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REVIEW ARTICLE Open Access

Assessment of Soil Physical Quality Index Using PCA Under Different Land Uses in Tutur District, Pasuruan Regency

Fryan Krisnaya Gumilang[1], Purnomo Edi Sasongko[1,*], Purwadi[1]

Abstract
Soil physical quality is an essential component that determines the soil's ability to support land productivity. This study aims to assess the Soil Physical Quality Index (SPQI) across various land-use types in Tutur District, Pasuruan Regency. The research was conducted based on surveys, field observations, and laboratory analyses. The assessment employed a Principal Component Analysis (PCA) approach to determine the weights of soil functions and the most influential physical indicators. Soil sampling points were selected using the purposive sampling method. Indicators of soil physical quality include bulk density, porosity, effective depth, permeability, aggregate stability, soil moisture, and soil texture. The SPQI values obtained ranged from 0.23 to 0.79, categorized from poor to good. Pine forest showed the highest SPQI value (0.734), whereas upland dryland had the lowest value (0.327). The results of this study provide a scientific basis for more effective land management efforts to maintain and improve soil physical quality in Tutur District.

Keywords: PCA, Soil Physical Properties, Soil Quality Index, Tutur District

1. Introduction

Tutur District is a major apple and horticultural production area that contributes significantly to the agricultural sector and the economy of Pasuruan Regency. In recent years, continuous agricultural intensification and land-use changes have altered land management characteristics in this region. These changes have the potential to exert pressure on the soil, particularly on its physical properties, leading to signs of declining soil capability. Efforts to improve soil quality are essential to prevent degradation that may hinder the long-term sustainability of agricultural production (Lal, 2020).

Soil quality is the capacity of soil to function (Rajamuddin *et al*., 2019). One of the key components that determines soil quality is its physical properties. These properties are often overlooked in agricultural management, even though they play an important role in maintaining stable land productivity. Farmers tend to give lower priority to physical soil properties because they do not have a direct impact on crop yield (Ulfa *et al*., 2024) However, degradation to soil physical properties is semi-permanent in nature and difficult to restore. Preventing the decline of soil physical quality is therefore more effective and economical than attempting rehabilitation.

The approach to assessing soil quality is now shifting toward more objective methods. Principal Component Analysis (PCA) is an effective technique because it can integrate multiple parameters into a single, representative index. PCA also provides more accurate results than conventional scoring methods because it evaluates the proportional contribution of each indicator (Duke *et al*., 2017). The use of PCA in determining the Soil Physical Quality Index (SPQI) remains limited, especially in studies examining differences in land use. In Tutur District, land-use changes are occurring rapidly, yet adequate information on soil quality is still lacking. PCA-based research is needed to generate a more measurable understanding of soil conditions in the area (Ariski *et al*., 2025).

The physical quality of soil can be assessed using the Soil Physical Quality Index method. Information on soil physical quality across different land-use types in Tutur District remains scarce, creating a gap in understanding how land-use changes affect soil functions. This study aims to address this gap by evaluating the Soil Physical Quality

*Correspondence: purnomoedi@upnjatim.ac.id
1) Universitas Pembangunan "Veteran" Jawa Timur - Jl. Rungkut Madya, Gunung Anyar, Surabaya, Jawa Timur 60294, Indonesia

Index across various land uses using a PCA-based approach. The findings are expected to serve as a reference for future efforts to improve and manage soil quality in Tutur District.

2. Material and Methods

This research was conducted on six types of land use in Tutur District, Pasuruan Regency, East Java. The land-use types in Tutur District include protected forest, pine forest, coffee plantation, apple orchard, mixed garden, and dryland fields. The area is located at coordinates 7°46'38.70" S – 7°57'14.80" S and 112°45'53.60" E – 112°54'47.50" E. Soil sampling points were selected using the purposive sampling method. Total of soil sampling is 18 points were collected, with three replications at each location. The analysis of soil physical quality indicators was conducted using a scoring method to determine the main limiting factors affecting soil quality. The score of each indicator was calculated using the equation proposed by Corstanje *et al*. (2017) as follows:

$$y = \frac{(x-s)}{(1{,}1t-s)} \quad \text{(1) “more is better”}$$

$$y = 1 - \frac{(x-s)}{(1{,}1t-s)} \quad \text{(2) “less is better”}$$

Description:
y = indicator score
x = soil parameter value
s = lowest value of the parameter
t = highest value of the parameter

