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# Comparison of two soil quality assessment models under different land uses and topographical units on the southwest slope of Mount Merapi

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**Abstract:** This study aims to compare the soil quality indexing model by adding and weighting the soil under different land uses and slope positions on the southwest slope of Mount Merapi, Indonesia. Soil sampling was carried out based on a landscape analysis divided into four geomorphological units (slopes): upper, middle, lower and foot slopes. The research design was nested where the soil sample was located (surface soil 0–30 cm). Based on the research results, soil quality indices (SQI) of forest on the upper slopes is very high. SQI of dry fields on the middle, lower and foot slopes is low to medium. SQI of mixed gardens on the middle and lower slopes is low to medium. SQI of snake fruit land on the middle, lower and foot slopes is medium to high. SQI of grassland on the lower slopes is medium to high, and SQI of paddy fields on the foot slopes is medium to high. Weighted soil quality index (SQIw) has a higher correlation ($R^2$ = 0.90) and can predict soil quality better than the adding soil quality index (SQIa) model ($R^2$ = 0.76). Indicators that most influence soil quality are the percentage of sand, total N, C-POM, C-Min, pH, and aggregate stability, that indicators are entirely influenced by organic matter, site-specific management to maintain SQI by maintaining organic matter. The selected indicators in this study can be used to determine the SQI in similar areas.

**Keywords:** indexing; indicators; land use; slope position; soil quality

Soil quality is the quality of the soil related to its function. The quality of the soil cannot be measured directly and is the result of the integration of physical, chemical and biological attributes combined as published by Karlen et al. (1997). Based on the Yogyakarta flat topography map, it shows that the southwestern slopes of Merapi are included in the area, with the main material being young Merapi volcanic deposits. Aini et al. (2019) state that Mount Merapi ash is included in the category of intermediate andesite rocks. The topography is relatively flat to mountainous and is divided into several different slope positions and land uses.

The response of soil quality to different land uses and slope positions is important in addressing the problem of agricultural sustainability. Research by Derakhshan-Babaei et al. (2021) found that topographical and geomorphological variations and human activities can affect soil quality. Different land uses also cause differences in soil characteristics as indicated by differences in physical, chemical, biological, mineralogical and morphological properties of the soil so that it can be used as an indicator for assessing soil quality. In addition, human activities on different land uses will also affect dynamic soil quality because the soil is treated in the form of soil management, which is a sweet factor of soil quality. Andrews et al. (2004), Lima et al. (2013), Masto et al. (2015), Noviyanto et al. (2017), Bünemann et al. (2018), and Prayitno et al. (2019) state that cultivated

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land or anthropogenic land has sensitive soil attributes to intensive land management so that soil quality assessment can be used to evaluate land productivity and identify appropriate land management.

The interesting thing about the soils on the southwestern slopes of Mount Merapi is that their level of development is relatively undeveloped, so they are easily subject to change due to disturbance as published by Kurniawan et al. (2021). In addition, these soils have relatively good chemical fertility potential because they have nutrient reserves from Merapi pyroclastic material originating from intermediate andesite magma with predominant easily weathered primary minerals in the form of plagioclase (albite and anorthite) containing 56% $SiO_2$ (Fiantis 2009; Anda & Sarwani 2012; Aini et al. 2019). This raises the question of how land use and different slope positions influence soil quality, which is considered undeveloped pedogenetically but has high fertility potential.

Measuring soil quality using indices is commonly used as published by Andrews et al. (2002), because soil quality indices (SQI) are easy to use and flexible. Various indexing models have been established to determine soil quality, but most soil quality researchers only calculate the index using one SQI calculation model. Comparison of methods that are commonly used becomes a necessity to find out which method is the most credible, so it is necessary to develop in determining the best soil quality indexing method through a comparison of various methods that are conceptually different from one another. Soil quality research using different assessment models on volcanic soils in tropical areas is still rarely carried out. The determination of the most influential indicators for tropical volcanic areas as well as the most appropriate soil quality assessment model is not widely known. Similar research has been carried out on land affected by salt and non-salt by Nabiollahi et al. (2017), coastal wetlands by Zhang et al. (2016), semi-arid land by Vasu et al. (2016).

This study aims to compare the soil quality indexing model using the adding soil quality index (SQIa) method, weighted soil quality index (SQIw) on land use and different slope positions on the southwest slope of Mount Merapi.

