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RESEARCH ARTICLE

Land Degradation Assessment Model Using Field Assessment And RUSLE Methods In Wai Ruhu Watershed, Ambon Island, Mollucas Province

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Abstract. Land degradation due to erosion is a serious threat to land sustainability of small tropical islands in Maluku, Indonesia. The current research was carried out in the Wai Ruhu Watershed, Ambon Island, Maluku; it was a part of studies conducted in Maluku in order to develop a suitable land degradation assessment model based on local conditions. Soil loss as the indicator of land degradation were determined using Stocking's field assessment and RUSLE methods. The study found that land degradation rates in the study area using field indicators ranged from the lowest soil loss 4.40–19.15t/ha/yr to the highest 202.84-675.62t/ha/yr, while the RUSLE method ranged from 0.11-16.92t/ha/yr to the highest 287.63-4207.41t/ha/yr. The developed land degradation model (LD) due to erosion LD = $0.1499xR^{1.000}\,xK^{0.0026}xLS^{0.0933}xC^{0.133}xP^{1.000}xBd^{0.700}xAv^{-0.652}$ is statistically significant because their p-values equal 0.000 with high R^2 of 82,5% at a confidence level of 95%. The second model was also produced with a correction factor of 0.2158, so LD = 0,2158xRxKxLSxCxP, where LD= land degradation (tons/ha/yr), R = rain erosivity value (ton.m/ha/cm-rain), K= soil erodibility index, LS= slope length and steepness factor index, C= plant or vegetation or land use factor index, P= soil conservation practices factor index, Bd= soil bulk weight factor (g/cm3), and Av= vegetation/plant or land use stage factor (years). These results promote the importance fact that the Stocking's land degradation field assessment indicators could be considered as a suitable land degradation assessment model for the specific local condition of small islands in Maluku.

1. Introduction

Today's rapid world population growth has increased population pressure on land and created various environmental problems leading to land degradation. The impact of population growth on the environment has been long recognized mostly through the over utilization of natural resources, deforestation and forest conversion, land use changes, agricultural activities, and overgrazing, and they can lead to land deterioration (AbdelRahman, 2023). However, extreme weathers are also considered as the natural cause of land degradation as they are related to soil degradation (Hermans & McLeman, 2021). The complexity of land degradation is defined differently from one region to another depending on the source of land degradation (Erlewein & Hecheltjen, 2018).

Land degradation is also a very complex phenomenon because it involves a series of bio-physical and socio-economic processes and some of them occur at different spatial, temporal, economic and cultural scales (Peprah, 2015). In developing countries, land degradation has become a major concern because it has been linked to environmental problems (Erlewein & Hecheltjen, 2018), food security and agricultural land productivity (Peprah, 2015), and poverty (Barbier & Hochard, 2016). According to (UNCCD & The Ministry of Environment and Forestry , 2015) land degradation does not only include soil degradation, but also degradation of vegetation, forests, agricultural land, water resources, and degradation of a nation's biodiversity. In Indonesia, soil erosion has been considered as one of the main and most widespread forms of land degradation as a result of land use changes and human activities (Sitorus & Pravitasari, 2017; UNCCD & The Ministry of Environment and Forestry, 2015). The latest report from (UNCCD & The Ministry of Environment and Forestry , 2015), states that degraded land in Indonesia reached 24.3 million ha in 2013, and this was mainly caused by soil erosion due to inappropriate land use and no soil conservation practices.

To address soil erosion as a major driver of land degradation, various erosion prediction models have been developed and applied worldwide. These models range from empirical approaches to physically based models, designed to estimate soil loss under different environmental and land management conditions. Empirical models, such as the Universal Soil Loss Equation (USLE) and its revised versions, have been widely used due to their simplicity, relatively low data requirements, and adaptability to diverse spatial scales. Among available erosion prediction models, the Revised Universal Soil Loss Equation (RUSLE) has remained one of the most widely applied tools for assessing soil erosion, particularly in developing countries and tropical regions. RUSLE integrates key factors influencing erosion, including rainfall erosivity, soil erodibility, topography, land cover, and conservation practices, making it suitable for spatial analysis when combined with Geographic Information Systems (GIS). The integration of RUSLE with field-based assessment has been increasingly adopted to improve model reliability and to better represent local environmental conditions. This approach allows erosion modeling to support land degradation assessment and watershed management, especially in areas where detailed process-based data are limited. According to Sahar (2025) that integrated RUSLE-GIS is very important for enhancing soil erosion management in Ghamima River Basin, because these results can be relied upon to support decision-makers in taking measures to mitigate the negative effects of soil erosion risk and designing soil protection strategies to prevent acceleration of erosion in high and very high-risk areas. So also, according to Enya, Obalum & Igwe, (2024) amongst all other soil erosion prediction tools, the RUSLE model is dependable and reliable in the tropics especially now that it combines with remote sensing (RS), digital elevation model (DEM) and geographical information system (GIS) to estimate annual soil loss (on a pixel-bypixel basis) and spatial distribution of the soil erosion.

The widespread degraded land in Maluku is related to deforestation activities in the past, and land conversion from natural forests to agricultural and plantation areas, and the rapid expansion of agricultural and residential areas in hilly areas. The impact of these human activities has resulted in higher soil erosion and lower soil quality to support agricultural development in Ambon and Seram Islands, and also lower environmental quality of watersheds as indicated by flooding and sedimentation during the rainy season, and water shortages in the dry season (Osok, Talakua, & Supriadi, 2018); (Talakua & Osok, 2019); (Talakua, Osok, & Talakua, 2024). Wai Ruhu Watershed in Ambon Island, Maluku Province was selected as the study area, because it plays a very important role as drinking water supply for Ambon City, and providing land for agriculture, plantations, settlements, livestock and forestry. The population growth by 2-4% per year and rapid land use conversion from forest to residential areas and public facilities, to agricultural land and high exploitation of natural resources have increased the pressure on land in the Wai Ruhu watershed as indicated by the increasing of erosion, floods and sedimentation in the rainy season (Tutuarima, Talakua, & Osok, 2021).

