Assessments of soil quality and soil erosion hazards in Arjasa Agricultural Sub Watershed, Indonesia

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Abstract

The study aimed to construct soil quality indices under different land uses, slopes, and soil types and predict a soil erosion hazard. The research location is in the Arjasa Sub-DAS which is the upstream part of the Bedadung DAS, Indonesia. The main vegetation cover in the area is secondary dryland forest, plantation forest, open land, dryland agriculture, mixed dryland agriculture, and rice fields with varying slope gradients 3-8% until >40%. Soil types in this area include Andic Dystrudepts, Lithic Hapludands, Typic Dystrudepts, Typic Eutrudepts, and Typic Hapludands. Soil samples were collected randomly representing the entire sub-DAS at a depth of 0-20 cm as many as 30 sample points. The soil samples were then analyzed in the Soil Science Laboratory, Faculty of Agriculture, UNEJ with physical parameters including percentage of sand, dust, and clay, bv, bjp, porosity, and erodibility, while chemical parameters include pH H_2O, pH KCl, P-available, exchangeable K, exchangeable Ca, exchangeable Na, exchangeable Mg, CEC, C-organic, total soil N, base saturation, and Hydraulic conductivity. Statistical analysis of all parameters was carried out using Anova, regression-correlation, and Duncan's test. In addition, PCA (principal component analysis) was also used; a multivariate statistical method used to reduce complex data sets to be minimum data set (MDS) as soil quality indicators. Quantitative analysis of erosion hazard levels can be performed using the USLE formula developed by Wischmeier and Smith (1978), expressed as A = R.K.LS.C.P. Cluster analysis is also used in evaluating, characterizing, and mapping the Soil Quality Index (SQI). The results of the study showed that the soil quality index in the study area was influenced by slope, while land use and soil type did not affect SQI. There was a negative relationship at a moderate level (r = 0.56) between the level of erosion hazard and the soil quality index.

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Keywords: Sub Watershed; Soil Erosion Hazard; Soil Quality Index

Introduction

Precision agriculture is becoming an increasingly popular approach to modern farmland management. It uses specialized technologies and techniques to evaluate variations in soil and crop properties to support optimal soil management. In some cases, soil quality evaluation requires many variables, but identification of key parameters can reduce analysis time and cost and improve the efficiency of spatial and temporal soil assessment. One method commonly used in precision agriculture analysis is principal component analysis (PCA). As such, PCA can help identify patterns hidden in soil and crop data, and accelerate the decision-making process in farmland management. In addition, PCA can also be used to identify relationships between variables, making it possible to formulate more effective land management strategies.

A recent study conducted by (Sishodia et al., 2020) showed that the application of PCA in precision agriculture analysis can improve the efficiency of farmland management. In their study, Smith et al. used the results of PCA analysis to show that only a few variables have a significant contribution to data variation, making it possible to identify key parameters that need to be prioritized in farmland management. In addition, research conducted by (Abdel-Fattah et al., 2021) also showed that PCA can be used to predict soil and crop quality in various agricultural sites. The results of this study make a significant contribution to the development of more effective and efficient precision agricultural analysis methods.

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Plant rooting depth is also an important factor in determining soil quality. Plants with deep root systems tend to be more resistant to drought and can absorb nutrients better. According to research conducted by (Ahluwalia et al., 2021), plants with deep root systems have better growth and higher yields compared to plants with shallow root systems. Finally, soil texture also affects overall soil quality. Soil texture refers to the size of soil particles consisting of sand, dust and clay. Soils with good texture tend to have good soil structure, good porosity, and good water retention ability. According to research conducted by (Johnson et al., 2022), soils with good texture have higher productivity compared to soils with poor texture.

Spatial variability of soil attributes is also measured by the Soil Quality Index (SQI) which includes physical and chemical characteristics of soil that are important to support plant growth. Recent studies have shown that factors such as bulk density, cation exchange capacity, rooting depth, and soil texture also influence soil quality. According to research conducted by (Li et al., 2020), high soil bulk density can inhibit plant growth and reduce crop yields. In addition, cation exchange capacity (CEC) is also an important parameter in assessing soil quality. CEC measures the ability of soil to exchange ions with plant roots. Soils with high CEC tend to have a good ability to provide nutrients to plants. However, soils with low CEC can cause nutrient deficiencies in plants. According to research conducted by (Mamehpour et al., 2021), soils with low CEC generally require additional fertilization to ensure plants get enough nutrients.

A good understanding of the factors that affect soil quality is essential for sustainable soil management. Through the use of methods such as PCA and SQI, it is expected to assist in the evaluation of soil quality more accurately and efficiently to support optimal plant growth and maximum crop yields. The spatial-temporal dimension must also be considered in the SQI assessment as soil properties are not permanent. The use of GIS technology has facilitated the calculation of spatial variability of phenomena including soil properties. Thus, the integration of GIS analysis and geostatistics can provide benefits in evaluating the spatial variation of soil characteristics and forecasting them in unsampled areas. For example, the application of variogram analysis can accurately capture and map complex spatial relationships between soil data. Kriging is one of the frequently used interpolation techniques, which can support efficient agriculture by identifying homogeneous sub-sets of similar yield limiting factors.

The Arjasa sub-watershed is located in the northern region of Jember and is the upstream portion of the Bedadung watershed, bordering Bondowoso District. A review of Jember Regency's long-term development plan indicates that the Arjasa sub-watershed is at risk of environmental challenges. A preliminary survey indicated that the main problem in the Arjasa sub-watershed is land degradation, which requires immediate attention. PCA analysis and cluster analysis were also used in evaluating, characterizing, and mapping the Soil Quality Index (SQI) in the Arjasa sub-watershed. By combining PCA and Geographic Information System (GIS), this study aims to provide a deeper understanding of soil quality in the region. Cluster analysis is used to map the distribution of SQI in the Arjasa Subwatershed in more detail. The use of GIS in this analysis will make it possible to create thematic maps that show the level of soil quality at various locations in the region. The results of this study are expected to provide valuable information for stakeholders related to soil management in the Arjasa Subwatershed. With a better understanding of soil quality and its influencing factors, it is expected that appropriate measures can be taken in maintaining and improving soil quality in the region.