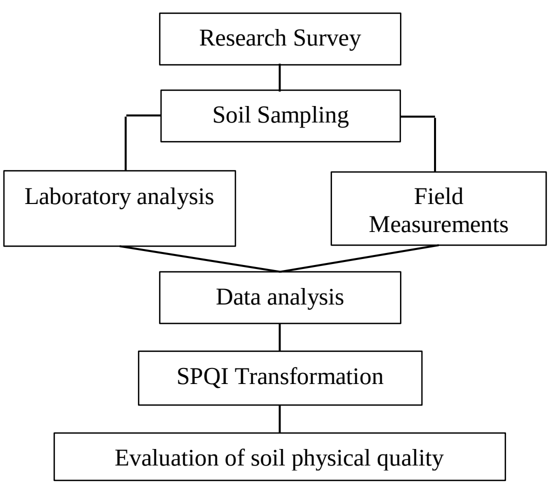

Figure 1. Research flow diagram

The analysis of the Soil Physical Quality Index (SPQI) was carried out by combining the weights of soil functions and the predetermined indicator scores. The determination of weights, both for functions and indicators, was obtained through Principal Component Analysis (PCA) using SPSS 25 software. Spatial analysis and mapping were performed using ArcGIS software to generate SPQI distribution maps. The calculation of the SPQI value refers to the formula applied by Riskawati *et al*. (2021) as follows:

$$\text{SPQI} = \sum_{i=1}^{n} Wi \times Si$$

Description:
W = weighted coefficient value
S = soil physical quality indicator score
n = total number of indicators

3. Results and Discussion

The analysis of soil physical quality in Tutur District was carried out across several land-use types, including protected forest, pine forest, coffee plantations, apple orchards, mixed gardens, and dryland (Figure 2). Tutur District, located in Pasuruan Regency, lies on the slopes of Mount Bromo and the Arjuno–Welirang mountain range, with elevations ranging from 700 to 1,700 meters above sea level. According to BPS (2024), Pasuruan Regency recorded an annual rainfall of 314.16 mm in 2023 and 148.25 mm in 2024, with January being the month of highest rainfall. Tutur District has a total area of 57.49 km². The region is predominantly characterized by steep to very steep slopes, with many areas exceeding a 45% gradient, and the dominant soil type is Andisol, which has developed from volcanic parent material.

3.1. Determination of Soil Physical Quality Index Value

Research on soil physical quality has increasingly begun to incorporate Principal Component Analysis (PCA), a modern method that integrates multiple physical parameters into a single measurable index. This approach is considered more objective because it assigns weights to variables based on their statistical contribution. Although it produces results that are more representative than conventional assessment methods, the use of PCA in evaluating soil physical quality indices remains limited and relatively uncommon, thereby providing studies that apply this method with a strong degree of novelty.

The determination of soil physical quality was based on soil physical aspects, with each parameter selected according to soil function. The results of the Principal Component Analysis (PCA) identified three principal components with a cumulative value of 79.328%, indicating that these three components represent most of the variability in soil physical properties and are suitable for determining the Soil Physical Quality Index (SPQI). The PCA results produced three principal components with nine indicators (Table 1).

Based on the results of the Principal Component Analysis (PCA), nine soil physical quality indicators were obtained, each having a factor loading value greater than 0.5 (Sinurat & Widadie 2025). The analysis produced three principal components (PCs) with eigenvalues greater than 1, each representing a major soil function. The first component (PC1) represents the root zone function, the second component (PC2) corresponds to the filtering and buffering function, while the third component (PC3) serves as the water regulation and distribution function (Romadhona & Arifandi, 2020).