Many different methodologies have been used to study soil erosion and land degradation such as field measurements, mathematical models, remote sensing, environmental indicators, including the use of simple models based on indicators that synthesize complex processes. Empirical soil erosion models, such as the Universal Soil Loss Equation (USLE) and Revised-USLE (RUSLE) have been applied throughout the world to assess soil loss by water (Pham, Degener, & Kappas, 2018); (Benavidez, Jackson, Maxwell, & Norton, 2018). These methods are generally still used by various government agencies for predicting soil erosion based on their local condition. In Indonesia, USLE and RUSLE methods have been used largely to predict soil loss from medium to large watersheds (Purwaamijaya, 2018); (Saptari, Supriadi , Wikantika, & Darmawan , 2015). A number of soils erosion studies at small-scale watershed (<10 km^2) using field assessment indicators coupled with the RUSLE model and GIS technique have been carried out in small islands of Maluku such as Ambon and Seram Islands (Talakua & Osok, 2018); (Talakua & Osok, 2019); (Talakua, Osok, & Talakua, 2024). These studies indicated high rates of land degradation due to high erosion, and the causes of soil erosion are high values of rain erosivity and soil erodibility, steep to very steep slope steepness, and land use types mainly residential and bushes areas, empty and marginal land, and areas without soil conservation practices. These studies also found that density of the upper and lower vegetation have a significant effect on the levels of land degradation. However, both the USLE and RUSLE methods only predict soil loss and do not show actual land degradation phenomena in the field. On the other hand, field assessment method by Stocking and Murnaghan (Talakua, 2016) has the advantage because it is able to determine land degradation both qualitatively and quantitatively based on actual land degradation indicators in the field, such as pedestals and plant/tree roots exposures, subsoil of the foundation structure exposure, the occurrence of rills and gullies erosion.

The objective of this study is to develop and apply a land degradation assessment model that integrates field-based assessment indicators with the Revised Universal Soil Loss Equation (RUSLE) to improve the accuracy of land degradation evaluation under the biophysical conditions of the Maluku Islands. Specifically, this study aims to model spatial patterns of land degradation by combining RUSLE erosion factors—rainfall erosivity, soil erodibility, topography, land use, and soil conservation practices with field-measured indicators, including soil bulk density and vegetation or land-use age, and to identify priority areas for land degradation control to support sustainable watershed management.

2. Methods

The study was carried out in the Wai Ruhu watershed Ambon Island, Maluku Province, Indonesia (Figure 1). The materials used in this research were 28 years of rainfall data (1989-2018) from Ambon city (BMKG, 2018), SRTM/DEM map Ambon Island (BIG, 2018), Topographic Map of Indonesia, Ambon sheet (BIG, 2018), geological map Ambon sheet (DJGSM, 1994), soil map of Wai Ruhu Watershed (Palawa, 2011), land use map of Ambon Island (BPKH Region IX Ambon, 2018). The study employed two approaches to assess land degradation: field-based indicators included pedestals, exposed roots and foundations, rills, gullies, and vegetation age (Stocking and Murnaghan, 2000) and RUSLE-based erosion prediction factors (Renard *et al.*, 1997; Meng, Cao, & Wang, 2021), including rain erosivity (R), soil erodibility (K), slope length and steepness (LS), actual vegetation/land cover (C) and soil conservation practices (P) were measured in all land units.

Field data collection, including field indicators assessment, erosion factors, and soil sampling, was conducted at a land unit scale of 1:22,500. A total of 79 land units were delineated through the overlay of four watershed characteristics—topography, geology, soil types, and land use using ArcGIS 10.8. The presence of land degradation field indicators was measured in all land units based on the Stocking and Murnaghan's method. Each indicator found was then measured 20 times according to the field measurement format. At the same time, land degradation prediction factors of the RUSLE method were measured in all land units. Five soil types were mapped in the study area, namely Typic Udipsamments, Typic Udifluvents, Typic Hapludalfs, Lithic Udorthents, and Typic Dystrudepts. These soil units formed the basis for soil erodibility assessment using the Revised Universal Soil Loss Equation (RUSLE) framework. A total of

65 disturbed soil samples were collected based on land unit delineation to quantify soil bulk density as an indicator of land degradation. For the estimation of the RUSLE soil erodibility (K) factor, ten paired disturbed and undisturbed soil samples were collected from the five soil types. Undisturbed samples were obtained using ring samplers at depths of 0–20 cm (upper layer) and 20–40 cm (lower layer). These samples were used to determine soil bulk density and soil permeability, which reflect soil structure and infiltration capacity. Disturbed soil samples were collected from the same depths and locations as the undisturbed samples and were analyzed in the laboratory for soil texture components, including total sand, very fine sand, silt, and clay, as well as soil organic carbon content. These parameters constitute the primary inputs for calculating the K factor.

Land degradation due to erosion variables were spatially analyzed using ArcGIS-10.8 software, using the RUSLE prediction method, A = R x K x LS x C x P; where A = the amount of erosion in each land unit (t/ha/yr), R = rain erosivity factor, K = soil erodibility factor, LS = length and slope steepness factors, C = vegetation cover/land use factor, P = erosion control practices factor (Renard *et al*., 1997; Meng, Cao & Wang, 2021). The rainfall erosivity factor was estimated using the Lenvain equation, R = 2.21 (P)^1.36, where P = average monthly rainfall (cm). Soil erodibility factor was calculated using K formula, K = [2.1(10-4) (12 - OM) M1,14 + 3.25 (s - 2) + 2.5 (p - 3)] / 100, where M = (% dust + % very fine sand) x (100 - % clay), a = organic matter content (%), b = the soil structure class, c = the permeability class (cm/hour) (Naharuddin, Malik & Ahyauddin, 2021). The slope length and steepness factors (LS) were generated from the SRTM/DEM map using geographic information system (GIS), and LS values were determined based on slope classes as follows: slope 0-8% = 0,25, slope 8-15% = 1,20, slope 15-25% = 4.25, slope 25-45% = 9.50, and slope >45% = 12.00 (Fadhilla, Kusumandari & Senawi, 2021). The value of the vegetation factor (C) was determined based on the land use map combined with the C factor value table (Arsyad et al., 2021). The amount of soil loss (tons/ha/yr) for each indicator found in the land units was calculated by formula of Stocking and Murnaghan's method, and by the RUSLE model, A=RxKxLSxCxP (ton/ha/yr). The level of land degradation due to erosion was classified according to the FAO criteria (very low to low = 0-20tons/ha/yr; moderate = 20-50tons/ha/yr; high = 50-200tons/ha/yr; very high = > 200tons/ha/yr (Ayalew & Sellasie, 2015).