## MATERIAL AND METHOD

This field research was conducted on the southwestern side of Mount Merapi, which belongs to the Turi District, Sleman Regency, D.I. Yogyakarta, Indonesia (Figure 1). Soil sampling was carried out based on a landscape analysis divided into four geomorphological units (slopes): upper, middle, lower and the slopes. The time of soil sampling is during the dry season in June–August 2022. Aini et al. (2019) found that the soil types in this region are Entisols, Inceptisols and Andisols. Soil classification is based on National Soil Survey Handbook from USDA (2014, 2016). Soil of Mount Merapi slope was observed with subgroups of Typic Hapludands, Vitrandic Udorthents, Andic Eutrudepts, Andic Dystrodepts and Typic Udorthents. Observations of soil types were based on 76 minipits, which are divided into 7 upper slopes, 7 middle slopes, 39 lower slopes and 23-foot slopes. Entisol soil is only found in upper slopes, and the soil type in other slopes was found Inceptisol because the soil was more developed, and the Bw horizon was also found. Yuliani et al. (2017) stated that the climate conditions around the Mount Merapi area are classified as wet tropical. Annual rainfall ranges from 2 500–3 000 mm and air temperature ranges from 20–33 °C and air humidity around 80–99%. The climate type based on the Schmidt and Fergusson classification of the Merapi region is included in type C or the slightly wet area category. The research design used was nested where the soil sample locations (soil surface 0–30 cm) were taken by considering aspects of land use and topographical position, namely land use on the upper slopes in the form of a forest, middle slope in the form of dry fields, mixed gardens and snake fruit gardens; lower slopes in the form of grassland, dry fields, mixed gardens, snake fruit gardens and paddy fields; as well as the foot of the slope in the form of fields, paddy fields, and snake fruit gardens. Before analysis, the prepared soil samples were dried, then sieved using a sieve with a hole diameter of 2 and 0.5 mm.

**Soil analysis.** Soil physical properties were analysed as published by Balittan (2009), soil texture pipetting method, bulk density (BD) ring method, soil porosity calculated by the formula $n = (1 - BD/BJ) \times 100\%$, aggregate stability de Leenher and de Boodt (1959) method. Soil chemical properties were analysed as published by SRI (2009), soil $pH_{H_2O}$ (1 : 2.5) and $pH_{NaF}$ (1 : 50) with a pH meter, available P (Bray), available K and cation exchange capacity (CEC) with ammonium acetate ($NH_4OAc$), total N Kjedhal method (destruction and distillation), organic C (Black 1965). Soil biological properties C mineralization (C-Min) (soil respiration) $CO_2$ capture method

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as published by SRI (2009), C microbial biomass (C-Mic) fumigation and extraction method as published by SRI (2009), C particulate organic matter (C-POM) fractionation method as published by Marriot and Wander (2006).

**Soil quality index assessment method.** (1) Selection of indicators, this study uses two indicator approaches, that is total indicators which are indicators in this research that are suspected to be sensitive to land management and selected indicators that are determined using principal component analysis (PCA) with an eigenvalue ≥ 1, the indicator with the highest loading value is chosen as the selected indicator as published by Bünemann et al. (2018).

(2) Interpretation of indicators, scoring for each indicator is based on its influence on the soil, whether it is good or bad for the function of the soil with a range of 0 to 1, using the following formula:

$$P = \frac{x - x_{min}}{x_{max} - x_{min}} \text{ (more is better)}$$

$$N = 1 - \frac{x - x_{min}}{x_{max} - x_{min}} \text{ (less is better)}$$

where:

$x$ – value of each indicator;

$x_{min}$ – minimum value of the indicator;

$x_{max}$ – maximum value of the indicator (Andrews et al. 2002; Askari and Holden 2015; Kusumawati et al. 2023).

(3) Intergration

Adding soil quality index (SQIa) is calculated using:

$$SQIa = \left( \frac{\sum_{i=0}^{n} S_i}{n} \right)$$

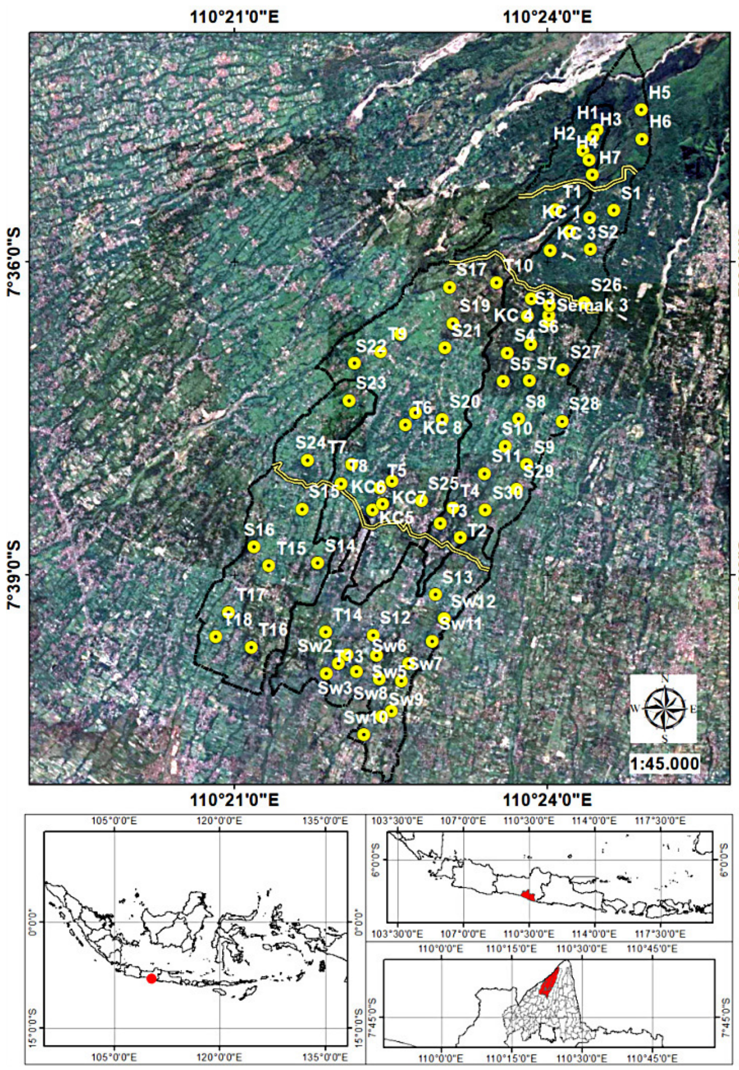


Figure 1. Location of the soil sample points from the top slope to the foot, which is located on the southwestern side of Mount Merapi