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Materials and Methods

Study Area

The study site is located in the Arjasa Subwatershed, Bedadung Watershed. The subwatershed is located between 8°0'51.95 “S - 113°41'4.46 ‘E and 8°5'23.81 ’S - 113°44'45.31 ”E. This area is the main upstream of the Bedadung watershed (Figure 1). The parent material units of the Arjasa Subwatershed include two main landforms, namely Argopuro volcanic rocks and Argopuro tuff. The main vegetation cover in the area is secondary dryland forest, plantation forest, open land, dryland farming, mixed dryland farming, and paddy fields with varying slopes; therefore, sensitivity to climate change differs greatly in the study area. The climate of the study area is characterized by a hot and dry tropical climate with limited rainfall and bright sunshine throughout the year. The area has annual rainfall ranging from 1,969 mm to 3,394 mm, with average annual minimum and maximum temperatures of 23º - 31ºC respectively. Soil types in this area include Andic Dystrudepts, Lithic Hapludands, Typic Dystrudepts, Typic Eutrudepts, and Typic Hapludands.

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Soil Sampling and Analysis

Soil samples were collected based on (Figure 1) at 0-60 cm depth at 30 different sample points. One mixed sample at each site was collected representing soil from the root zone. The sample points used represent spatial changes in the area characterized by wide physiographic variations, such as land use, soil type, and slope. Samples were air-dried and sieved through a 2 mm sieve to prepare for physical and chemical analysis according to standard protocols described according to (Chaudhry et al., 2024; Demir et al., 2023; Hyun et al., 2022). Soil physical and chemical analysis measurements were carried out by various methods as shown in Table 1 below.

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Statistical Analysis

Soil characteristics were analyzed by descriptive statistics, including minimum, maximum, arithmetic mean, and standard deviation values, which were calculated using SPSS version 26.0. Duncan's further test was used to confirm the normal distribution of the data. Pearson's correlation coefficient was used to measure the strength and direction of the relationship between two variables. R-Studio software and SPSS version 26.0 were used to perform principal component analysis (PCA). PCA is a multivariate statistical method used to reduce the dimensionality of complex data sets, called principal components, and to avoid multicollinearity between variables. PCA is used to identify patterns hidden in the data and describe them in the form of new variables called principal components. The results of this PCA analysis will provide a deeper understanding of the variation in the original variables under study. Thus, PCA can identify the main factors affecting the soil characteristics under study.

Soil Quality Index (SQI)

The SQI was developed based on the method of (Hermiyanto et al., 2016), using equation (1) and the indicator scoring equation (2). An additive weighting equation is used, using the PC variability obtained from the SQI development process, which provides greater precision in determining soil quality. SQI has advantages over other techniques (fixed additive weighting equation, expert opinion and linear additive index).

$$\mathrm{SQI} = \sum_{i=1}^{n} \mathrm{Wi \ x \ Si} \qquad (1)$$

where: Wi is the proportion of PC variability correlated with the indicator, Si is the indicator value resulting from the redundancy reduction process, obtained from soil sample analysis. Equation (2) is used to evaluate indicators whose function in soil is “the more the better” or “the less the better”:

$$Si = \frac{a}{1+(\frac{x}{xm})^{b}} \qquad (2)$$

where: a is equal to the maximum standardized value of the indicator, Xm is the average value of the indicator obtained from the analysis, X is the value of the indicator and b is the slope of the indicator scoring function. (-2.5 for indicators whose function is “the more the better” and 2.5 for indicators whose function is “the less the better”).

Equation (3), used to assess indicators whose function in the soil is considered “optimal” and whose maximum or optimal value is 0.5:

$$Si = \frac{1}{[1+(\frac{(B-L)}{(X-L)})^{2L(B+X-2L)}} \qquad (3)$$

where: B is the indicator value with a slope of 0.5, L is the lowest limit value of the indicator and X is the indicator value. The purpose of the SQI is to assign a value between 0 and 1, thus to determine soil quality according to the classification shown in Table 2.

Cluster Analysis

Cluster analysis was performed using SPSS software version 25.0. In selecting the number of clusters, clustering trials were conducted with 9, 8, and 7 clusters. The test that produced usable and sufficient members was the test with 7 clusters, with members of 3, 12, 3, 3, 2, and 4 groups, respectively. This cluster analysis was used for erosion calculations, but the SQI was also clustered for correlation and regression with erosion.

Erosion Calculation

The determination of the erosion hazard level was carried out using the USLE method based on rainfall data, soil properties, slope length and slope, crop management and soil conservation management based on clustering. Analysis of the level of erosion hazard quantitatively using the Universal Soil Loss Equation (USLE) formula. Systematically the USLE model is expressed by:

$$A = R \times K \times LS \times C \times P$$

where: A is soil loss (tons/ha/year), R is the rainfall erosivity index, K is the soil erodibility index, LS is the slope length and slope index, C is the vegetation cover index, P is the land management/soil conservation measures index. The results of the calculation of the amount of soil loss are used in determining the Erosion Hazard Level according to the classification of erosion hazard levels shown in Table 3.

The research framework

The research framework used in analyzing the soil quality index and the level of erosion hazard in the Arjasa Subwatershed is shown in Figure 2 below. The research framework is determined according to the research steps to be carried out. The main analysis of soil quality index and the level of erosion hazard using USLE resulted in the level of influence between the two in Arjasa Subwatershed.

Results and Discussion

Soil Characteristics of the Study Area

The ANOVA test results show that the errors are normally distributed in some treatments, but unevenly distributed in certain treatments. From this analysis it was found that the significant value (p-value) on some variables was less than 0.05 which means H0 was rejected, indicating that there were significant differences among the various groups of data tested. The results of the Duncan's further test table 4 reinforced these findings by showing pairs between groups that had significant differences in mean values. Duncan's further test was then conducted to further assess which treatment pairs had significant differences in means. This test is essential in eliminating ambiguous interpretations that may arise from ANOVA results by detecting specific differences between treatment pairs. This study shows that soil quality in the Arjasa subwatershed has significant variations depending on land use factors as well as topographic variations.