Before continuing with the model developing test process, first, the classical assumption test (pre-analysis Test) including normality, linearity, heteroscedasticity, multicollinearity and autocorrelation tests was conducted to know whether the model is good and applicable or not. If the residual error is normally distributed, there exists a linear relationship between the independent and the dependent variables, with homogeneous variance, and no multicollinearity between the independent variables, or no linear relationship between the independent variables, and no autocorrelation between the residuals error of the independent and the dependent variables. The next step is to prove that the land degradation data based on the field assessment method and predictions using the RUSLE method for each land unit in the Wai Ruhu watershed are completely different using different test analysis Paired Sample T-test (Kang & Sharma, 2024), with the basic T test formula , thit = [(X-μ)/(S/√n)], where thit = calculated t value, sample (number of observation points). If the probability value or sig (2-tailed) < α = 0.05, then there is a significant difference between the two groups of data.

The land degradation model development test was carried out using multiple linear and non-linear regression-correlation analysis (Sarkar & Mishra, 2018), with the basic model Yi = βo+β1X1i+β2X2i+β3X3i+β4X4i+β5X5i+β6X6i+β7X7i+ εi, where Yi=amount of land degradation resulting from field indicator measurements using the method of field assessment; βo=intercept coefficient; vegetation/plants; β1-β7= regression coefficient for factors X1-X7; εi=error. All data were analyzed using MS Office 2007, SPSS20 and Minitab16 programs (Purwanto, Asbari, Santoso, Sunarsi, & Ilham, 2021).

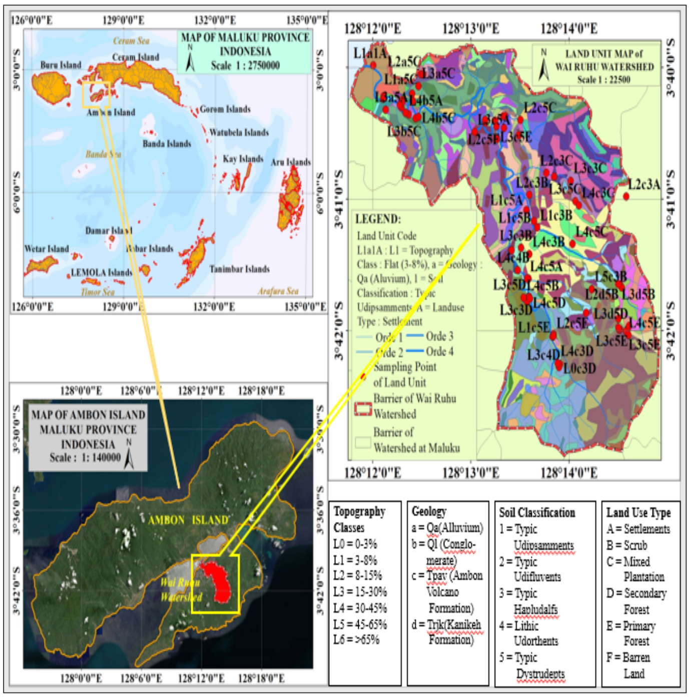

Figure 1. Location Research and Land Unit Map of Wai Ruhu Watershed

3. Result and Discussion

3.1. Result

a. Land Degradation Rates Using Field Assessment Method

This study found 1840 land degradation indicators in the 65 land units consisted of 620 pedestals and 1060 plant/tree roots exposures, 40 subsoils of the house foundation exposure (indication of sheet erosion), 40 rills and 80 gullies. These finding were used to calculated soil loss, and the rates and spatial distribution of land degradation due to erosion was classified based on the distribution of soil loss in the study area.

Figure 2 and 3 showed that the lowest land degradation rate ranges from 4.40 to 19.15tons/ha/yr and covering 37.30% of the study area or 607.64ha, and it was indicated by the average height of 62,21 mm pedestal and 75,88mm of plant/tree roots exposure; the average depth of 0,126m rills and the average weight of 0.85g/cm^3 soil bulk density. The formation of exposed pedestal and plant/tree roots, and the rills were estimated within 51.92 years with the average soil loss is 1.47mm/year. While the highest rate ranges from 202.84 to 675.62tons/ha/yr covering 6.20% of the study area or 100.97ha, and it is indicated by the average height of 146, 81mm pedestal and 146,42mm plant/tree roots exposure, the average depth of 0.16m rills and 0.60m gullies, and the average weight of 1.16g/cm^3 soil bulk density. The occurrence of exposed pedestal and plant/tree roots, rills and gullies were estimated within 7.92 years with the average soil loss was 22.26mm/yr.

The moderate and high land degradation rates ranged from 22.20 to 49.75tons/ha/year and from 50.34 to 187.73tons/ha/yr, respectively. The medium rate covered 13.03% of the study area or 212.37 ha and it was indicated by the average height of 44,39mm pedestal and 68,29mm of plant/tree roots exposure, and the average weight of 1.03 g/cm^3 soil bulk density. The occurrence of these indicators was estimated within 17.21 years with the average soil loss was 3.51mm/year.

The high rate covers 43,46% of the study area or 708.14ha, and it was indicated by the average height of 51,06mm pedestal, 63,91mm exposed plant/tree roots, and 93,31mm subsoil of the houses foundation structure, the average depth of 0.22m rills and 0.57m gullies, and the average weight of 1.14g/cm^3 soil bulk density. The formation of these field indicators was estimated within 9.18 years with the average soil loss due to erosion was 9.33mm/yr.

b. Land Degradation Prediction Using the RUSLE Method

The rate and spatial distribution of degraded areas due to erosion in the study area obtained by the RUSLE prediction method (Figure 4 and 5). The lowest land degradation rate ranged from 0.11 to 16.92tons/ha/yr soil loss covering 33,30% of the study area or 542.48ha, and they were mostly found in soils with the very low to low soil erodibility (K factor), flat to gentle slope steepness (low LS factors), and the primary and secondary forest land uses (the lowest C value). While, the highest degradation rate ranged from 287.63 to 4207.41tons/ha/yr soil loss, covering 34.81% of the study area or 567.16ha, and they were largely occurred in the low soil erodibility (K values) with steep to very steep slope steepness (high to very high LS factors), and the dominant land uses were residential areas (the highest C value), mixed dry land cultivation areas, bushes and bare land (high C values).

The moderate land degradation rate ranged from 21.04 to 33.22tons/ha/yr soil loss covering 11,17% of the study area or 181.93ha, and they were dominantly occurred in soil conditions with the low to very low erodibility (K values), gentle to slightly steep slope steepness (low LS values) and the land uses were shrubs, mixed dry land cultivation areas, and secondary dry land forests.

The high land degradation rate ranged from 63.82 to 159.44tons/ha/yr covering 20,72% of the study area or 337.65ha, and they were generally occurred in the low to very low soil erodibility (K values), slightly slope steepness (moderately LS values), and the land uses were dominated by residential areas (the highest C value), mixed dry land cultivation, shrubs and bare land.