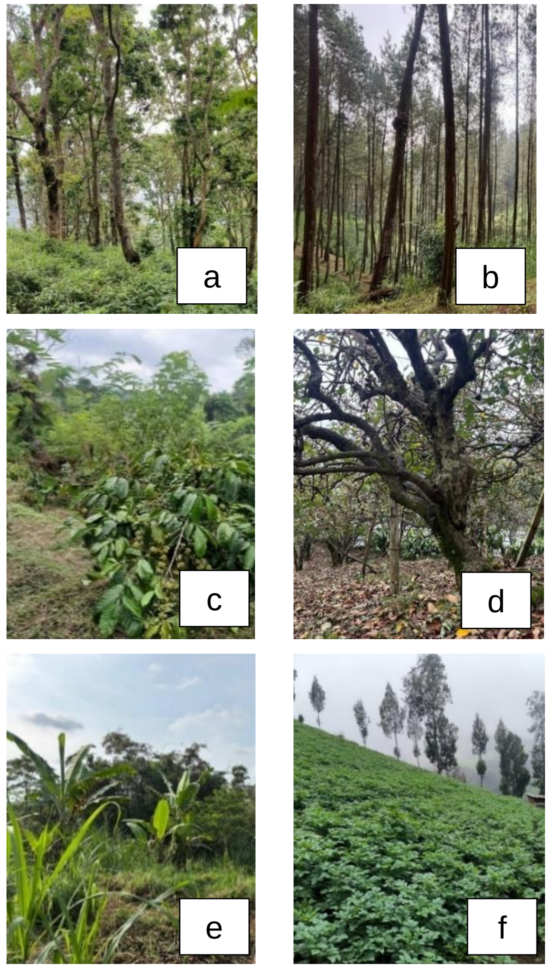

Figure 1. Land Conditions. (a) Protected forest; (b) Pine forest; (c) Coffee plantation; (d) Apple orchard; (e) Mixed garden; (f) Dryland field.

Table 1. Principal Component Matrix of Soil Physical Quality Indicators

PC	PC1	PC2	PC3	
Eigenvalue	3,903	2,228	1,009	
% Variance	43,365	24,754	11,209	
Cumulative%	43,365	68,119	79,328	
Eigenvector:				**Communalities**
Permeability	0,358	-0,06	0,775	0,732
Bulk Density	-0,939	-0,123	-0,089	0,905
Porosity	0,964	-0,016	0,027	0,930
Aggregate Stability	0,229	0,662	0,279	0,569
Water Content	0,414	-0,345	-0,723	0,813
Texture				0,000
Sand	0,15	0,943	0,121	0,926
Silt	0,217	-0,83	0,013	0,736
Clay	-0,446	-0,647	-0,2	0,658
Effective Depth	0,706	0,481	0,378	0,873

Table 2. Minimum Data Set (MDS) Matrix of Soil Physical Quality Indicators

PC	% Variance	Cumulative %	Weight	Indikator MDS
1	43,365	43,365	0,55	Bulk Density, Porosity, Effective Depth
2	24,754	68,119	0,31	Aggregate Stability, Sand, Silt, Clay
3	11,209	79,328	0,14	Permeability, Water Content

The Soil Physical Quality Index (SPQI) value was determined through weighted scoring of soil functions based on the ratio between the percentage of variance and the cumulative value. The soil physical quality indicators are presented in Table 2, with the corresponding weights of PC1 = 0.55, PC2 = 0.31, and PC3 = 0.14. The weight of each indicator was calculated by comparing its eigenvector value to the total eigenvector (Table 3). Scores were assigned to each parameter based on a specific scale ranging from 0 to 1. The selection of soil physical indicators according to their functional capacity was made by considering each indicator's tendency to contribute to soil quality improvement. The closer an indicator's score is to one, the better its quality is considered to be (Maulana & Rudiarto, 2020).

Table 3. Soil Function Weights and Soil Physical Quality Indicator

	Function	Weight 1	Indikator	Weight 2
Soil Physical Quality Index	Rooting Function	0,55	Bulk Density	0,36
			Porosity	0,37
			Effective Depth	0,27
	Filtering and Buffering Function	0,31	Aggregate Stability	0,21
			Sand	0,31
			Silt	0,27
			Clay	0,21
	Water Regulation and Distribution Function	0,14	Permeability	0,52
			Water Content	0,48