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Based on the ANOVA results and Duncan's further test, it was found that in some soil quality parameters such as BV, K, Na, Mg, pH H_2O and Ca, showed significant impact values on soil quality. In Typic Eutrudepts soil type, the available P and Na contents were higher than the other two soil types. In soil, the main source of P is the mineral apatite ($AlPO_4$) while other sources of P come from organic compounds (Yustika et al., 2023). Phosphorus is available from the decomposition of organic matter such as crop residues, which enriches the soil with phosphorus. The Na content in this soil type is very high compared to other soil types. The use of chemical fertilizers containing sodium such as complex fertilizers can increase the sodium content in the soil. In line with research (Qalati et al., 2023) which revealed that inadequate water management, poor drainage, and the use of sodium-containing fertilizers can increase the percentage of sodium in the soil, thus having a negative effect on soil and plants. In production forest land use, Bv and Mg have the highest median values compared to dryland agriculture and savanna. High Bv and Mg in production forest land use indicates high organic matter content in this land use (Enters et al., 2006). Although the pH in all land uses was neutral, the pH in the production forest land use was greater than the pH in the other land uses. Soil pH that is close to neutral can support the availability of nutrients for plants (Gondal et al., n.d.; Neina, 2019). Soils with pH close to neutral are usually more stable and support plant growth (Gondal et al., n.d.; Minasny et al., 2016; Neina, 2019).

This can be influenced by various factors such as slope, soil type and land use. This finding is in line with research by (Reis & Dindaroğlu, 2024) which showed that different land management methods resulted in varied soil quality with forest land having higher soil quality scores compared to cropland and pasture. Research by (Hyun et al., 2022) also confirmed the results of this study. They developed uSQI to evaluate urban soil quality and found that bulk density and cation exchange capacity are some of the main indicators that influence the urban soil quality index. These findings support evidence that physical soil parameters, such as bulk density and cation exchange capacity, play an important role in determining soil quality (Hermiyanto et al., 2024). Low bulk density and high cation exchange capacity generally indicate good soil quality and high ability to support plant growth, which was also found in this study in the Arjasa subwatershed. Thus, overall, this study successfully demonstrated that there were significant values in the ANOVA test and Duncan's further test that showed important differences in soil quality between the various treatments in the Arjasa subwatershed.

Boxplot of Duncan variation in different cluster

The boxplot analysis shown in Figure 3 shows the effect of soil type, land use and slope on the value of each soil physical and chemical parameter in each cluster. The results of the anova test and boxplot analysis revealed that all clusters showed significant values for all parameters. The boxplot shown in Figure 3 reveals that for each parameter only pH H_2O and BJP show insignificant values.

In the cluster with Typic Hapludands soil type, the exchangeable Ca content shows the highest value compared to the other two soil types. The factor that can affect the high Ca content in this soil is the parent material that forms the soil. Ca in the soil comes from the parent material that forms the soil, as well as the weathering and dissolution of limestone which has a high calcium content (Luo et al., 2023; Zhang et al., 2021). Typic Hapludands are formed from volcanic materials such as volcanic ash or glass that are rich in minerals (Anggriawan et al., 2023; Hall & Scheidl, 1939). Minerals that are weathered will release nutrients into the soil, besides that these types of soils tend to have a high cation exchange capacity, allowing the soil to store and retain large amounts of nutrients (Alaboz et al., 2021). This soil type also has a high organic matter content (Marbun et al., 2018). Organic matter can increase cation exchange capacity. A high CEC can retain more calcium and nutrients, making them available to plants.

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Clusters with dryland agricultural land use have higher median Ca, Na, and CEC compared to other land uses. The high content of Na, Ca and CEC in this land use is due to the use of chemical fertilizers containing these elements (Selim, 2020). The addition of Na fertilizers can increase the Na content in the soil, but if used excessively sodium can accumulate. In addition, on irrigated drylands, irrigation water containing sodium and inefficient soil management practices can cause salinization, where salts including sodium will settle in the soil. The addition of Ca fertilizer is done to improve soil pH and increase fertility. Calcium is important in agriculture to regulate nutrient balance and soil health, and reduce soil acidity. A decrease in soil structure due to agricultural activities can increase the risk of erosion (Yusran et al., 2020; Zheng et al., 2024).

In clusters with savanna soils, porosity values were higher than the other two soil types. High porosity on this land means that it has a good ability to absorb water. This can help in maintaining soil moisture and preventing erosion, as well as supporting vegetation growth by providing adequate water. Despite having good porosity the nutrient content of this land use is low. Nutrient availability is important in supporting plant growth, if nutrient availability is low the soil may not support plant growth effectively. In clusters with a slope of 3-8% the median values of Ca, available P, Na and porosity are higher compared to other slopes. On these slopes the erosion process is usually lower than on steeper slopes. This allows more nutrients to be stored in the soil without significant leaching by surface water.

High porosity also allows water and air to move more freely in the soil, supporting mineral weathering and nutrient uptake by plants. On slopes of 15-25% and >40% the erodibility values are highest compared to other slopes, indicating that these slopes are more susceptible to erosion. Stronger water flow leads to increased erosion and nutrient leaching. Overall, the parameters Ca, Na, and CEC have the highest significant difference value compared to other parameters that can affect the soil quality of the Arjasa Subwatershed.

Principal Component Analysis

The Principal Component Analysis (PCA) in Table 5 shows that five principal components successfully explain the variability of the data. The first component (PC1) has the greatest contribution in explaining the variability of the data, followed by the second (PC2), third (PC3), fourth (PC4) and fifth (PC5) components. Variables that have high loadings on PC1 are related to soil chemical properties such as pH, magnesium, potassium, calcium, and organic carbon. This indicates that the first component reflects soil chemical fertility.