H – forest; T – dryland; KS – snake fruit garden; KC – mixed garden; semak – grassland; S – paddy field

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where:
SQI – soil quality index;
$S_i$ – score of indicator;
$n$ – number of indicators.

Each weight for total indicators is calculated from the commonality quotient divided by the total commonality of total indicators as published by Guo et al. (2017). Meanwhile, the weight of selected indicators from PCA is calculated using the following formula as published by Martín-Sanz et al. (2022):

$$\text{Weight} = \frac{\%\text{VarPC}}{\%\text{VarTotal}} / \sum \frac{\%\text{VarPC}}{\%\text{VarTotal}}$$

where:
%VarPC – percentage of variance for each PC;
%VarTotal – percentage of the total PC variance.

The weighting soil quality index (SQIw) is calculated according to Raiesi (2017) as follows:

$$\text{SQIw} = \sum_{i=0}^{n} W_i \times S_i$$

where:
$W_i$ – weight of indicator;
$S_i$ – score of indicator (Andrews et al. 2002; Nabiollahi et al. 2017; Raiesi 2017)

**Soil indicators and functions.** Indicators pH, CEC, available K, available P, C-Mic, C-POM, C-Min, and total N were chosen to represent the function of soil nutrient cycles as published by Andrews et al. (2004). This is because it shows the capacity of the soil to store available nutrients, and the capacity of the soil to facilitate the recovery of available nutrients for plants. The indicators of BD, texture and aggregate stability were chosen to represent the function of soil physical stability because BD is considered to be used to estimate soil compaction and the ability of roots to penetrate the soil.

**Types of assessment curves and formulas for each indicator.** There are 3 types of assessment curves, namely negative, positive and optimum as published by Karlen and Scott (1994). Negative rating curves are used when low-score indicators are positively associated with soil quality. Positive rating curves are used when high-score indicators are better associated with soil quality. In contrast, optimum rating curves are used when indicators positively affect soil quality to a certain extent, and negative beyond that limit. The more curves for assessing soil quality are better for indicators of C-Min, aggregate stability, available K, CEC, C-POM, total N, organic C, available P, and C-Mic (Nabiollahi et al. 2017; Kusumawati et al. 2023). Soil quality assessment curves are slightly better for BD parameters as published by Nabiollahi et al. (2017). Optimum assessment curve for pH, porosity, and sand, silt and clay fraction percentage (Wander et al. 2002; Andrews et al. 2004).

**Soil quality grade.** Determination of the grading class is calculated using the Sanchez et al. (2015) formula, namely after obtaining the SQI value, the next step is to make several different quality levels by dividing the SQI value by the desired number of intervals. This study has five SQI scores (Table 1), so the SQI score that is calculated is divided by five to determine the interval from one level to another. Then add this value to the lowest SQI value in each calculation model so that the upper limit of the first interval is obtained, and so on successively until the top of the SQI range is reached. The results of calculating the SQI grade in each calculation model are as follows:

**Statistical analysis.** The data obtained were analysed using variance (ANOVA) with nested design, followed by Duncan's multiple range test (DMRT) using R Studio 2022. PCA was performed using SPSS (Ver. 25). The scoring, SQI, and correlation calculations were carried out using Microsoft Excel Professional Plus 2010.

Table 1. Soil quality grade

| Grade | $SQIa_{ti}$ | $SQIa_{si}$ | $SQIw_{ti}$ | $SQIw_{si}$ |
|---|---|---|---|---|
| Very low | ≤ 0.338 | ≤ 0.269 | ≤ 0.329 | ≤ 0.362 |
| Low | 0.339–0.437 | 0.270–0.369 | 0.329–0.427 | 0.362–0.490 |
| Moderate | 0.438–0.536 | 0.370–0.469 | 0.428–0.526 | 0.491–0.618 |
| High | 0.537–0.635 | 0.470–0.569 | 0.527–0.624 | 0.618–0.746 |
| Very high | > 0.635 | > 0.569 | > 0.624 | > 0.746 |

$SQIa_{ti}$ – adding soil quality index total indicator; $SQIa_{si}$ – adding soil quality index selected indicator; $SQIw_{ti}$ – weighting soil quality index total indicator; $SQIw_{si}$ – weighting soil quality index selected indicator

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## RESULTS AND DISCUSSION

**Physical, chemical and biological soil attributes.** Results of the analysis of physical properties (Table 2), it was found that there was a significant difference in the clay and sand silt fractions with the slope position. Khan et al. (2013) states that the highest clay fraction is on the foot slopes, presumably due to erosion and translocation processes, while based on land use, the highest sand fraction is found in paddy fields. Furthermore, the soil BD was not significantly different between treatments. The BD value was classified as very low, presumably due to the influence of volcanic ash (Nanko et al. 2014; Delmelle et al. 2015). Significant differences exist in the porosity values between slope positions; the upper and middle slopes significantly differ from the lower slopes and foot. In addition, aggregate stability was not significantly different between treatments. Porosity and aggregate stability are greatly influenced by soil texture. The dominant sand fraction is thought to cause very high porosity and unstable aggregate stability.

