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Assessment of Factors Affecting Agricultural Soil Damage in the Upper Stream Sub-Watershed

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ABSTRACT

Soil damage can be caused naturally or by human activities. Potential areas that have high soil damage are sub-watershed areas and one of them is the Upper Serang Sub-watershed in Central Java. Assessment of potential and actual land damage will help to make wise land use planning. This research aims to assess actual and potential soil damage and the factors affecting the Upper Serang Sub-watershed. This research used descriptive quantitative and qualitative methods, where quantitative descriptive methods were used to assess soil damage and descriptive qualitative methods were used to determine farmer activity factors about soil conservation. The research result, that potential soil damage was included in the highly class soil damaged category with limiting factors are high rainfall of around > 2500 mm/year, slopes that exceed 25% (25-40% and >40%), soil type was dominated by Inceptisol soil and land use dominated by the moor. Meanwhile, actual soil damage has a slightly soil-damaged class with the limiting factors being permeability, redox potential, and the combined permeability and the soil fraction composition. Actual soil damage has a slightly soil-damaged class (RI) because farmers have taken soil conservation measures by mechanical methods dominant. Future efforts that farmers must do are to increase soil conservation measures with a combination of mechanical and biological conservation methods.

1. INTRODUCTIOIN

The watershed is one of the land areas that receive rainwater, holds it, and drains it through the main river into the sea or lake (Nilda, 2014). One of the watershed areas in Central Java Province is the Jratunseluna watershed. Jratunseluna consists of two main watersheds, namely the Jratun watershed (Jragung and Tuntang Rivers) and the Seluna watershed (Serang, Lusi, and Juana Rivers). The Seluna watershed, especially in the Serang sub-watershed area, is one of the priority watershed areas where according to previous research there are still areas that have suffered damage, especially in the upstream part (Suyana & Muliawati, 2014; Fatahilah, 2013). Watersheds by function have different uses in each region. The upstream part is based on a conservation function that is managed to maintain the environmental conditions of the watershed so that it does not degrade. The central part is based on the function of utilizing managed river water to provide benefits for social and economic interests. While the downstream part is based on the function of water utilization in economic and social terms for the sustainability of human activities (Lestari & Simanjuntak, 2022).

The upstream part of the Serang watershed is utilized for the use of agricultural land covering an area of 6801.29 Ha, with varied land use patterns including plantation, moor, lowland rice, and rainfed rice. Agricultural areas around the Upper Serang Sub-Watershed also experience a decrease in agricultural productivity every year, this is supported by data from BPS (2021a; 2021b) the results of agricultural productivity that have decreased, namely various vegetable crops such as chili with an average production yield of 269.02 quintal/ha, mustard plants with an average production of 7.49 quintal/ha, and cabbage plants with an average production of 269.02 quintal/ha, and there are various food crops such as corn with an average production of 74.39 quintal/ha and rice with an average production of 6.07 ton/ha. The decline in agricultural productivity is suspected to be caused by cultivation methods that do not apply conservation principles properly, and steep land slopes resulting in soil damage. This is supported by research by Suyana & Endang (2014) that the Upper Serang Sub Watershed still has land use mismatches that have the main inhibiting factors including steep slopes and erosion. This is as stated by Dariah *et al* (2015) that low soil quality due to high soil damage will affect crop productivity.

According to BPS (2021), Upper Serang Sub-Watershed is located in the administrative area of Boyolali Regency and Semarang Regency, Central Java Province. Based on the results of the Digital Elevation Model, the Upper Serang Sub-watershed is located at an elevation above sea level 130-2400 meters above sea level, with a slope between 8% to > 40% (DEMNAS, 2021). In general, the Upper Serang Sub-watershed is located on the slopes of Mount Merbabu so the physiography of the land varies from the highlands to the lowlands. The Upper Serang Sub-watershed has rainfall ranging from 2500-3500 mm/year with soil types including Alfisols, Histosols, and Inceptisols (BAPPEDA Jawa Tengah, 2021). Based on the condition of the land, the Upper Serang Sub-watershed has 5 classes of erosion potential, namely very light, light, moderate, heavy, and very heavy (Lestari & Simanjuntak, 2022).