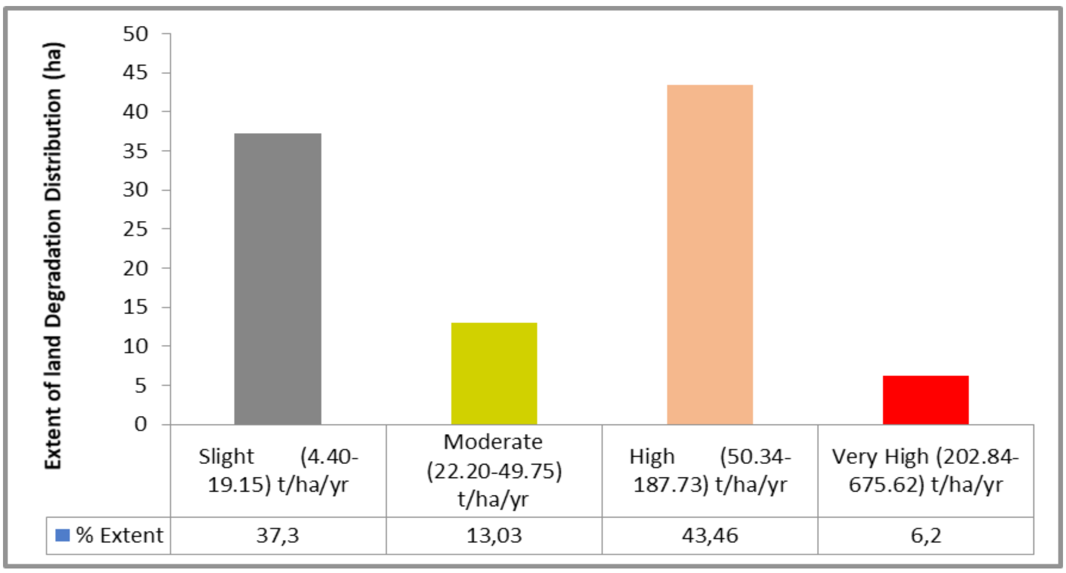

Figure 2. The rate of land degradation due to erosion based on the field indicators assessment method in the Wai Ruhu watershed

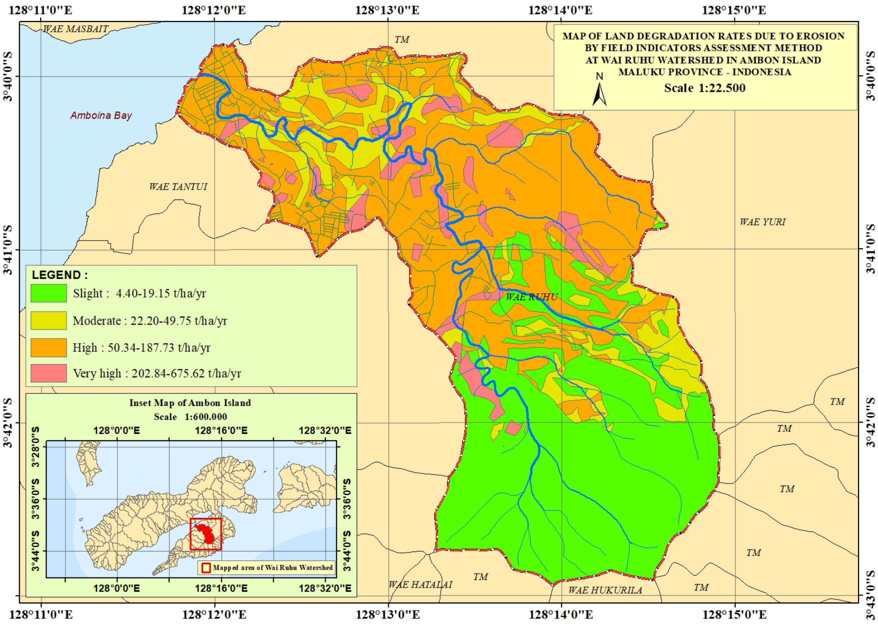

Figure 3. The spatial distribution of degraded land due to erosion in the Wai Ruhu Watershed by the field indicators assessment

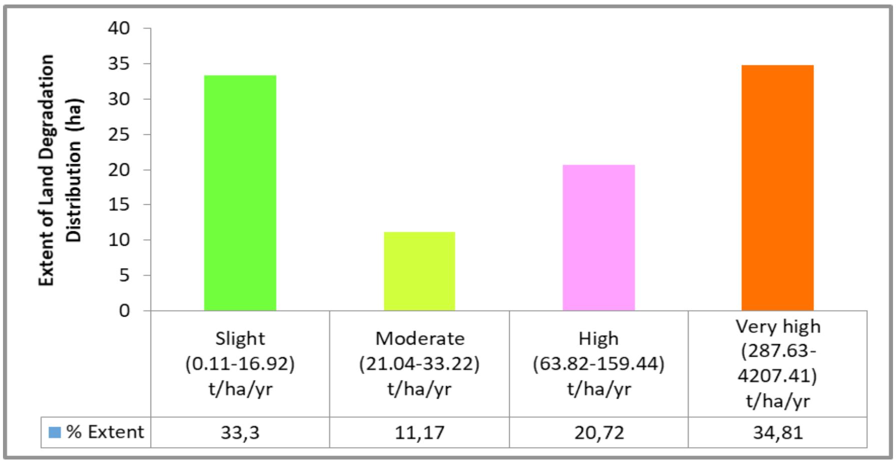

Figure 4. The land degradation rates due to erosion in the Wai Ruhu watershed by the RUSLE method