The analysis of chemical properties found that the $pH_{NaF}$ value decreased as the slope position decreased (Table 2). The $pH_{H2O}$ was not significantly different between treatments, and its value was classified as slightly acidic, and this was thought to be due to the influence of the intermediate parent material as published by Kartikawati et al. (2019). Organic C values were significantly different at the position of the slopes; the upper and middle slopes were significantly different from the lower and foot slopes. The organic C value decreases as the slope position decreases, presumably due to climate influence as published by Jaksic et al. (2021). Total N, there is a significant difference between treatment N in the soil is strongly influenced by organic matter, so its value also follows the value of organic matter. Available P was significantly different between treatments. The P content is higher on the lower slopes than the upper, presumably due to the translocation process as published by Belayneh et al. (2021). The available K was not significantly different between treatments, while the CEC was significantly different. The highest CEC value was on forest land, while the lowest was on grassland.

The results of the analysis of the biological properties of the soil observed that there was no significant difference in C-min between treatments. The C-Min value was classified as very low, presumably due to the presence of amorphous minerals that inhibited microbial activity (Chevallier et al. 2008; Anda & Dahlgren 2020). C-Mic differed significantly between land uses, with the highest value on forest land and the lowest on grassland. The value of C-POM was not significantly different between treatments. C-POM was classified as very low, with a value of < 5% of the total C. However, the value was still higher than C-Mic, so the microbial food needs were still fulfilled. This was because C-POM was the primary energy source for microbes as published by Ermadani et al. (2018).

**Selection of selected indicators.** The indicators that most influence soil quality can be selected using PCA. Each PC in PCA has an indicator variable with a high factor load which is considered the indicator that best represents changes in soil quality and is defined as the value that has the absolute 10% of the highest factor loading (Andrews et al. 2002; Sharma et al. 2005; Govaerts et al. 2006). The multivariate correlation will decide the selected indicator if more than one variable is maintained under the PC. When two or more variables have the same correlation, it is considered redundant if all of them are maintained on one PC. Thus, only the variable with the highest value is included in the selected indicator. Two uncorrelated high-weighted variables are considered important and selected in the selected indicators as published by Guo et al. (2017).

The results of the PCA analysis showed that the five PCs analysed explained 86.11% of the variance of the original data (Table 3). The eigenvectors show that there is only one indicator with the highest loading factor value on the four PCs, namely PC1, PC3, PC4 and PC5, so the four automatically become the selected indicators in this study. The selected indicator for PC1 is the percentage of sand, PC3 is C-Min, PC4 is pH, and PC5 is aggregate stability. While on PC2, there are two indicators with the highest factor loading values, namely the C-POM and total N indicators. Based on the results of the correlation analysis, there is no real correlation between the two at the level of analysis $P < 0.05$ and $P < 0.01$, so both are considered important and used as selected indicators.

PCA analysis results obtained six indicators that most influence soil quality. The indicator is then given a weight. There are differences in weight values between total indicators and selected indicators (Table 4). The selected indicators have a higher value than the total indicators because, in the selected indicators, the weight is assigned to each PC which represents

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Table 2. Soil physical, chemical and biological attributes