Land use and management in a sub-watershed with conditions such as the Upper Serang Sub-watershed must be adjusted to the characteristics of the land so that no soil damage occurs. Land use must be by land capabilities, and land use that is inappropriate and not by land capabilities has the potential to cause soil damage (Mohawesh *et al*., 2015). Soil damage is the loss of soil function due to loss of nutrients, soil saturation with water, and erosion, where various human activities, be it agriculture, households, or industry, contribute to the decline in soil function (Arsyad, 2010). Meanwhile, Turner *et al*. (2016) mention soil damage caused by erosion, deforestation, soil compaction, soil acidity, salting, and desertification. However, agricultural activities contribute greatly to soil damage, both on land with high, medium, or low rainfall or in tropical, semi-arid, or arid regions (Cerda *et al*., 2009). Soil damage causes a decrease in soil quality which includes damage to the physical, chemical, and biological properties of the soil (Sasikarn & Suwit, 2018).

To prevent and control soil damage, it is necessary to identify land characteristics, assess potential and actual soil damage, and determine the causes of soil damage as a basis for prevention and control of soil damage. This is very important to do on agricultural land in the upstream sub-watershed which is on the slopes of mountains such as in the Upper Serang sub-watershed. Based on the background above, the purpose of the study is to assess soil damage on agricultural land and the determinants of soil damage in the Upper Serang Sub-watershed, Central Java.

2. MATERIALS AND METHODS

The research was carried out from May to December 2021 in the Upper Serang Sub-watershed, Semarang Regency, and Boyolali Regency, Central Java (Figure 1). Materials used include maps of soil types, rainfall maps, land use maps, slope maps, administrative maps, as well as a set of soil sample analysis materials in the laboratory. The tools used include stationery, GPS devices, shovels, trowels, label paper, tape measure, soil sample rings, and equipment for chemical, physical, and biological soil analysis in the laboratory.

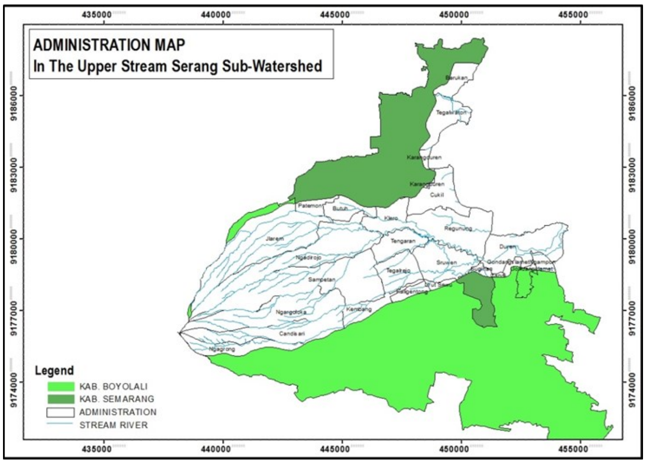

Figure 1. Upper Serang Sub-Watershed administration map

The study method is descriptive quantitative and qualitative, where Sugiyono (2013) states that the two methods are used to examine objects with data obtained in the form of numbers or attributes or information, which are then described in sentences.

Soil damage measurement is carried out on potential land damage and actual land damage. Before carrying out an actual soil damage assessment, a potential soil damage assessment is preceded by using soil type maps, land use maps, rainfall maps, and slope maps. Determination of potential soil damage was based on the guidance from the Ministry of Environment (Kementerian Negara Lingkungan Hidup, 2009) through the collection of quantitative soil data from measurements on 33 soil samples scattered throughout the Upper Serang Sub-Watershed with an area of 4102.71 ha (Figure 2).

The method for determining soil samples is determined independently and systematically based on the variation of potential soil damage, slope, land use, soil order, and rainfall. Measurement of soil samples consisted of measurements in the field for soil solum depth (cm) and surface rock cover (%), as well as measurements in the laboratory for soil fractional composition (%), bulk density (g/cm^3), total porosity (%), permeability (cm/h), pH (H_2O), electrical conductivity (mS/cm), redox (mV), total soil microbes (CFU/g soil). Quantitative data from soil samples are used to assess actual soil damage according to the guidance from the Ministry of Environment (Kementerian

Negara Lingkungan Hidup, 2009). Qualitative data were obtained from interviews with 12 farmers as informants to find out information on cultivation and conservation actions that have been carried out by farmers.

Watershed areas are usually quite large and complex, so soil damage analysis will be effective if done with geographic information systems (Halengkara *et al*., 2012). Therefore, this study utilized ArcGIS 10.4 which was used to create maps and calculate the extent and percentage of potential and actual soil damage. The stages of this research are shown in Figure 3.