Table 4. Soil Physical Quality Index Values in Tutur Sub-district

Land use	SPQI	Category	Mean ± *Standard Error*
Protected forest 1	0,661	Good	
Protected forest 2	0,553	Moderate	0,601 ± 0,032
Protected forest 3	0,586	Moderate	
Pine forest 1	0,789	Good	
Pine forest 2	0,692	Good	0,734 ± 0,029
Pine forest 3	0,722	Good	
Coffee plantation 1	0,538	Moderate	
Coffee plantation 2	0,434	Moderate	0,453 ± 0,045
Coffee plantation 3	0,386	Poor	
Apple orchard 1	0,595	Moderate	
Apple orchard 2	0,547	Moderate	0,561 ± 0,018
Apple orchard 3	0,539	Moderate	
Mixed plantation 1	0,626	Good	
Mixed plantation 2	0,426	Moderate	0,537 ± 0,059
Mixed plantation 3	0,558	Moderate	
Dryland field 1	0,391	Poor	
Dryland field 2	0,356	Poor	0,327 ± 0,048
Dryland field 3	0,234	Poor	

Based on Table 4, the soil physical quality index at the research sites ranged from poor to good. The highest index value was found in the pine forest, with an average of 0.734, categorized as good. The good soil physical quality in the pine forest is supported by Rusdiana & Nursjahbani (2020) who state that pine forests have the potential to improve soil physical properties. Figure 1. shows that the protected forest has a higher SPQI than the other land uses, although still lower than that of the pine forest. This may be attributed to the protected forest being located on a very steep slope. According to research Vallensiana *et al*. (2023), slope steepness can reduce soil physical quality through erosion. Erosion leads to the thinning of the upper soil layer, which is rich in organic matter, ultimately decreasing land capability (Eraku, 2019). The lowest average index value was found in the dryland agriculture areas, with an index value of 0.327. Dryland agriculture consistently showed the lowest index across all land-use types, falling into the poor category. This is consistent with research Elbersen *et al.*, (2020) who reported that dryland agricultural areas generally have low soil quality and are highly susceptible to land degradation. The results of the soil physical quality index in Tutur District were processed into a soil physical quality map (Figure 3).

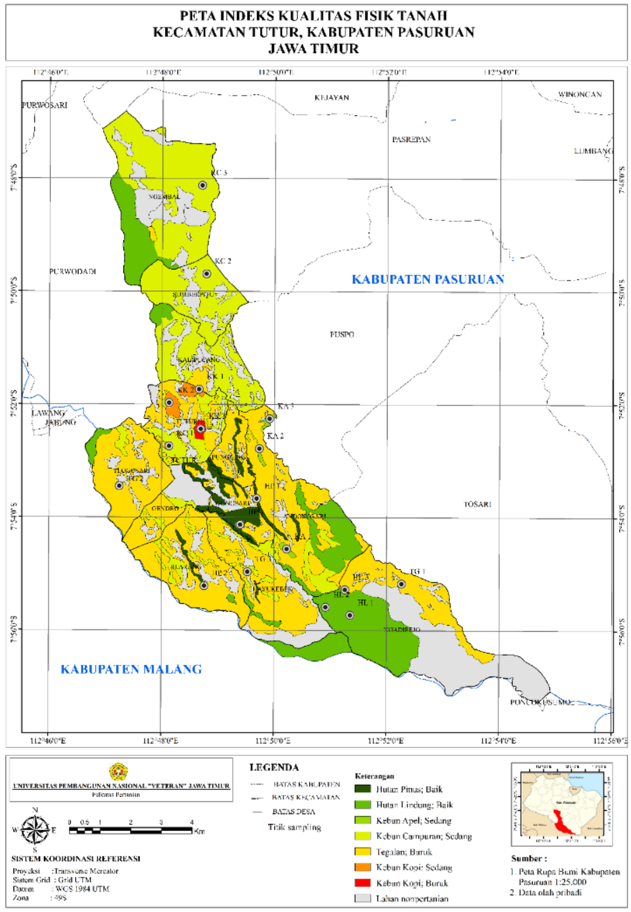

Figure 2. Soil Physical Quality Map of Tutur Sub-district

4. Conclusion

The Soil Physical Quality Index (SPQI) in Tutur District ranges from poor to good categories. Pine forest land use shows the highest soil physical quality (0,734), while dryland exhibits the lowest quality (0,327). PCA analysis identifies bulk density and permeability as the dominant factors determining SPQI variation. Land-use types with low SPQI values require specific treatments, such as the addition of organic matter and the implementation of soil conservation measures.

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