Based on the results of the analysis, 5 main components were obtained that contained the loading factor values. In each component, the highest value is selected. A parameter is considered high when it is in the highest 10% range of the highest load factor value. If there is more than one parameter in one component, it is eliminated by looking at the correlation value between parameters. Correlation <0.50 then the parameter is included in the MDS, but otherwise correlation >0.5 MDS determination is done by summing the correlation, the highest correlation value is determined as MDS. Based on 5 principal components (PCA), there are 5 parameters that are selected as MDS. In PC 1 is represented by Ca. PC 2 is represented by % sand. PC 3 is represented by N. PC 4 is represented by porosity. On PC 5 is represented by pH H2O. The second component (PC2) is more related to physical soil properties such as sand and dust. These variables indicate that the second component describes soil texture. The third component (PC3) also shows a relationship with soil chemical properties, especially sodium and nitrogen.

The fourth (PC4) and fifth (PC5) components have smaller contributions in explaining the variability of the data and may represent more specific variations in the data. Based on these PCA results, it can be concluded that a soil quality index can be constructed based on a combination of soil chemical and physical properties. Soil chemical properties such as fertility and organic matter content have a significant influence on soil quality. In addition, soil texture is also an important factor to consider in determining the soil quality index. Thus, the soil quality index

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generated from this PCA analysis can provide a more comprehensive picture of soil conditions and can be used as a basis for decision-making in soil management.

Analysis of soil quality index

The level of contribution of MDS used in determining soil quality according to Figure 4. MDS that have been obtained by PCA method are exchangeable Ca, percentage of sand, N, porosity, and pH H2O. These MDS have their respective contribution values in compiling soil quality. the five MDS have their respective contribution values in compiling soil quality. Each indicator contributes to soil quality with different portions.

Each cluster shows that Ca content has the highest contribution to soil quality, then the percentage of sand is the second highest in soil quality, and the third highest is Nitrogen. The Typic Hapludands soil type contributes the highest Ca content to soil quality. This type of soil is formed from volcanic material that is rich in minerals. Mineral weathering releases nutrients into the soil. Weathering contributes to soil nutrient richness and can improve soil quality. Calcium plays an important role in the formation and stability of soil aggregates. Calcium helps to bind soil particles into more stable structures, supporting the formation of good soil aggregates. A stable soil structure is important for optimal plant root growth.

In dryland agricultural land use, nitrogen content has a high contribution to soil quality. The more frequent application of nitrogen fertilizers in dryland agriculture is one of the factors that cause high nitrogen in this land use. In addition, the addition of straw can also increase soil nitrogen, this is in line with research (Wang et al., 2023) which revealed that the addition of straw can increase soil nitrogen compared to fertilizer treatment. A slope of 3-8% contributes the highest Ca content to soil quality. At this slope, Ca content is higher due to fertilizer inputs given in agricultural practices. High Ca content on the lower slopes can also be caused by runoff that carries nutrients from top to bottom, so that Ca concentration increases on the lower slopes (Yustika et al., 2023). Soil erosion can transport nutrients in the topsoil, leading to nutrient loss (Su et al., 2010; Yustika et al., 2023).

At this slope, applied fertilizers are more easily absorbed by the soil and plants, without experiencing much loss due to erosion or runoff that often occurs on upper slopes. This allows nutrients to remain available in the root zone, thus supporting optimal plant growth. On slopes >40%, exchangeable Ca shows the second highest contribution to soil quality. At this slope the movement of water and soil material occurs more intensively, but the content of exchangeable Ca still shows a high contribution compared to the slope of 25-40% and 15-25%, this can be caused by the vegetation cover on the slope is still in good condition. On this slope the vegetation is woody trees. Woody trees can help hold soil and minimize excessive erosion. Good land cover can also slow down water flow and reduce the risk of soil erosion so as to keep nutrients available (Wu & Hu, 2020).

The 25-40% slope showed slightly lower Ca content compared to the 15-25% slope. The exchangeable Ca content on this slope shows a contribution to soil quality but not as much as the 3-8% and >40% slopes. This can be caused by less than optimal land management and little vegetation protection that can trigger erosion. As explained above, erosion can transport nutrients in the top soil layer, which can trigger nutrient loss. The contribution of Nitrogen content on each slope increases from the lower to the upper slopes. The highest nitrogen content is found on slopes of 25-40% and >40%. Besides exchangeable Ca and nitrogen, porosity is the fourth contribution to soil quality.

Porosity has an important role in determining soil quality, because the ability of soil to hold and drain water and air is highly dependent on the level of porosity. Soils with good porosity allow efficient movement of water and air, which is essential to support the growth of plant roots, soil microorganisms and the decomposition of organic matter. This helps maintain soil moisture balance and provides an optimal environment for plants to absorb nutrients, thus directly improving overall soil fertility and quality.

Erosion hazard level based on cluster

Analysis of erosion data in Table 6 shows the level of erosion hazard in the Arjasa Subwatershed based on clusters in each cluster is different and is influenced by several factors such as length and slope, soil erodibility, land cover, and soil conservation measures. The results of the analysis on the 7 clusters show significant variations in the erosion value (A) between clusters. This indicates that the level of vulnerability to erosion in each cluster is different.

The level of erosion hazard in the Arjasa Subwatershed is categorized into very light to heavy classes. The table shows that cluster 3 has the highest level of erosion hazard categorized as heavy and clusters 1 and 7 have the lowest level of erosion hazard categorized as very light. According to (Meshram et al., 2023; Setyawan et al., 2020) erosion rates are influenced by various factors, including CP and LS factors. The influence of the LS factor on erosion depends on the slope and length of the slope, which affects the flow of water on the soil surface. The steeper the slope, the greater the velocity of surface water flow, which has the potential to transport soil more efficiently. The most dominant factor affecting erosion values is the length and slope (LS). The greater the LS value, the higher the potential for erosion. This can be seen in clusters 3 and 4 which have the highest LS values and high erosion values.

Second, the soil erodibility factor (K) also contributes to the amount of erosion. Although the variation in K value is not as large as LS, the difference in K value still affects the final erosion value. Soils with high K values tend to erode more easily than those with low K values. The influence of CP factors on erosion is influenced by land use, where the greater the forest area can reduce the erosion rate (Zeng et al., 2023). Reduced forest area can increase soil erosion, as well as reduce water infiltration capacity and the ability to store water, which can accelerate erosion. Erosion that occurs on the same land use often varies due to the influence of conservation techniques applied. The use of appropriate conservation techniques that suit the land conditions can significantly reduce erosion rates.