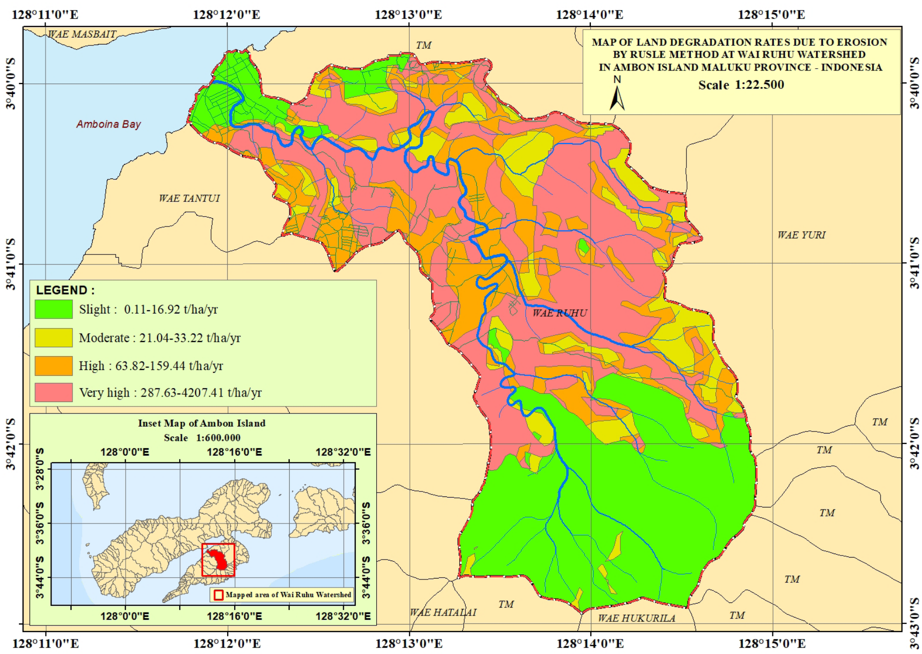

Figure 5. The spatial distribution of degraded land due to erosion in the Wai Ruhu Watershed by the RUSLE method

c. Development of a Land Degradation Assessment Model

To find out whether the regression model used is free from deviations in assumptions and it meets the conditions for obtaining good linearity, and to ensure that the regression model obtained is the best model, in terms of estimation accuracy, unbiased and consistent, several classic assumption tests were conducted before carrying out multiple regression analysis. The classical assumption tests used were the normality, linearity, heteroscedasticity, multicollinearity and autocorrelation assumption tests.

Figure 6 illustrated the result of the normality assumption test that the Asymp.Sig. (2-tailed) using the Kolmogorov-Smirnov test was 0.063 greater than 0.05(α), with R^2 of 81,4% (high category), which means that the residual distribution (error) of the variables was normally distributed at a confidence level of 95%. While the results of the linearity assumption test were 1.000 bigger than 0.05(α), with R^2 of 82,5% (high category) indicating that the linearity assumption was met, and the dependent and independent variables had a linier relationship at the 95% confidence level (Figure 7).

The results of the heteroscedasticity assumption test showed that the Sig. (2-tailed) Spearman Correlation for the variables logK, logLS, logC, logBbtIsi and logAgePL were 0.896, 0.842, 0.769, 0.153, and 0.708, respectively, and they were > 0.05(α), thus there was no heteroscedasticity. Figure 8 indicates that the residuals versus fit were spread evenly both above and below the zero axis and do not form a particular pattern, or the residuals are not systematically related to the independent variables, suggesting the resulting regression model was free from heteroscedasticity, in other words the assumption of homoscedasticity was met at the 95% confidence level. The results of the multicollinearity assumption test showed that the variance inflation factors (VIF) values of the variables logK, logLS, logC, logBbtIsi and logAgePL were 1.193; 1,044; 3,048; 1.599 and 3.108, respectively, which are <10 (VIF standard value). This means that there was no multicollinearity between the independent variables in the regression model at the 95% confidence level. The values of the autocorrelation assumption test using the Durbin-Watson Statistics is 2.11521 ranged between the DU (1.8430) and 4-DU (2.157). This means

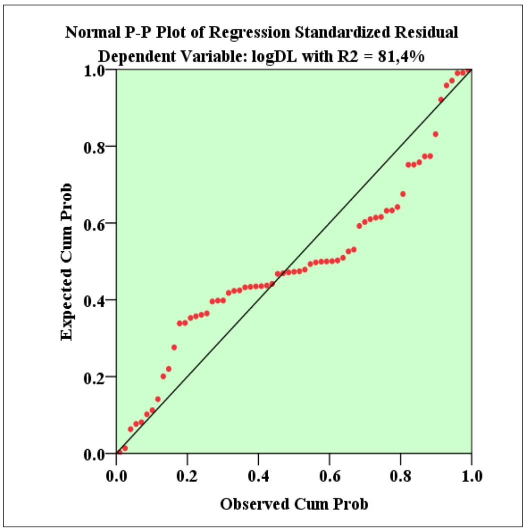

Figure 6. Graph of residual normality (error) using log transformation model for land degradation variables in the Wai Ruhu Watershed

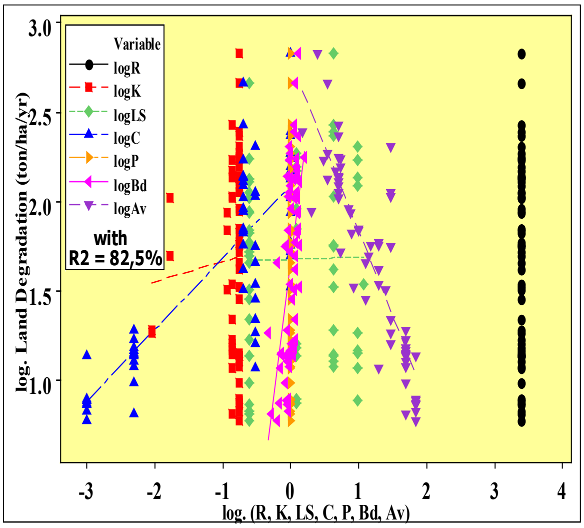

Figure 7. Graphs of linearity using log transformation model for land degradation variables in the Wai Ruhu Watershed

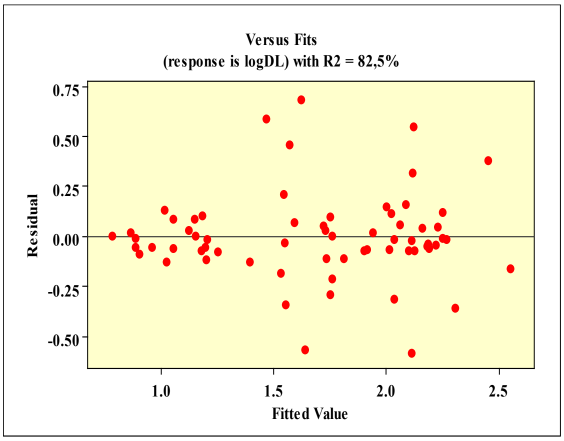

Figure 8. Graph of residual heteroscedasticity versus fit using log transformation for land degradation variables in the Wai Ruhu Watershed

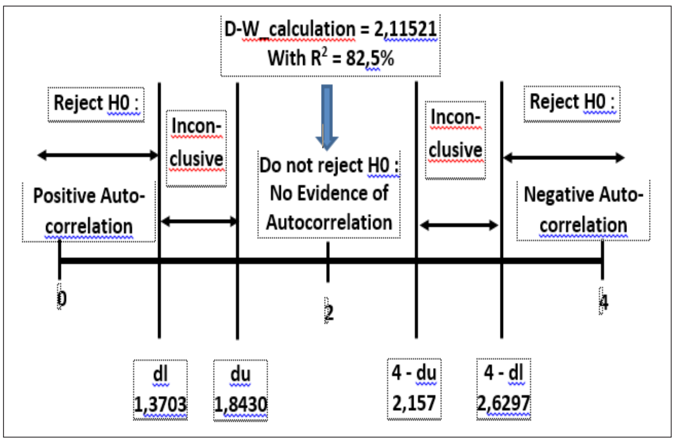

Figure 9. Autocorrelation test graph for land degradation variables using log transformation in the Wai Ruhu Watershed

that there was no autocorrelation detected in the samples or no autocorrelation between the residuals (error) of the independent variables and the dependent variables at the 95% confidence level (Figure 9).

