (%)	1,43 (L)	0,4	0,2	0,08
4.	N-total (%)	0,28 (M)	0,1	0,6	0,06
5.	P-available (ppm)	29,25 (H)	0,1	0,8	0,08
6.	K-available (me/100g)	0,65 (H)	0,1	0,8	0,08
Soil Quality Index (SQI)					0,68
Criteria					Good

Description : SA (Slightly Acidic); L (Low); M (Medium); H(High)

Dryland Soil Quality Index

The calculation of the Soil Quality Index (SQI) on dryland was based on six key parameters: soil texture, pH, organic carbon (C-organic), total nitrogen (N), available phosphorus (P), and available potassium (K). Based on the results presented in Table 3, the Soil Quality Index (SQI) value for upland (dryland) land was 0.68, which falls under the “good” category, although slightly lower than that of garden land. This value indicates that the moorland land is still capable of performing essential soil functions, both ecologically and agronomically.

Table 3. Results of Moorland Soil Quality Index

No.	Soil Parameters	Dryland			
		Analysis Result	Weight (1)	Score (2)	Value (1 x 2)
1.	Texture	Dusty Loam	0,2	0,8	0,16
2.	pH	5,35 (A)	0,1	0,6	0,06
3.	C-organic (%)	1,37 (H)	0,4	0,6	0,24
4.	N-total (%)	0,26 (M)	0,1	0,6	0,06
5.	P-available (ppm)	42,02 (VH)	0,1	1,0	0,10
6.	K-available (me/100g)	0,49 (M)	0,1	0,6	0,06
Soil Quality Index (SQI)					0,68
Criteria					Good

Description : A (Acidic); L (Low); M (Medium); H(High); VH (Very High)

The greatest contributions to the SQI score came from soil texture (silty clay loam) and organic carbon content, both of which received high individual scores. Although the soil pH was categorized as acidic, and total nitrogen was moderate, both parameters still provided a positive contribution to the overall SQI value, although organic matter remained a limiting factor due to its low concentration (Zhao *et al.*, 2019).

Interestingly, despite the very high levels of available phosphorus and potassium, these nutrients did not proportionally enhance the total SQI score. This finding underscores the importance of nutrient balance in soil systems; excess levels of certain nutrients do not necessarily reflect better soil quality, especially when other critical components such as pH and organic matter are suboptimal (Schröder *et al.*, 2016).

Overall, upland land requires careful attention to balanced nutrient management and crop-specific fertilization strategies. These interventions are crucial to sustaining and improving long-term soil quality, as well as ensuring consistent land productivity. Integrated soil fertility management should be prioritized to address both deficiencies and excesses in soil nutrient content.

Rice Field Soil Quality Index

The calculation of the Soil Quality Index (SQI) on rice field was based on six key parameters: soil texture, pH, organic carbon (C-organic), total nitrogen (N), available phosphorus (P), and available potassium (K). As shown in Table 4, the Soil Quality Index (SQI) value for rice field land was 0.68, classified under the “good” category. This suggests that the soil remains capable of performing essential ecological and agronomic functions (Stavi *et al.*, 2016). The main contributors to this score were soil texture (silty clay loam) and organic carbon content, both of which provided high individual scores. The soil pH of 6.25, although slightly acidic, still falls within the optimal range for tropical crops, and thus positively supports soil productivity.

Table 4. Results of Rice Field Soil Quality Index

No.	Soil Parameters	Rice Field			
		Analysis Result	Weight (1)	Score (2)	Value (1 x 2)
1.	Texture	Dusty Loam	0,2	0,8	0,16
2.	pH	6,25 (SA)	0,1	0,6	0,06
3.	C-organic (%)	1,22 (L)	0,4	0,6	0,24
4.	N-total (%)	0,23 (M)	0,1	0,6	0,06
5.	P-available (ppm)	82,73 (VH)	0,1	1,0	0,10
6.	K-available (me/100g)	0,42 (M)	0,1	0,6	0,06
Soil Quality Index (SQI)					0,68
Criteria					Good

Description: SA (Slightly Acidic); L (Low); M (Medium); H(High); VH (Very High)

Despite the high scores in several parameters, organic matter content remains a critical issue. Most rice field soils in Indonesia are characterized by low levels of organic matter (<2%), with only a small fraction (around 4%) reaching the >3% threshold considered healthy. This observation is consistent with the findings of this study, reinforcing the importance of organic matter management as a key strategy in sustaining long-term soil fertility.

Moreover, while phosphorus (82.73 ppm) and potassium (0.42 me/100g) were classified as high, their influence on the total SQI score was relatively moderate. This reflects the importance of balanced nutrient availability, where excess concentrations do not necessarily enhance soil quality if other factors, such as organic carbon or pH, remain limiting. Overall, although the soil quality of the rice field remains intact, intensive land use without proper nutrient and organic matter management poses a risk to future productivity (Paramesh *et al.*, 2023). Therefore, SQI can serve as an essential reference for sustainable land-use planning and adaptive soil management practices.

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CONCLUSION

Land use change in the Manten Sub Watershed Catchment Area, Malang Regency, showed notable shifts from 1998 to 2024, with settlement areas increasing by 12%, and garden land declining due to conversion into built-up areas. These changes were driven by population growth and urbanization. Land use change is associated with lower SQI values, primarily due to reduced organic matter and altered soil functions; however, causality requires further long-term or experimental studies.

Future research should incorporate continuous soil monitoring and detailed land-use mapping to enhance understanding of soil quality dynamics and support sustainable land management in the region.

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