Land cover (C) and soil conservation measures (P) also need to be considered. Clusters with low C and P values generally have higher erosion values. This suggests that lack of land cover and ineffective conservation measures can increase the potential for erosion. There are several erosion classes in the Arjasa Subwatershed, from very light to heavy. This uneven distribution of erosion classes indicates that there are areas that are highly vulnerable to erosion and require special handling. Areas with severe erosion classes need to be prioritized in erosion control efforts, because if left unchecked they can cause serious environmental damage.

Relationship of erosion to soil quality index based on cluster

Erosion is one of the influencing factors in soil quality degradation. Erosion is the process by which the fertile topsoil is eroded by water or wind, resulting in the loss of essential nutrients and organic matter important for plant growth. According to (Liu & Wu, 2022) showed that soil erosion directly affects soil quality with an adjusted R2 of 0.33. Soil quality degradation due to erosion is caused by poor land use practices and management. Through plot data analysis, (Winarso et al., 2020) also revealed that the soil quality index (SQI) decreases as soil erosion increases, according to the analysis in Arjasa Subwatershed figure 5 below.

Based on the graph of the relationship between erosion and soil quality in the Arjasa Sub-watershed based on the cluster. The graph shows an r value of 0.56 or the correlation between erosion and soil quality has a moderate level of relationship. The effect of erosion on soil quality in the Arjasa Subwatershed has a negative regression direction with a regression value of 0.31 or it can be said that the erosion factor has an influence of 31% on soil quality in the Arjasa Subwatershed. The graph above shows the relationship between erosion rate and soil quality. There is a tendency for soil quality to decrease as the erosion rate increases. This is indicated by the downward sloping regression line. The regression line equation obtained is $y = -0.0005x + 0.5884$. The coefficient of determination

(R^2) of 0.3138 and the correlation coefficient (r) of 0.56 indicate that there is a moderate negative relationship between the two variables.

The results of this analysis indicate that erosion has a significant impact on soil degradation. Erosion causes the loss of the topsoil layer which is rich in nutrients and organic matter, thus reducing the soil's ability to support plant growth. In addition, erosion can also damage soil structure, increase soil density and reduce the soil's ability to retain water. While there is a negative relationship between erosion and soil quality, it is important to remember that other factors can also affect soil quality. Factors such as soil type, climate, land use and soil management can modify the impact of erosion on soil quality. Therefore, it is important to conduct further analysis by considering these factors. To solve erosion problems and improve soil quality, comprehensive soil conservation efforts are needed.

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Conclusion

The soil quality indicators included in the MDS, in order of greatest contribution to the SQI, are Exchangeable Ca, percentage of sand, total N, soil porosity, and pH H_2O. The soil quality index ranges from 0.47 to 0.60 which is categorized as low to high, respectively. The soil quality index in the study area is influenced by soil type and slope, while land use has no effect. The level of erosion hazard in the study area is categorized in the class of very light (4.39 tons/ha/th) to heavy (184.81 tons/ha/th). There is a negative relationship at a moderate level (r = 0.56) between the level of erosion hazard and soil quality index, which indicates that the greater the erosion the lower the soil quality index. Since the soil erosion has negative impacts to the soil quality through reduction of productive soil layer, decreased soil nutrients, increased soil density, and changes in Soil pH.

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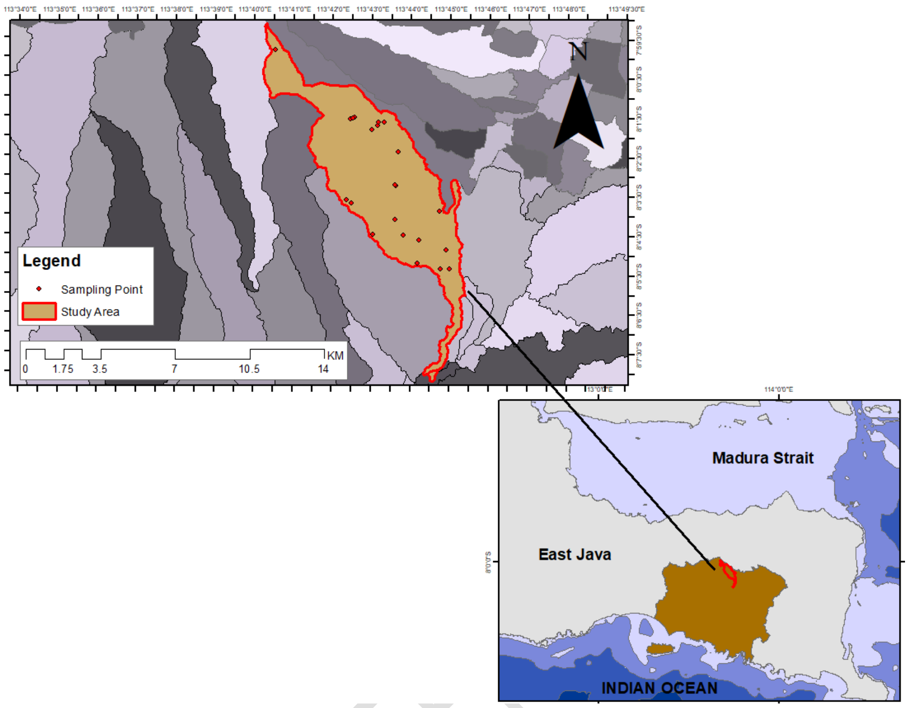

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Figure 1. Study area and locations of soil samples.