The results of the classical assumption test above, the transformed land degradation variables had fulfilled the assumptions of normality, linearity, homoscedasticity or the data were normally distributed and linear, and there was no multicollinearity and autocorrelation. Therefore, the model could be further tested using nonlinear regression models.

The results of paired difference test analysis, showed that the sig (2-tailed) value is 0.001 which was <0.05. This means that the rates of land degradation based on the field indicator assessment method and the RUSLE prediction model for each land unit in the Wai Ruhu watershed was significantly different at the 95% confidence level. It suggested that field indicator assessment could be used as a reference for developing a land degradation assessment model in the Wai Ruhu watershed.

This study found that the average soil loss by the RUSLE predicted model was 292.51tons/ha/yr, which was much higher compared to the value based on field-measured using the land degradation field indicator which was 91.23tons/ha/yr. The comparison of soil loss by the RUSLE and field indicator assessment for each land unit in the study area is described as follow (see Figure 10 to 20).

In the L0b5A land unit with flat slope (0-3% steepness), conglomerate rock, typic dystrusdept soil type, and the high-density residential land use, soil loss by land degradation field indicators was 57.97tons/ha/yr, and classified high erosion rate. The field indicators of land degradation found in this land unit were 3.79mm/yr exposed plant/tree roots formation and 4.75mm/yr exposed house foundations structures, and the soil bulk density was 1.36g/cm^3 (Figure 10). While soil loss by the RUSLE was 110.72tons/ha/year and classified high erosion rate.

Figure 10. Exposed tree roots and eroded building foundations structure in land unit L0b5A with density-housing land use. Soil loss by field indicators was 57.97tons/ha/yr, and by RUSLE was 110.72tons/ha/yr. Land degradation rate by erosion was categorized high

Figure 11. Exposed tree roots in land unit L0c5B with shrub land use. Soil loss by field indicator was 24,42tons/ha/yr, and by RUSLE was 33,22 t/ha/yr. Land degradation rate by erosion was categorized moderate.

Figure 12. Exposed tree roots in land unit L1b5A with shrub land use. Soil loss by field indicators was 59,33tons/ha/yr, and by RUSLE was 110,72 t/ha/yr. Land degradation rate by erosion is categorized high

In the L0c5B land unit with flat slope (0-3% steepness), the Ambon volcanic rock (composed of andesite, dacite, breccia, and tuff), typic dystrudepts soil type, and shrub land use, soil loss by land degradation field indicator was 24.42tons/ha/yr and classified moderate erosion rate. The land degradation field indicators found in this land unit included 3.08mm/yr exposed plant/tree roots formation, and 0.792g/cm^3 soil bulk density (Figure 11). While soil loss by the RUSLE was 33.22tons/ha/yr and classified moderate erosion rate.

The land unit L1b5A with a gentle slope (3-8% steepness), conglomerate rock, typic dystrudepts soil type, and the high-density residential land use, soil loss based on land degradation field indicators was 59.33tons/ha/yr and classified high erosion rate. The field indicators of land degradation found in this land unit was 4.7mm/yr pedestals and 5.29mm/yr exposed tree roots formations, and 1.188g/cm^3 soil bulk density (Figure 12). While soil loss by the RUSLE was 110.72tons/ha/yr and classified high erosion rate.

In the land unit L2a5C with a slightly sloping slope class (8-15%), alluvium geology, typic dystrudepts soil type, and mixed dry land agricultural land use, soil loss based on land degradation field indicators was 70.58tons/ha/yr and classified high erosion rate. Field indicators found in this land unit were 5.43mm/yr exposed roots and the soil bulk density was 1.30g/cm^3. While soil loss by the RUSLE method was 106.29tons/ha/year and classified high erosion rate (Figure 13).

In the land unit L2d5B with a slightly sloping slope class (8-15%), Kanikeh geology formation, typic dystrudepts soil type, and shrub land use, soil loss by land degradation field indicators was 27.60tons/ha/yr and classified moderate erosion rate. The field indicator was 2.68mm/yr soil pedestal with 1.03g/cm^3 soil bulk density. While soil loss by the RUSLE was 159.44tons/ha/year and classified high erosion rate (Figure 14a, 14b).

In the land unit L3c3B with sloping slope (15-30%), Ambon volcanic rock, typic hapludalf soil type, and shrub land use, soil loss by land degradation field indicators was 107.46tons/ha/yr and classified high *erosion rate*. Field indicators in this land unit included 2.3mm/yr soil pedestals and 22.27mm/yr gully, and the soil bulk density was 0.915g/cm^3. While soil loss by the RUSLE was 431.44tons/ha/yr and classified very high erosion rate (Figure 15a, 15b).

Figure 13. Exposed plant/tree roots in land unit L2a5C with mixed dryland farming land use. Soil loss by field indicator was 70,58tons/ha/yr, and by RUSLE was 106,29tons/ha/yr. Land degradation rate by erosion was categorized high.

Figure 14a. Soil pedestal in land unit L2d5B with shrub land use. Soil loss by field indicators was 27,60tons/ha/yr (moderate), and by RUSLE was 159,44tons/ha/yr. Land degradation rate by erosion was categorized moderate to high.

Figure 14b. Shrub land use and soil pedestal by erosion in the land unit L2d5B

Figure 15a. Soil pedestal and gully in land unit L3c3B with shrub land use. Soil loss by field indicators was 107.46tons/ha/yr, and by RUSLE was 431,44tons/ha/yr. Land degradation rate by erosion was categorized high to very high.

Figure 15b. Shrub land use (left), and soil pedestal and gully (right) in the land unit L3c3B

Figure 16. Soil pedestal and rill in the land unit L3c5A with settlement land use. Soil loss by field indicators 675.62tons/ha/yr, and by RUSLE was 1882.26tons/ha/year. Land degradation rate by erosion was categorized very high.