| Indicator | Treatments | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | slope position | | | | forest | dry land | mix garden | snake fruit garden | grassland | paddy field |
| | upper | middle | lower | foot | mean of slope | | | | | |
| **Physical properties** | | | | | | | | | | |
| Sand (%) | $62.59^{b}$ | $79.28^{a}$ | $83.08^{a}$ | $68.39^{b}$ | $62.59^{a}$ | $78.10^{a}$ | $83.51^{a}$ | $74.72^{a}$ | $85.04^{a}$ | $64.82^{a}$ |
| Silt (%) | $34.33^{a}$ | $17.93^{bc}$ | $12.27^{c}$ | $22.49^{b}$ | $34.33^{a}$ | $17.40^{a}$ | $12.95^{a}$ | $19.91^{a}$ | $9.70^{a}$ | $22.79^{a}$ |
| Clay (%) | $3.08^{b}$ | $2.79^{b}$ | $4.65^{b}$ | $9.12^{a}$ | $3.08^{b}$ | $4.50^{b}$ | $3.54^{b}$ | $5.36^{b}$ | $5.26^{b}$ | $12.38^{a}$ |
| Bulk density ($g/cm^3$) | 1.01 | 1.07 | 1.11 | 1.08 | 1.01 | 1.03 | 1.14 | 1.08 | 1.16 | 1.11 |
| Porosity (%) | $55.64^{a}$ | $55.85^{a}$ | $55.22^{ab}$ | $52.54^{b}$ | $55.64^{a}$ | $56.61^{a}$ | $54.88^{a}$ | $54.42^{a}$ | $53.93^{a}$ | $49.24^{a}$ |
| Aggregate stability (%) | 64.91 | 53.99 | 58.46 | 56.28 | 64.91 | 52.48 | 57.56 | 59.50 | 59.17 | 58.82 |
| **Chemical properties** | | | | | | | | | | |
| $pH_{NaF}$ | 11.58 | 11.45 | 11.19 | 10.42 | 11.58 | 10.82 | 11.55 | 11.03 | 11.55 | 10.13 |
| $pH_{H_2O}$ | 6.44 | 6.24 | 6.09 | 6.21 | 6.44 | 6.15 | 6.22 | 6.22 | 6.14 | 6.00 |
| Organic C (%) | $3.87^{a}$ | $2.67^{a}$ | $1.90^{b}$ | $1.52^{b}$ | $3.87^{a}$ | $1.92^{a}$ | $1.92^{a}$ | $1.76^{a}$ | $2.24^{a}$ | $1.60^{a}$ |
| Total N (%) | $0.25^{a}$ | $0.21^{b}$ | $0.15^{bc}$ | $0.12^{c}$ | $0.25^{a}$ | $0.19^{bc}$ | $0.10^{d}$ | $0.16^{bcd}$ | $0.18^{b}$ | $0.12^{cd}$ |
| Avalaible P (mg/kg) | $14.76^{c}$ | $25.49^{ab}$ | $60.05^{a}$ | $35.63^{ab}$ | $14.76^{c}$ | $55.76^{b}$ | $25.72^{c}$ | $39.89^{bc}$ | $103.39^{a}$ | $23.25^{c}$ |
| Avalaible K ($cmol^{(+)}$/kg) | 1.06 | 0.67 | 2.32 | 2.37 | 1.06 | 1.11 | 1.50 | 2.26 | 3.12 | 2.22 |
| CEC (cmol(–)/kg) | $24.29^{a}$ | $14.52^{c}$ | $14.01^{c}$ | $18.41^{b}$ | $24.29^{a}$ | $15.25^{b}$ | $12.98^{bc}$ | $16.83^{b}$ | $9.76^{c}$ | $22.87^{a}$ |
| **Biological properties** | | | | | | | | | | |
| C-Min (mg/kg/day) | 1.93 | 2.97 | 3.67 | 3.70 | 1.93 | 2.92 | 3.71 | 4.98 | 1.79 | 4.77 |
| C-Mic (mg/kg) | $295^{a}$ | $261^{a}$ | $225^{a}$ | $249^{a}$ | $295^{a}$ | $253^{ab}$ | $219^{bc}$ | $265^{ab}$ | $159^{c}$ | $283^{a}$ |
| C-POM (mg/kg) | 1 484 | 685 | 664 | 560 | 1 484 | 460 | 849 | 739 | 730 | 549 |

CEC – cation exchange capacity; C-Min – C mineralization; C-Mic – C microbial biomass; C-POM – C particulate organic matter; numbers with different notations in the same column indicate significant differences, based on the Duncan multiple range test (DMRT)

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Table 3. Principal component analysis (PCA) analysis results

| PCA parameter | PC1 | PC2 | PC3 | PC4 | PC5 |
|---|---|---|---|---|---|
| Eigenvalue | 5.030 | 3.511 | 1.637 | 1.543 | 1.196 |
| Variance (%) | 33.534 | 23.406 | 10.913 | 10.286 | 7.974 |
| Cumulative (%) | 33.534 | 56.940 | 67.853 | 78.139 | 86.113 |
| Indicator | Eigenvectors | | | | |
| %sand | **–0.968** | –0.019 | –0.085 | –0.088 | –0.020 |
| %silt | 0.855 | 0.218 | 0.151 | 0.288 | 0.063 |
| %clay | 0.625 | –0.491 | –0.137 | –0.470 | –0.102 |
| Aggregate stability | 0.110 | –0.052 | 0.016 | 0.166 | **0.948** |
| BD | –0.309 | –0.774 | –0.385 | –0.160 | 0.095 |
| Porosity | –0.552 | 0.682 | 0.147 | 0.273 | 0.062 |
| pH | 0.087 | 0.081 | 0.010 | **0.844** | 0.163 |
| Available K | 0.116 | –0.290 | –0.647 | –0.454 | 0.434 |
| CEC | 0.778 | 0.082 | 0.491 | –0.042 | 0.340 |
| C-POM | –0.098 | **–0.824** | 0.267 | 0.053 | 0.210 |
| Total N | –0.017 | **0.826** | 0.337 | –0.013 | 0.254 |
| Organic C | 0.056 | 0.533 | 0.312 | 0.301 | 0.563 |
| Available P | –0.524 | 0.026 | –0.140 | –0.566 | –0.116 |
| C-Mic | 0.304 | 0.103 | 0.851 | 0.133 | 0.113 |
| C-Min | –0.080 | –0.098 | **–0.951** | 0.047 | –0.079 |

BD – bulk density; CEC – cation exchange capacity; C-Min – C mineralization; C-Mic – C microbial biomass; C-POM – C particulate organic matter; numbers in bold indicate indicators that have a high loading factor; the numbers in bold and underlined indicate the selected indicator

the total indicators in the PC. In contrast, the total indicator weight is assigned to each indicator. The weight value for each indicator is obtained from the commonality ratio of each indicator divided by the number of total indicator communities as published by Nabillahi et al. (2017).