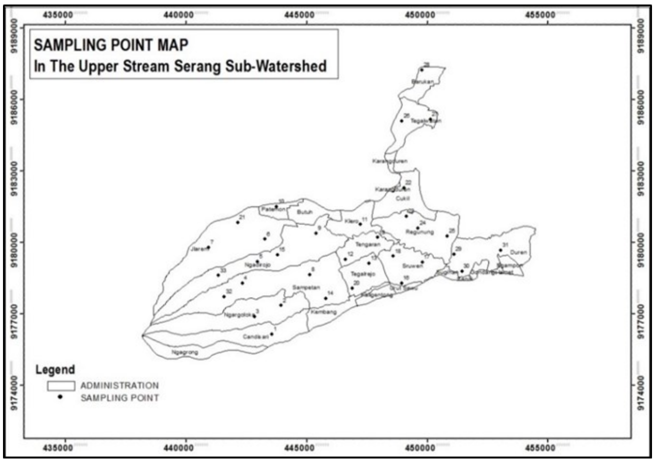

Figure 2. Sample points for the measurement of actual soil damage in the Upper Serang Sub-watershed

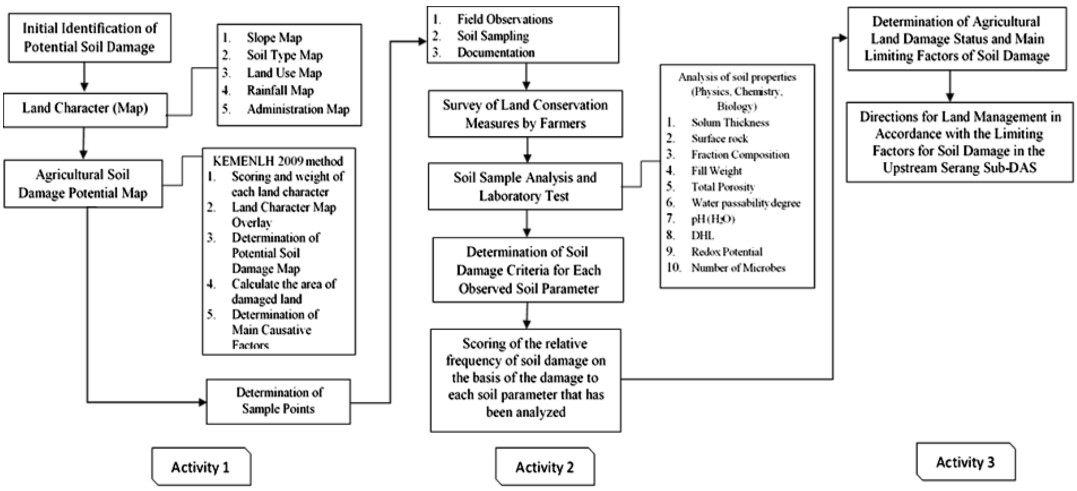

Figure 3. Work stages of agricultural soil damage study

3. RESULTS AND DISCUSSION

3.1. Potential Soil Damage in the Upper Serang Sub-watershed

Potential soil damage is indicative damage based on soil type, slope, rainfall, and land use which is assessed by giving a score and weight based on the strong influence on soil damage (Kementerian Negara Lingkungan Hidup, 2009). The condition of soil type, rainfall, slope and land use in the Upper Serang sub-watershed can be seen in Figure 4. The results of Surya & Fahrunsyah (2022) show that rainfall intensity, slope, soil type, and land use are the most important factors affecting soil damage. Based on the type of soil, slope, rainfall, and land use, the Upper Serang Sub-watershed has a potential class of soil damage which includes Low Damage Potential (PR. II) with an area of 279.91 ha or 4.12% of the area of the Upper Serang Sub-watershed, Moderate Damage Potential (PR. III) with an area of 4377.18 ha or 64.36% of the area of the Upstream Serang Sub-watershed, and High Damage Potential (PR. IV) with an area of 2144.20ha or 31.53% of the area of the Upper Serang Sub-watershed, Upper Serang Watershed (Figure 5).