Table 1. Soil physical and chemical analysis methods

Parameter analysis	Unit	Method
Erodibility	-	USLE
% Sand	%	Method pipette
% Silt	%	Method pipette
% Clay	%	Method pipette
BV	$g.\,cm^{-3}$	Silinder method
BJP	$g.\,cm^{-3}$	Silinder method
Porosity	$g.\,cm^{-3}$	-
pH H_2O	-	pH meter H2O) (1; 2,5)
pH KCL	-	pH meter KcL (1; 2,5)
Available P	Ppm	Olsen
Exchangeable K	cmol±/kg	AAS, NH4OAC pH 7
Exchangeable Ca	cmol±/kg	AAS, NH4OAC pH 7
Exchangeable Na	cmol±/kg	AAS, NH4OAC pH 7
Exchangeable Mg	cmol±/kg	AAS, NH4OAC pH 7
CEC	cmol±/kg	AAS, NH4OAC pH 7
Organic C	%	Kurmis

Total N	cmol±/kg	Kjeldahl
Base Saturation	%	-
Hydraulic conductivity	μS/cm	EC

Table 2. Soil quality classification

Soil Quality	Scale	Class
Very High	0.80–1.00	1
High	0.60–0.79	2
Moderate	0.40–0.59	3
Low	0.20–0.39	4
Very Low	0.00–0.19	5

Table 3. Classification of erosion hazard levels

Soil Solum (cm)	**Erosion Hazard Class**				
	I	**II**	**III**	**IV**	**V**
	Erosion (Ton/Ha/Year)				
	<15	**15-60**	**60-180**	**180-480**	**>480**
Deep >90	SR 0	R I	S II	B III	SB IV
Medium 60-90	R I	S II	B III	SB IV	SB IV
Shallow 30-60	S II	B III	SB IV	SB IV	SB IV
Very shallow <30	B II	SB IV	SB IV	SB IV	SB IV

Notes: SR “Very light”, R “Light”, S “Medium”, B “Heavy” SB, “Very heavy”

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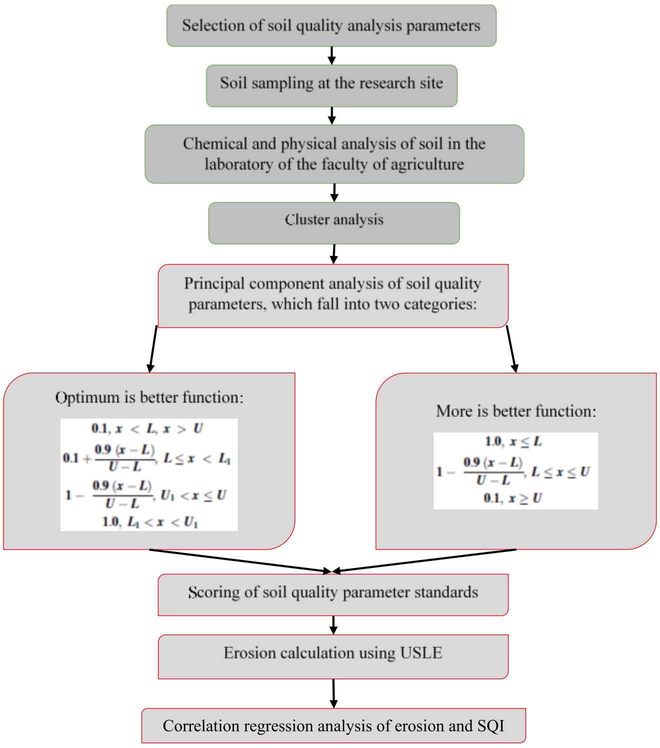

Figure 2 Research framework

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Tabel 4. Soil Characteristics of Arjasa Sub Watershed

Property	N	Std. Dev	Land use			Soil type			Slope			
			1	2	3	4	5	6	7	8	9	10
pH H_2O	30	0,20	$6,13^{a}$	$6,25^{a}$	$6,19^{a}$	$6,23^{a}$	$6,05^{a}$	$6,14^{a}$	$6,07^{a}$	$6,35^{b}$	$6,21^{ab}$	$6,20^{ab}$
Available P	30	8,04	$7,41^{a}$	$3,24^{a}$	$24,85^{b}$	$4,37^{a}$	$12,79^{a}$	$10,77^{a}$	$12,26^{b}$	$4,05^{ab}$	$2,29^{a}$	$8,79^{ab}$
Total N	30	0,76	$0,61^{a}$	$0,61^{b}$	$0,53^{b}$	$0,60^{a}$	$0,59^{a}$	$0,65^{a}$	$0,59^{a}$	$0,65^{a}$	$0,62^{a}$	$0,58^{a}$
Exchangeable Mg	30	0,14	$1,10^{a}$	$0,99^{ab}$	$1,17^{b}$	$1,01^{a}$	$1,17^{b}$	$1,14^{ab}$	$1,18^{b}$	$1,09^{b}$	$0,95^{a}$	$1,08^{ab}$
Exchangeable Ca	30	3,60	$2,50^{a}$	$2,18^{a}$	$2,64^{a}$	$2,16^{a}$	$2,78^{b}$	$2,91^{b}$	$2,74^{b}$	$2,65^{b}$	$2,07^{a}$	$2,38^{ab}$
Exchangeable K	30	1,18	$0,83^{a}$	$0,87^{a}$	$0,90^{a}$	$0,84^{ab}$	$0,78^{a}$	$0,99^{b}$	$0,81^{a}$	$1,00^{b}$	$0,80^{a}$	$0,89^{ab}$
Exchangeable Na	30	5,77	$2,77^{a}$	$4,49^{a}$	$2,21^{b}$	$3,89^{b}$	$2,25^{a}$	$3,23^{ab}$	$2,32^{a}$	$4,21^{b}$	$4,30^{b}$	$3,21^{ab}$
CEC	30	4,82	$22,64^{a}$	$19,16^{a}$	$22,50^{a}$	$19,47^{a}$	$24,47^{a}$	$24,79^{a}$	$23,40^{a}$	$24,19^{a}$	$18,58^{a}$	$21,29^{a}$
Base Saturation	30	7,47	$5,99^{a}$	$5,80^{a}$	$6,29^{a}$	$5,71^{a}$	$6,29^{a}$	$6,57^{a}$	$6,37^{a}$	$6,28^{a}$	$5,55^{a}$	$5,96^{a}$
Organic C	30	0,56	$0,07^{a}$	$0,12^{a}$	$0,10^{a}$	$0,08^{a}$	$0,02^{a}$	$0,28^{b}$	$0,03^{a}$	$0,28^{b}$	$0,09^{a}$	$0,10^{a}$
% Sand	30	80,06	$71,57^{a}$	$67,60^{a}$	$71,86^{a}$	$69,10^{a}$	$72,33^{a}$	$69,85^{a}$	$72,22^{a}$	$72,24^{a}$	$65,54^{a}$	$72,12^{a}$
% Silt	30	19,15	$10,21^{a}$	$12,43^{a}$	$11,24^{a}$	$11,35^{a}$	$11,13^{a}$	$11,36^{a}$	$10,86^{a}$	$9,01^{a}$	$12,84^{a}$	$10,60^{a}$
% Clay	30	1,23	$1,12^{a}$	$1,14^{a}$	$1,11^{a}$	$1,13^{a}$	$1,10^{a}$	$1,13^{a}$	$1,11^{a}$	$1,13^{a}$	$1,15^{a}$	$1,11^{a}$
BV	30	0,14	$1,05^{a}$	$1,25^{ab}$	$1,15^{b}$	$1,19^{a}$	$1,01^{b}$	$1,11^{ab}$	$1,03^{a}$	$1,22^{b}$	$1,21^{b}$	$1,14^{ab}$
BJP	30	0,73	$-1,36^{a}$	$-1,32^{a}$	$-1,51^{a}$	$-1,32^{a}$	$-1,55^{a}$	$-1,28^{a}$	$-1,55^{a}$	$-1,43^{a}$	$-1,28^{a}$	$-1,33^{a}$
Porosity	30	5,51	$3,54^{a}$	$2,25^{a}$	$2,92^{a}$	$2,68^{a}$	$3,51^{a}$	$3,23^{a}$	$3,31^{a}$	$2,31^{a}$	$2,67^{a}$	$3,06^{a}$
Hydraulic conductivity	30	0,47	$-0,27^{a}$	$-0,13^{a}$	$0,39^{a}$	$-0,18^{a}$	$-0,06^{a}$	$-0,18^{a}$	$-0,07^{a}$	$-0,11^{a}$	$-0,35^{a}$	$-0,03^{a}$