**Assessment of soil quality index.** SQI assessment uses two calculation models, namely weighting soil quality index (SQIw) and adding soil quality index (SQIa), as well as two indicator approaches, namely total indicators and selected indicators. So that four combinations of SQI calculations are obtained, namely SQIw total indicators ($SQIw_{ti}$), SQIw selected indicators ($SQIw_{si}$), SQIa total indicators ($SQIa_{ti}$) and SQIa selected indicators ($SQIa_{si}$). Assessment of each indicator on the soil quality is carried out linearly.

Comparison of SQI values at study locations shows varying grades (Table 5). The SQI values for different calculation models and indicator approach methods show low to very high scores. The highest SQI value in the calculation model is found on the upper slopes, which land use as forests. The forest in the research area is classified as a protected forest and is one of the nature conservation areas called Gunung Merapi National Park (GNMP) (Figure 2). The high SQI calculation for forest land follows the findings of Ghimire et al. (2018) that forest land has better soil quality than cultivated land. This is presumably due to land management carried out by humans. Following the findings of De Paul Obade and Lal (2014), who examined that soil quality is affected by land management. Management without soil, as found in forest ecosystems, is considered the best management because it can maintain soil organic matter by reducing soil erosion so that organic matter, aggregate stability, create a soil microclimate, and allows better and more sustainable recycling of soil nutrients after the decomposition of soil organic matter. Indicators with a high contribution and the cause of the high SQI value on forest land are the percentage of sand, organic matter, total nitrogen, C-POM, pH and aggregate stability.

Soil quality shows better results on the upper slopes compared to other slopes in all SQI calculation mod-

Table 4. Weight of total and selected indicators

| Indicator | Total indicator | | Selected indicator |
|---|---|---|---|
| | communality | weight | weight |
| %sand | 0.953 | 0.074 | 0.389 |
| Total N | 0.861 | 0.067 | 0.272 |
| C-POM | 0.806 | 0.062 | 0.272 |
| C-Min | 0.928 | 0.072 | 0.127 |
| pH | 0.752 | 0.058 | 0.119 |
| Aggregate stability | 0.941 | 0.073 | 0.093 |
| %silt | 0.889 | 0.069 | |
| %clay | 0.882 | 0.068 | |
| BD | 0.876 | 0.068 | |
| Porosity | 0.870 | 0.067 | |
| Available K | 0.910 | 0.070 | |
| CEC | 0.971 | 0.075 | |
| Organic C | 0.792 | 0.061 | |
| Available P | 0.628 | 0.049 | |
| C-Mic | 0.857 | 0.066 | |

BD – bulk density; CEC – cation exchange capacity; C Min – C mineralization; C-Mic – C microbial biomass; C-POM – C particulate organic matter

Table 5. Soil quality index (SQI) results

| Treatment | | SQI | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $SQIa_{ti}$ | grade | $SQIa_{si}$ | grade | $SQIw_{ti}$ | grade | $SQIw_{si}$ | grade |
| Slope position | upper | 0.724 | very high | 0.774 | very high | 0.734 | very high | 1.052 | very high |
| | middle | 0.428 | low | 0.451 | moderate | 0.426 | low | 0.579 | moderate |
| | lower | 0.432 | low | 0.432 | moderate | 0.428 | moderate | 0.510 | moderate |
| | foot | 0.520 | moderate | 0.476 | high | 0.520 | moderate | 0.645 | high |
| **Land use on slope position** | | | | | | | | | |
| Forest | upper slope | 0.724 | very high | 0.774 | very high | 0.734 | very high | 1.052 | very high |
| Dryland | middle slope | 0.410 | | 0.384 | | 0.413 | | 0.533 | |
| | lower slope | 0.418 | | 0.269 | | 0.407 | | 0.466 | |
| | foot slope | 0.485 | | 0.436 | | 0.452 | | 0.509 | |
| | mean | 0.442 | moderate | 0.363 | moderate | 0.424 | moderate | 0.503 | moderate |
| Mix garden | middle slope | 0.338 | | 0.435 | | 0.329 | | 0.552 | |
| | lower slope | 0.373 | | 0.398 | | 0.379 | | 0.362 | |
| | mean | 0.364 | low | 0.416 | moderate | 0.354 | low | 0.457 | low |
| Snake fruit garden | middle slope | 0.537 | | 0.534 | | 0.536 | | 0.652 | |
| | lower slope | 0.495 | | 0.564 | | 0.496 | | 0.664 | |
| | foot slope | 0.547 | | 0.569 | | 0.496 | | 0.763 | |
| | mean | 0.511 | moderate | 0.556 | high | 0.509 | moderate | 0.693 | high |
| Grassland | lower slope | 0.442 | moderate | 0.497 | high | 0.428 | moderate | 0.546 | moderate |
| Paddy field | foot slope | 0.530 | moderate | 0.424 | moderate | 0.546 | high | 0.663 | high |