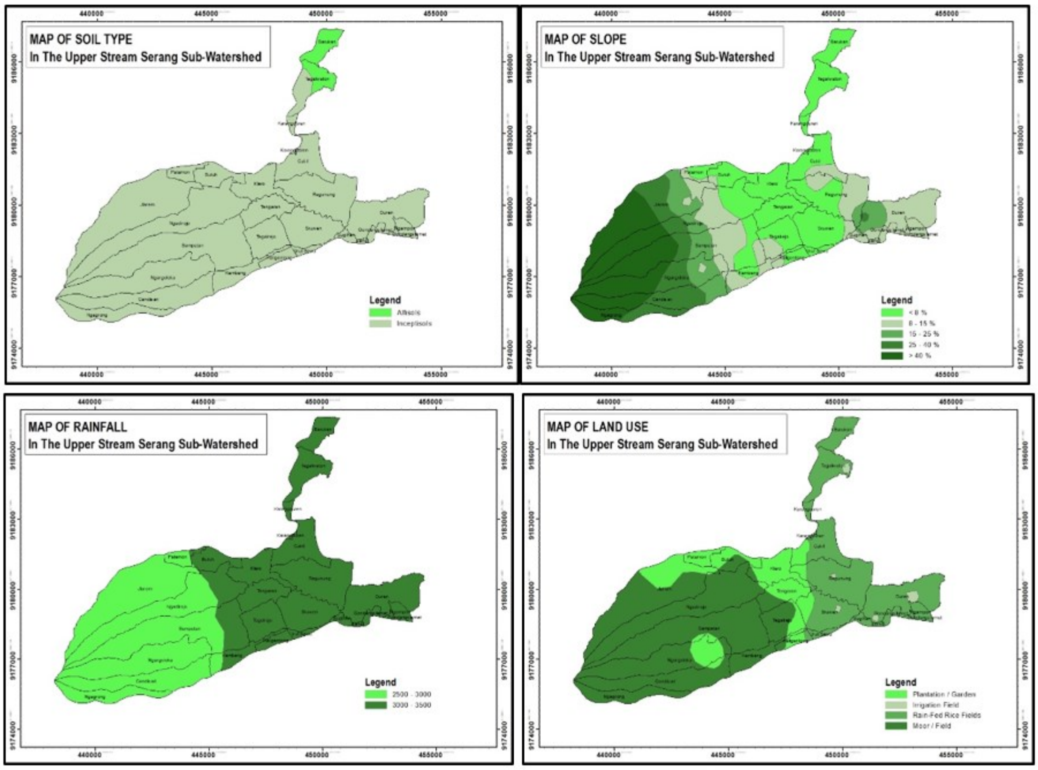

Figure 4. Map of soil type, slope, rainfall and land use in the Upper Serang Sub-watershed

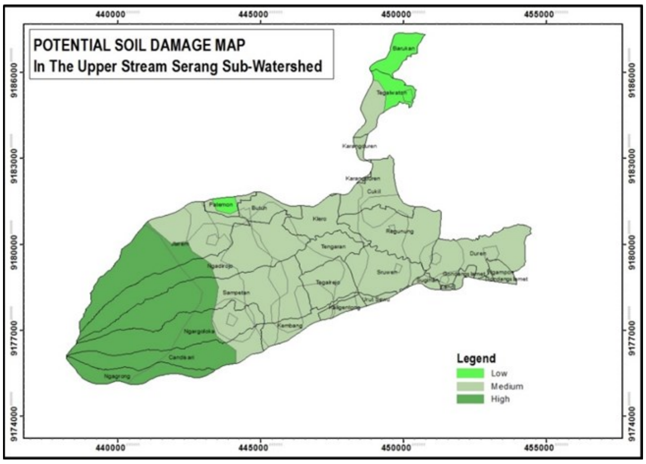

Figure 5. Map of potential soil damage on Upper Serang Sub-watershed

Table 1. Potential Soil Damage in the Upper Serang Sub-watershed

Class	Potential Soil Damage Weight score	Area (Ha)	%	Soil order	Land use type	Slope (%)	Rainfall mm/y
High	37 – 40	2144.20	31.53	Inceptisols	Moor	25 – 40; >40	2500 – 3000
Medium	35 – 34	4377. 18	64.36	Inceptisols	Lowland rice; Rainfed rice; Plantation; Moor	< 8; 8 – 15; 15 – 25; 25 – 40	2500 – 3500
Low	23 – 24	279.91	4.12	Alfisols; Inceptisols	Lowland rice; Moor	< 8%	2500 – 3500

Based on the category of potential soil damage, the Upper Serang Sub-watershed has areas with a high level of potential damage of around 31.53% of the total land area caused by several factors, namely relatively high rainfall with an average of > 2500 mm per year, steep slopes more than 25% (25-40% and >40%), the soil type is dominated by Inceptisol soil, and predominantly used as moorland (Table 1). The slope will determine the level of soil damage and crop productivity. Even in perennials such as rubber, crop production is not only determined by the altitude, but also by the level of slope (Andrian *et al*., 2014).