In the land unit L3c5A with sloping slope (15-30%), Ambon volcanic rocks, typic dystrudepts soil type, and residential land use, soil loss by land degradation field indicators was 675.62tons/ha/yr and classified very high erosion rate. Field indicators found in this land unit were 23.39mm/yr soil pedestal, 10.43mm/yr exposed roots, 63.7mm/yr rill, and the soil bulk density was 1.301 g/cm^3. Soil loss by the RUSLE method was 1882.26 tons/ha/year and classified very high erosion rate (Figure 16).

In the land unit L3c5F with sloping slope (15-30%), Ambon volcanic rock, typic dystrudepts soil type, and bare land, soil loss by land degradation field indicators was 246, 94tons/ha/yr and classified very high erosion rate. field indicators found in this land unit were 21.83 mm/yr soil pedestal with the soil bulk density was 1.131g/cm^3. While soil loss by the RUSLE was 1882.26tons/ha/yr and classified very high erosion rate (Figure 17a, 17b).

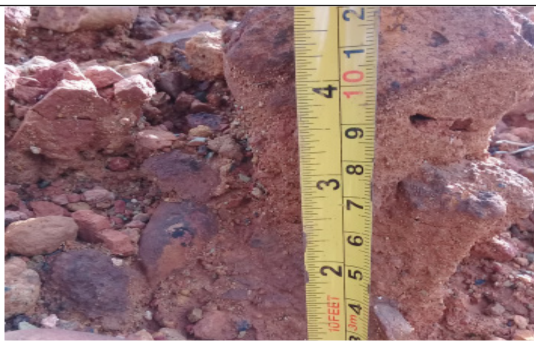

Figure 17a. Soil pedestal in the land unit L3c5F with bare land. Soil loss by field indicators was 246.94tons/ha/yr, and by the RUSLE was 1882.26tons/ha/yr. Land degradation rate by erosion was categorized very high.

Figure 18. Exposed plant/tree roots in the land unit L3d5B with shrub land use. Soil loss by field indicators was 15.64tons/ha/yr, and by the RUSLE was 564.68tons/ha/yr. Land degradation rate by erosion was categorized moderate to very high.

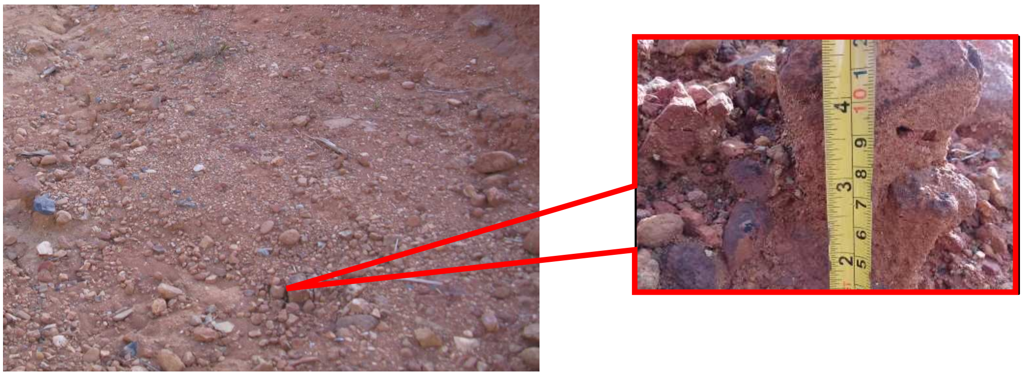

Figure 17b. Bare land (left), and soil pedestal in the land unit L3c5F

Figure 19. Soil pedestal in the land unit L4c4B with shrub land use. Soil loss by field indicators was 18,44tons/ha/yr, and by RUSLE was 63,82tons/ha/yr. Land degradation rate by erosion was categorized low to high.

Figure 20. Exposed roots in the land unit L5c3B with with shrub land use. Soil loss by field indicators was 34,99tons/ha/yr, and by the RUSLE was 1218,18tons/ha/yr. Land degradation rate by erosion was categorized moderate to high

In the land unit L3d5B with a sloping slope (15-30%), Kanikeh geology formation, typic dystrudepts soil type, and shrub land use, soil loss by land degradation field indicators was 15.64tons/ha/yr and classified moderate erosion rate. Field indicators in this land unit included 1,32mm/yr soil pedestal with 1.188g/cm^3 soil bulk density. While soil loss by the RUSLE was 564.68tons/ha/yr and classified very high erosion rate (Figure 18).

In the land unit L4c4B with slightly steep slope (30-45%), Ambon volcanic rocks, lithic udorthents soil type, and shrub land use, soil loss by land degradation field indicators was 18.44tons/ha/yr and classified low erosion rate. Field indicators found in this land unit included 4.09mm/yr soil pedestal formation 3.86mm/yr exposed roots, and the soil bulk density was 0.464 g/cm^3. While soil loss by the RUSLE was 63.82tons/ha/yr and classified high erosion (Figure 19).

In the land unit L5c3B with steep slope (45-65%), Ambon volcanic rock (Tpav), typic hapludalfs soil type, and shrub land, soil loss by land degradation field indicators was 34.99tons/ha/yr and classified moderate erosion rate. The field indicator found in this land unit was 4.48mm/yr exposed roots, and the soil bulk density was 1.007g/cm^3. While soil loss by the RUSLE was 1218.18tons/ha/yr and classified very high rate (Figure 20).

3.2. DISCUSSION

a. Soil Loss by Field Indicators Assessment and RUSLE Method

This study uses the RUSLE method and land degradation field indicator assessments to estimate soil loss and provide different rates of land degradation and a suitable land degradation model based on local environmental conditions.

The results of the field indicator assessments indicated the fact that the land units with well-stratified upper and lower vegetation covers have a low land degradation rate of 4.40–19.5 tons/ha/yr and a moderate land degradation rate of 22,20–49,75 tons/ha/yr. However, in the land units where the upper and lower vegetation covers and the stratification of vegetation structure were sparse due to human presence and activities such as deforestation, land clearing for agriculture fields, and residential and road construction, the land degradation rate was high (50,34–187,73 tons/ha/yr) and very high (202,84–675,62 tons/ha/yr), respectively.