$SQIa_{ti}$ – adding soil quality index total indicator; $SQIa_{si}$ – adding soil quality index selected indicator; $SQIw_{ti}$ – weighting soil quality index total indicator; $SQIw_{si}$ – weighting soil quality index selected indicator





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els. This shows that differences in slope position can cause land degradation. Following Bufebo's statement (Bufebo et al. 2021), slope differences are an important cause of soil loss and environmental degradation. They are a factor in environmental disturbance by affecting runoff, soil nutrient content and river flow. The higher SQI values on the upper slopes are consistent with the findings in the study of Fu et al. (2004) that the highest SQIs are on the upper slopes, and the middle slopes and the lower slopes have the lowest SQI values. SQI is improving on land at the foot of the slope. This is presumably because the upper slopes have better soil properties, these soil properties decrease on the middle and lower slopes and on the toe slopes, the soil properties improve due to deposition and translocation processes.

The SQI on dry land, located on the middle, lower and foot slopes, has a low score when calculated using the selected SQIa indicators. Still, if it is calculated using the total adding soil quality index (SQIa) and weighting soil quality index (SQIw) indicators, the evaluation criteria change to moderate. This is in contrast to mixed garden. If it is calculated using SQIa, the selected indicators have moderate criteria, but if it is calculated using other models, the criteria are low. This is presumably due to very little input given by farmers to the mixed garden and only relying on nutrient input from the existing litter so that the mixed garden has a low SQI. In addition, it is also affected by the low total N and a high percentage of sand. The value of SQI is influenced by land use and the impact on each slope position because soil properties have a bigger role in determining changes in SQI.

The SQI values for snake fruit land, which are on the middle, lower and foot slopes, have a low score, namely the SQIa and SQIw total indicators, while the scoring criteria change to high in SQIa and SQIw selected indicators. Indicators that have a big role in SQI in snake fruit plantations are the percentage of sand, total nitrogen and C-POM. In addition, the high quality of the soil on this land is also due to the contribution of organic mulch nutrients. Farmers in the research location took steps to improve land conditions by applying organic mulch to the alleys between the snake fruit plants where the farmer's roads were not traversed during the maintenance, weeding and harvesting processes. Paddy fields at the foot of the slopes have moderate SQI criteria when calculated using SQIa, but these criteria increase to high in SQIw calculations. The highest contribution indicators are the percentage of sand and C-POM.

Soil quality in this area is also influenced by the type of soil , which is an inherent soil quality, that is, the character or composition of each soil or can be called an expression or result of the pedogenesis process. Mount Merapi is classified as the most active volcano in the world and is recorded as having erupted 83 times since the 16th century (Kartikawati et al. 2019). The frequent eruptions of Mount Merapi cause the surrounding land to be classified as young and relatively undeveloped land. Based on research

Figure 2. Forest land: minipit of forest soil (left), large vegetation (middle) and small vegetation of forest land (right)

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results, Aini et al. (2019) stated that the soil on the slopes of Mount Merapi is dominated by Entisol, Inceptisol and Andisol. Young soils such as Inceptisol have a problem faced by Inceptisols soil is the chemical attribute. The chemical soil is not too good as seen from the C-organic and low N of the soil, generally Inceptisols have less fertile soil (Harahap et al. 2021).

The soil-forming factors strongly influence the SQI value. One of the factors is organisms; soil properties can be influenced by human actions or activities in soil management and the activities of microorganisms in the soil, so SQI values that vary in the study area can be used as a way to determine changes in land use that represent dynamic soil quality and has the potential to assess the effects of land use or management practices on soil quality. Soil function degradation is caused by converting natural forests into agricultural land, which is indicated by a lower SQI value than forest land. This study's most critical indicators for maintaining and improving soil quality are sand percentage, total nitrogen, C-POM, C mineralization (C-Min), pH, and aggregate stability, which can determine soil health and capacity to receive, retain, and release nutrients. And other chemical constituents. As verified in this study, these selected soil quality indicators are the most powerful tools for assessing soil quality regarding land use type and slope position.

The SQI assessment can be used as a basis for improving several indicators, although not all can be repaired. Total nitrogen, C-POM, C-Min, pH, and aggregate stability are indicators that include dynamic soil properties whose values can change due to human and microorganism activities. At the same time, the percentage of sand is an indicator that cannot be repaired because it includes inherent properties related to soil development. Based on the analysis results (Table 2), the N-total is in line with the organic C value, following the statement of Benbi and Ritcher (2002) that the N mineralization process utilizes C as an energy source. Gosling's research (2013) found that C-POM is part of soil organic C. Ermadani et al. (2018) stated that C-POM is a primary energy source for microorganisms. The C-Min indicator results from the performance of soil microorganisms, and C-POM influences its value as an energy source.