Description:
Letters on the same line indicate significant differences*
Land use:
1 “Dryland Agriculture”
2 “Forest Plantation”
3 “Dryland Mixed Farming”
Soil type:
4 “Andic Dystrudepts”
5 “Typic Eutrudepts”
6 “Typic Hapludands”
Slope:
7 “Flat”
8 “Very steep”
9 “Steep”
10 “Somewhat steep”

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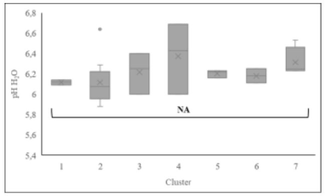
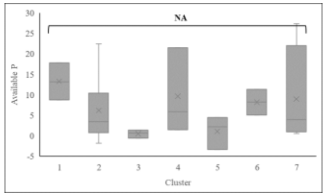
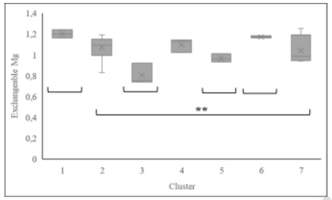


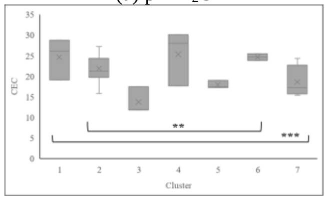
(a) pH H_2O



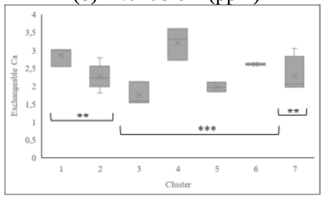
(b) Available P (ppm)



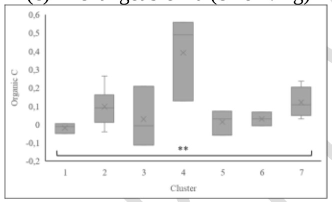
(c) Exchangeable Na (cmol+/Kg)



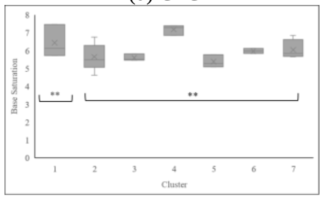
(d) CEC



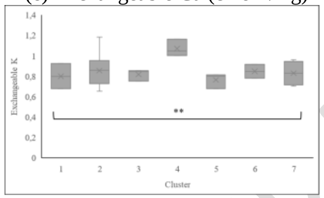
(e) Exchangeable Ca (cmol+/Kg)



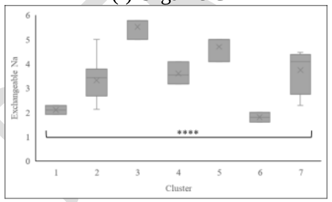
(f) Organic C



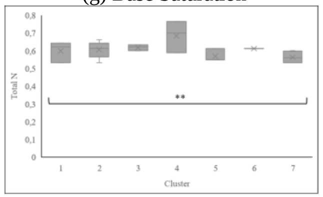
(g) Base Saturation



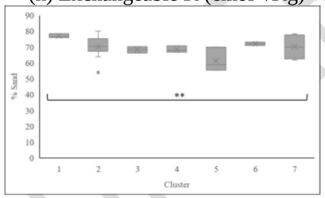
(h) Exchangeable K (cmol+/Kg)



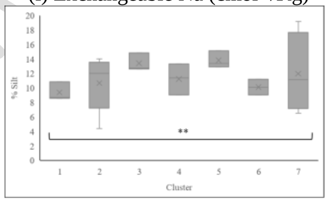
(i) Exchangeable Na (cmol+/Kg)