As stated by Valentiah *et al*. (2015) that the soil type factor will determine the magnitude of the potential for soil damage, whereas Inceptisols soil is soil that is prone to erosion. Due to its characteristic of having a low clay content; rather a thick solum depth; pH 5.0 – 7.0; Inceptisols are also classified as moderately weathered and leached soils (Kateren *et al*., 2014). Reza *et al*. (2021) stated that Inceptisols are resistant to soil damage. On the other hand, the high potential for soil damage is also influenced by the rainfall factor, which according to the classification from the Ministry of Environment (Kementerian Negara Lingkungan Hidup, 2009) in areas with rainfall of 2500 – 3000 mm/year is classified as moderate class rainfall.

Moderate rainfall has been able to destroy soil aggregates and cause surface runoff. According to Rajiman (2014) that if rainwater falls directly on the soil surface it will experience infiltration, if the soil aggregates are destroyed due to the energy of rainwater blows, the fine particles of the soil will clog the soil pores so that potential runoff occurs which can cause erosion. This is reinforced by the statement of Reza *et al*. (2021) that rainfall of 2500–3000 mm/year makes the soil sensitive to soil damage. Coupled with the slope factor can also affect the high potential for soil damage. This is because the slope > 25% according to the classification of the Ministry of Environment (Kementerian Negara Lingkungan Hidup, 2009) is classified as high to very high. According to Syahidah *et al*. (2016) that the magnitude of the slope level will cause a large level of erosion and the ability of the soil to store rainwater is low, so it can have a high potential value for soil damage. It is also influenced by land use which is dominated by field/moorland, with seasonal crop cultivation, and incentive land use so that it can cause the soil to become more easily degraded by soil erosion. Such conditions will make dry land or fields have a high potential value of soil damage (Nugroho & Setiawan, 2015). Potential soil damage is indicative of soil damage, therefore it is necessary to carry out field measurements to determine actual soil damage. According to Abdulkarim *et al*. (2015) to prove potential soil damage, field verification is needed to determine actual soil damage.

3.2. Actual Soil Damage in Upper Serang Sub-watershed

As stated by Mentis (2020) that land damage needs to be measured continuously in the field and reported so that the actual soil damage will be known and how to repair it. Actual soil damage is soil damage that is assessed based on the results of soil analysis on the chemist, physical, and biological soil which was compared with data parameter criteria for soil damage, and then has been calculated for weight score values and produces relative frequency values which can be used as scoring determinations for determining the status of land damage (Kementerian Negara Lingkungan Hidup, 2009; Abdulkarim et al., 2015). The determination of the actual land damage can be seen in Table 2. The mapping results for the status distribution of actual soil damage classes can be seen in Figure 6.

Table 2. Standard criteria soil damage and actual soil damage status in the Upper Serang Sub-watershed

Soil Degradation Standard Criteria *			Average range of soil chemical, physical and biological measurements from 33 samples	Relative Frequency of Soil Damage	
Soil Parameters	Symbol	Critical Threshold		%	Score
Solum thickness	*s*	< 20 cm	75 cm to 200 cm	0	0
Surface rock	*b*	> 40 %	2 % to 35 %	0	0
Fraction composition	*f*	< 18% colloid; > 80% quartz sand	13 % to 64 % colloids; 11.30 % to 74.38 % quartz sand	15	1
Soil bulk density	*D*	> 1,4 g/cm³	0.8 g/cm³ to 1.3 g/cm³	0	0
Total porosity	*v*	< 30%; > 70%	47.74 % to 69.34 %	0	0
Permeability	*p*	< 0.7 cm/h; > 8.0 cm/h	2.04 cm/h to 226.03 cm/h	88	4
pH (H_2O) 1 : 2.5	*a*	< 4.5 ; > 8.5	5.08 to 6.77	0	0
Electrical conductivity	*c*	> 4.0 mS/cm	0.041 mS/cm to 0.370 mS/cm	0	0
Redox potential	*r*	< 200 mV	190 mV to 224 mV	12	1
Number of microbes	*m*	< 10^2 CFU/g soil	$2.31(10^6)$ to $9.01(10^6)$	0	0
			Total score		6
			Actual soil damage status		Light
			Symbol		R.I-f,p,r