Organic matter has the same function as clay, an adhesive material between soil particles to unite into soil aggregates, as published by Liu et al. (2019). A relatively high percentage of organic matter in the soil can stabilize soil aggregates. This can be seen in the forest land with the highest organic matter content so that the soil aggregates are better (Table 2). Therefore, a soil management strategy that focuses on soil organic matter components and biological activity is the best way to provide soil buffering capacity needed to increase soil's ability to withstand changes caused by human and natural factors. Organic matter consists of completely decomposed humus, semi-decomposed organic residues, microorganisms and feces (Malone et al. 2023). Storage of organic matter is influenced by soil N availability through regulation of decomposition and formation of organic matter by microbial communities and plant litter input (Geng et al. 2021). Forests have a higher N content and more litter input compared to other land, so the quality of organic matter on forest land is better, which also affects overall soil quality.

The results of the correlation analysis show that the SQIw model has a higher $R^2$ value (Figure 3), and the statistical correlation coefficient uses a simple value compared to the SQIa model (Figure 4).

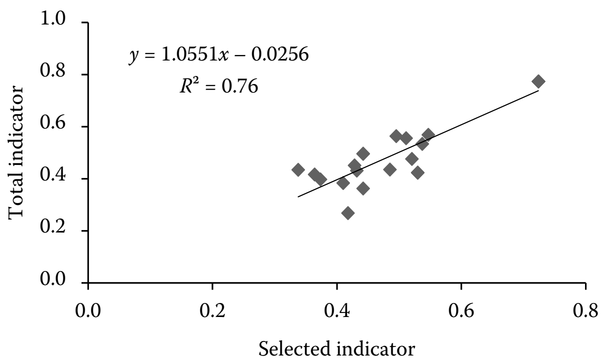


Figure 3. Correlation between total indicators and selected indicators in the adding indexing model (SQIa)

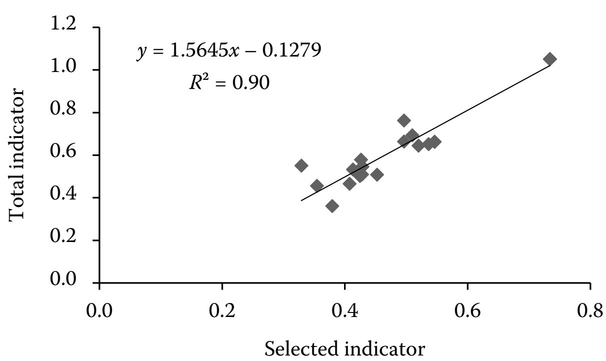


Figure 4. Correlation between total indicators and selected indicators in the weighting indexing model (SQIw)

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It can happen because in the SQIw model, weights are applied to the main of and all of soil properties. In the SQIa model, the sum of the soil indicator scores is calculated without weight. So, SQIw value is more thorough than SQIa. The correlation results indicate that all indexing models can be used to assess SQI in the study area. It's just that the ability of each model is different in predicting soil quality. Indicators using PCA analysis are the best and most much-needed way to provide precise information and make it easier to select representative parameters for SQI calculations. Selected indicators can represent SQI assessments marked by a positive correlation between the two.

The highest correlation on SQIw shows that the mean can predict soil quality better than adding indexing models. The correlation value for SQIa is $R^2$ = 0.76, while the SQIw calculation model has a value of $R^2$ = 0.90. So the most suitable SQI indexing model for this area is SQIw. The SQIw scores equally well compared to other indices in other agricultural land SQI assessment studies worldwide. Vasu et al. (2016) assessed soil quality in the Deccan upland by applying the SQIa and SQIw models and showed that the SQIw model had a better correlation with yields than the SQIa model. Mukherjee and Lal (2014) assessed soil quality in Ohio by comparing the SQIa and SQIw models and showed that SQIw correlated better ($R^2$ = 0.79) with yields than SQIa ($R^2$ = 0.65). Zhang et al. (2016), in assessing the soil quality of coastal wetlands in the Chinese Yellow River delta, showed the best correlation ($R^2$ = 0.65) between total indicators and selected indicators with the SQIw indexing model.

## CONCLUSION

Soil quality assessment using the SQIw has the highest correlation ($R^2$ = 0.90). It can predict soil quality better than the SQIa ($R^2$ = 0.76) because the SQIw model uses weights applied to the overall soil properties and the main soil properties, which are key indicators. Selected indicators can represent total indicators based on a positive correlation between the two. Selected indicators using PCA is the best and most much-needed way to provide precise information and facilitate the assessment of representative parameters for calculating SQI. The selected indicators in this study can be used as indicators that most determine SQI in similar regions. The indicators that most influence soil quality in this study area are dynamic properties whose values can change due to human and microorganism activities. Indicators of total N, C-POM, C-Min, pH, and aggregate stability are influenced by organic matter. The total N and C-POM values are in line with the organic C values. Forest land with high organic matter has criteria for a better value than other lands on the aggregate stability indicator. So the strategy for maintaining and improving soil quality indicators can be carried out by maintaining and increasing organic matter. Site-specific soil management that focuses on soil organic matter components and biological activity is the best way to provide the soil resilience or buffer capacity needed to increase the soil's ability to withstand changes caused by human and natural factors. Proper soil management is by adding organic material periodically. The main problem in adding organic material in the field is synchronization and unavailability of organic material sources. To help synchronize the availability of nutrients with the nutrient needs of plants, this can be done by mixing high-quality materials with low quality or by composting.

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