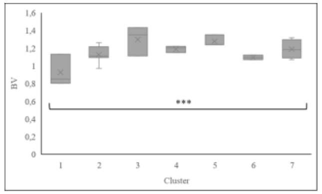
(j) Total N



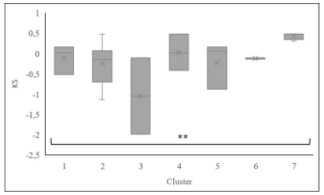
(k) % Sand



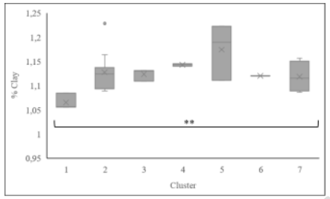
(l) % Silt



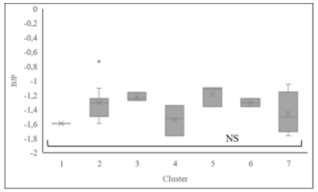
(m) BV



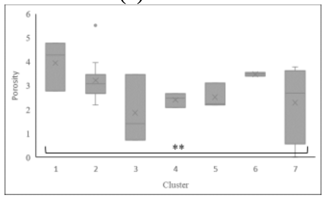
(n) KS



(o) % Clay



(p) BJP



(q) Porosity

Figure 3 Boxplot of Duncan variation in different cluster

Table 5. Analysis principal component analysis

Component Matrix[a]					
% of Variance	32,312596	15,964325	14,418758	9,5950782	8,0489048
Eigenvalue	0,4021998	0,1987104	0,1794725	0,1194314	0,1001859
	PC1	PC2	PC3	PC4	PC5
pH H_2O	-0,094	0,512	0,078	-0,001	**0,769**
Available P	0,684	0,032	-0,432	-0,222	-0,204
Exchangeable Mg	0,762	0,081	-0,373	0,201	-0,081
CEC	0,723	0,152	0,051	0,456	-0,176
Exchangeable Ca	**0,903**	0,344	0,044	-0,007	-0,073
Organic C	0,537	0,358	0,625	0,171	0,065
Base Saturation	0,710	0,274	0,082	-0,415	0,067
Exchangeable K	0,571	-0,060	0,547	-0,171	0,121

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Exchangeable Na	-0,603	-0,150	0,594	-0,251	0,087
Total N	0,199	0,236	**0,714**	0,361	-0,150
% Sand	0,555	**-0,759**	0,121	-0,174	0,199
% Silt	-0,477	0,607	-0,259	-0,156	-0,374
% Clay	-0,482	0,724	0,020	0,320	-0,045
Hydraulic conductivity	0,138	0,326	-0,520	0,016	0,586
BJP	-0,587	-0,352	0,010	0,501	0,087
Porosity	0,348	-0,398	-0,241	**0,636**	0,162

Extraction Method: Principal Component Analysis.
a. 5 components extracted.

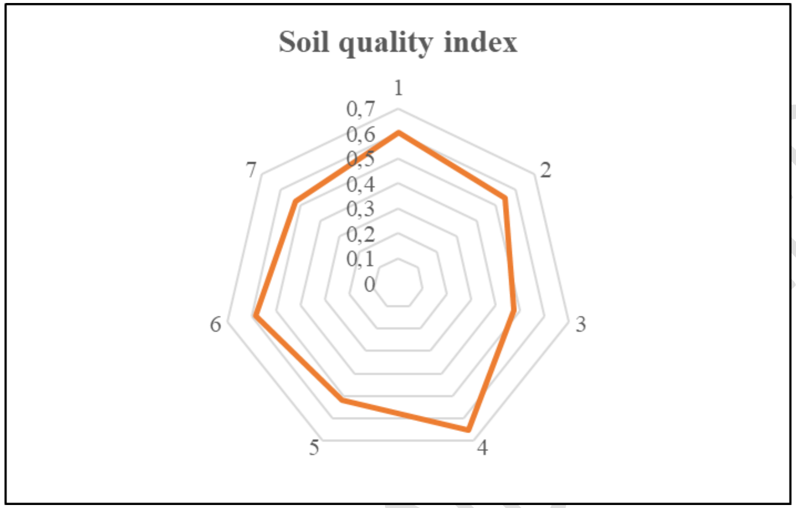

Figure 4. soil quality index

Table 6. Erosion hazard level of Arjasa Sub Watershed

Cluster	**R**	**K**	**LS**	**C**	**P**	**A**	**Solum**	**EHL**	**Class**
1	1617.72	0.32	0.4	0.53	0.04	4.39	>90	SR 0	Very light

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2	1617.72	0.27	3.1	0.64	0.04	34.66	>90	R I	Light
3	1617.72	0.28	6.8	0.6	0.1	184.81	>90	B III	Heavy
4	1617.72	0.25	9.5	0.1	0.1	38.42	60-90	S II	Medium
5	1617.72	0.28	6.8	0.1	0.15	46.20	>90	R I	Light
6	1617.72	0.24	3.1	0.4	0.15	72.22	>90	S II	Medium
7	1617.72	0.29	3.1	0.1	0.1	14.54	>90	SR 0	Very light

Note ; EHL “erosion hazard level”

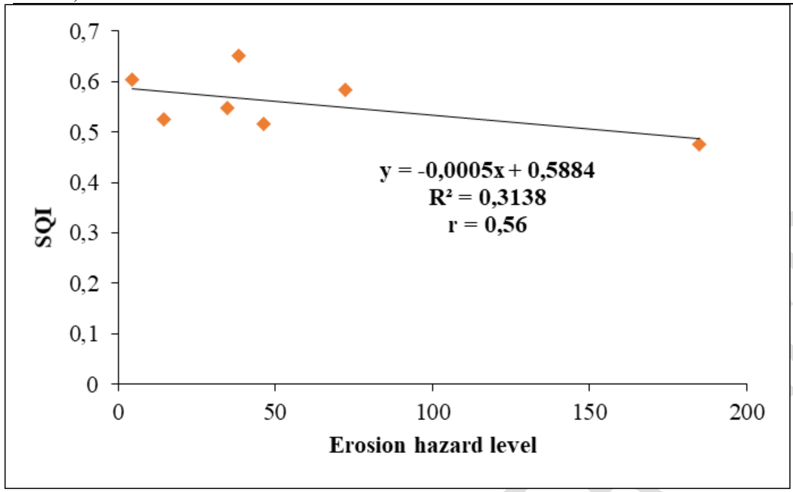

Figure 5. Chart relationship of erosion to soil quality index

UNDER PEER REVIEW