* Soil Degradation Standard Criteria by Kementerian Negara Lingkungan Hidup (2009)

Based on Table 2, shows that the actual soil damage in the Upper Serang Sub-watershed is in the status of lightly damaged (R.I) with 3 limiting factors causing soil damage, namely fractional composition, degree of water permeability, and redox potential. In more detail, the spatial analysis of the limiting factors that cause actual soil damage listed in Table 3 and Figure 6, shows that the actual soil damage in the slightly damaged category is due to the limiting factor for the degree of water permeability (R.I-p) with an area of 2802.04 ha or 53. 97% of the area of the Upper Serang Sub-watershed, the lightly damaged category was caused by redox potential limiting factors (R.I-r) with an area of 1819.26 ha or 35.03% of the area of the Upper Serang Sub-watershed, the lightly damaged category was caused by a combination of limiting factors from permeability and composition of the fraction (R.I-p, f) with an area of 571.43 ha or 11% of the area of the Upper Serang Sub-watershed.

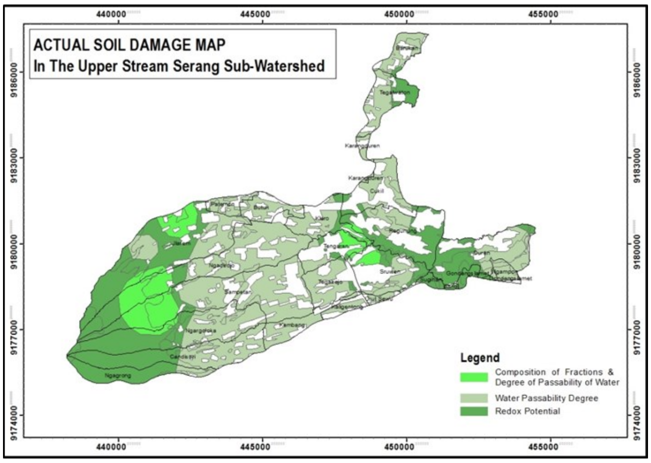

Figure 6. Map of actual soil damage in the Upper Serang Sub-watershed

Condition on the water permeability factor was based on the actual soil damage map (Figure 6) that the area distribution is dominant in the central part of the Upper Serang Sub-watershed with land use including plantation land, and moor. This shows that the permeability was influenced by the soil type factor which is dominated by Inceptisol soil types with soil textures dominated by a sand fraction of around 11.30% to 74.38% quartz sand and has an impact on a high total pore space value of about 47.74 % to 69.34 %. The high sand fraction and total porosity can affect the soil's ability to pass water very quickly. This condition has an impact on the permeability of dominant high analysis value around 11.51 cm/hour to 226.03 cm/hour which has exceeded the critical threshold of around > 8.0 cm/h (Arisandi et al., 2015; Zaffar & Lu, 2015).

Table 3. Status and limiting factors of actual soil damage in the Upper Serang Sub-Watershed

No	Symbol	Actual Soil Damage Status	Main Limiting Factors	Information	Area	
					ha	%
1.	R.I – p	Light Damage	Permeability	Water speed is very fast	2802.04	53,97
2.	R.I – r	Light Damage	Redox Potential	The redox content is below a critical threshold	1819.26	35,03
3.	R.I – f, p	Light Damage	Fractions composition & Permeability	The speed of the water is very fast plus the low soil colloid content	571.43	11
		Total Area (ha)			6801,29	100

Source: Spatial analysis of actual land damage status

The potential redox factors based on the actual soil damage map (Figure 6) are dominantly distributed in the lower part of the Upper Serang Sub-watershed with land uses that include lowland rice and rainfed rice. This shows that the redox potential factor is influenced by the presence of soil texture dominated by the colloid fraction of soil around 20% to 64%, and the rainfall is relatively high around 3000-3500 mm/year, and is characterized by a low permeability around 2.09 cm/h to 7.79 cm/hour indicates that the slow water velocity infiltration which has an impact on soil aeration has decreased. The condition of the clay fraction and rainfall affect the results of the analysis of the redox potential to be low with a value of around 190-196 mV below the critical threshold value for soil damage around <200 mV (Kementerian Negara Lingkungan Hidup, 2009).

The permeability and the composition of the fractions are based on the actual soil damage map (Figure 6), that the distribution of the area is dominant in the upper part of the Upper Serang Sub-Watershed with land use utilization including moor and plantation. The permeability and the composition of the fractions are influenced by several factors including the soil type which was dominated by Inceptisol with the soil texture being dominated by the sand fraction of around 11.30% to 74.38% quartz sand, %, and rainfall belonging to a height of about 2500-3000 mm/year, and characterized by a relatively high total pore space value of around 47.74% to 69.34%. The high sand fraction and total pore space can affect the soil's ability to pass water very quickly. This condition has an impact on the permeability of high dominant water around 11.51 cm/hour to 226.03 cm/hour which has exceeded the critical threshold of around > 8.0 cm/hour. On the other hand, the analysis of the soil colloid fraction is classified as low, ranging from 13% to 17% below the critical threshold value for soil damage of around <18% (Kementerian Negara Lingkungan Hidup, 2009).

3.3. Soil Conservation Measures by Farmers

According to the Central Statistics Agency for Sub-districts figures (2021) land use in the Upper Serang Sub-DAS is mostly used as a moor, which is around 56.10%, and there are still many residents who work in the agricultural sector.

Table 4 shows that farmers in the Upper Serang Sub-watershed have taken conservation measures, so the form of soil damage that exists depends on the type of land use. Land use for moor is carried out using mechanical and biological-vegetative conservation methods such as terracing, bed terraces, mulching, and intercropping planting or agroforestry models. Meanwhile, for lowland rice and plantation, the dominant conservation action is mechanically by making terraces, but for rainfed rice was combined with biological-vegetative conservation by making terraces and crop rotation.

Table 4. Farmer Activities in the Upper Serang Sub-Watershed on Land Management

Land Use	Agricultural System	Plant Type	Conservation
Moor	Intercropping	Tobacco, Chili, and Vegetable plants	Terraces, terraces mounds and mulch
Plantation	Multiple Cropping, Agroforestry	Coffee, Spices crop, Cassava, Tea, Coconut trees, and other annual crops	Terassering
Lowland rice	Monoculture	Rice	Terassering
Rainfed Rice	Crop Rotation	Rice, Various beans, Cassava	Crop rotation

Source: Result of primary analysis of conservation action survey data by farmers

3.4. Directions for Land Management in the Upper Serang Sub-Watershed

Land in the Upper Serang Sub-watershed has a high class for potential soil damage. Therefore farmers in the Upper Serang Sub-watershed have taken conservation measures to minimise soil damage as shown in Table 4. The efforts of soil conservation measures by the farmers show that the actual soil damage has a light class. Therefore, the direction of land management is done by maintaining the land so that the class of soil damage does not increase.

Future efforts that farmers must do are to increase soil conservation measures with a combination of mechanical and biological conservation methods. Therefore, terracing can be combined with land tillage according to contours, mound terraces, and bench terraces for plantations. It is necessary to seek the use of cover crops, mulch, the addition of organic materials such as manure, green manure, and the use of biochar. The application of biochar which is currently often used as a soil conditioner in dry land will greatly assist in maintaining good soil conditions (Hartatik *et al*., 2015; Nurida, 2014; Widowati & Sutoyo, 2012).

4. CONCLUSION

Assessment of soil damage status in the Upper Serang Sub-watershed was carried out in potential and actual soil damage. The potential soil damage was included in the highly class soil damaged category with limiting factors are high rainfall of around > 2500 mm/year, slopes that exceed 25% (25-40% and >40%), soil type was dominated by Inceptisol soil and land use dominated by the moor. Meanwhile, actual soil damage has a slightly soil-damaged class (RI) with the limiting factors being permeability (R.I-p), redox potential (R.I-r), and the combined permeability and the soil fraction composition (R.I-p,f). Actual soil damage has slightly soil damaged class (RI) because farmers have taken soil conservation measures by mechanical methods dominant. Future efforts that farmers must do are to increase soil conservation measures with a combination of mechanical and biological conservation methods.

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