These results show that, despite being a natural process, human activity in the environment might accelerate land deterioration. In land units that are well protected, rainfall interception by the higher vegetation canopy reduces the erosivity energy of rainfall, while the lower vegetation cover extends the time that water can penetrate into the soil and reduces the velocity of surface flow. According to (Senn, Fassnacht, Eichel, & Seitz, 2020), vegetation covers, both the upper (aerial cover) and lower (contact cover), are crucial in lowering the destructive kinetic energy of rainfall drops on the surface. It also protects the soil surface from the direct impact of rainwater and prevents splash erosion and constantly maintains soil infiltration rates (Rakhim & Nurnawaty, 2019).

Activities such as the removal of vegetation cover expose the soil surface to rainfall and surface runoff. Consequently, soil pedestals, exposed plant and tree roots, rills, and gullies were formed in a shorter time compared to light and moderate land degradation levels. (Blinkova & Lavrov, 2017) and (Li, Zhang, He, & Yang, 2023) demonstrated that a multi-stratified vegetation cover significantly reduces the risk of erosion compared to land that is dominated by trees but has less undergrowth and litter. The presence of vegetation cover, including litter and living plant biomass, protects the soil surface from the impact of rainfall, and also lower the volume and velocity of surface runoff and soil loss.

It is also noted that the impact of various land use systems on land degradation and erosion rates ranges from the lowest to the highest and is supported by the environmental conditions of the study area, especially rainfall, soil types, slope steepness, and forest conversion. Study of (Hariyanto, Sisinggih, & Andawayanti, 2024) indicated that the rate of sedimentation due to erosion is determined by the relationship between rainfall, changes in forest cover, type of forest management, and the characteristics of the catchment.

Results of the RUSLE method indicated that land degradation rates as a result of erosion ranged from low (0,11 – 16,92tons/ha/yr) to moderate (21,04 – 33,22tons/ha/yr), and they were typically found in the land units with flat to gentle slopes, agricultural land uses (food crops and mixed gardens), shrubs, and settlement land uses. In these land units, the lower slope steepness tends to reduce surface flow and results in a lower land degradation rate. However, in the steeper slopes with secondary and primary forest land uses, well-layered canopy by multi-stratified vegetation cover protects the soil surface from the impact of raindrops and surface flow, so they have relatively low erosion compared to agricultural land use.

On the contrary, in the land units with steep to very steep slope steepness, moderate to high soil erodibility, and shrubs, poor-covered mixed garden land uses, the land degradation rates were high (63,82 – 159,44 tons/ha/yr) and very high (287 – 4207,4 tons/ha/yr). This study indicated that soil loss per unit area increases with increasing slope length and steepness, conversely, soil loss will decrease with decreasing slope length and slope steepness. According to (Nicosia, Guida, Stefano, Pampalone, & Ferro, 2021), steep and extremely steep slopes enhance surface flow velocity and sediment transport capacity, and the high erodibility of the soil makes it less resilient to the effects of rainfall. Due to the increased influence of rainfall and surface flow on the exposed soil surface, land uses with less plant cover and steep to extremely steep slopes are particularly vulnerable to soil erosion, which raises the rate of land degradation (Xu, Yang, Qian, & Chen, 2019).

b. The Developed Model Based Local Environmental Condition

The classical assumption tests, including correlation and regression analyses, confirmed that the land degradation variables met the requirements of normality, linearity, and homoscedasticity, with no evidence of multicollinearity or autocorrelation. In addition, the paired sample t-test indicated that land degradation values derived from field indicators and those predicted using the RUSLE method exhibited similar statistical characteristics across land units. These findings support the use of field-based land degradation indicators as a reliable reference for developing land degradation assessment models, particularly at the watershed scale, as also suggested by previous studies integrating empirical observations with erosion prediction models (Renard *et al.*, 1997; Stocking & Murnaghan, 2000). The models tested, using the MINITAB 16 Statistical Analysis Program, were in the form of 8 linear regression models and nonlier regression, as presented in Table 1.

Table 1. Results of Land Degradation Assessment Modeling Tests for Small Islands in Maluku Case Study: in the Wai Ruhu Watershed

No.	Models	Result Models (β0, β1, β2, β3, β4, β5, β6, β7)	P-value	R^2 (%)
1.	DL/RP = β0 + β2K + β3LS +β4C	DL/RP = - 0.0150 + 0.177K + 0.00177LS + 0.0517C	0,001*	22,8
2.	DL/RP = β0 + β2K + β3LS + β4C + β6Bd – β7Ac	DL/RP = 0.0022 + 0.147K + 0.00162LS + 0.0134C + 0.0225Bd - 0.000837Ac	0,000*	36,3
3.	$LD/RP = \beta o.K^{\beta 2}.LS^{\beta 3}.C^{\beta 4}.\varepsilon$	logDL/RP = - 1.08 + 0.247 logK + 0.0836 logLS + 0.413 logC	0,000*	67,2
4.	$LD/RP = e^{(\beta o + \beta 2K + \beta 3LS + \beta 4C + \varepsilon)}$	lnDL/RP = - 5.17 + 2.59K + 0.0379LS + 1.90C	0,000*	38,3
5.	$LD/RP = e^{(\beta o + \beta 2K + \beta 3LS + \beta 4C + \beta 6Bd + \beta 7Ac + \varepsilon)}$	lnDL/RP = - 4.09 +1.47K + 0.0277LS + 0.158C + 0.763Bd - 0.0402Ac	0,000*	77,9
6.	$e^{DL/RP} = \beta o.K^{\beta 2}.LS^{\beta 3}.C^{\beta 4}.\varepsilon$	DL/RP = 0.0827 + 0.0121 lnK + 0.00471 lnLS + 0.00951 lnC	0,000*	28,7
7.	$e^{DL/RP} = \beta o.K^{\beta 2}.LS^{\beta 3}.C^{\beta 4}.Bd^{\beta 6}.Ac^{\beta 7}.\varepsilon$	DL/RP = 0.114 + 0.00263 lnK + 0.00483 lnLS - 0.00210 lnC + 0.0152 lnBd - 0.0289 lnAc	0,000*	48,0
8.	$\mathbf{LD/RP = \beta o.K^{\beta 2}.LS^{\beta 3}.C^{\beta 4}.Bd^{\beta 6}.Ac^{\beta 7}.\varepsilon}$	**logDL/RP = - 0.824 + 0.0026 logK + 0.0933 logLS + 0.133 logC + 0.700 logBd- 0.652 logAc**	**0,000***	**82,5**

Among the tested models, Model 8 (rank regression model) showed the best performance, with a coefficient of determination (R^2) of 82.5% and a significance level of 95% (P-value = 0.000). The resulting land degradation model based on field-measured indicators can be expressed as:

logDL/RP = - 0.824 + 0.0026 logK + 0.0933 logLS + 0.133 logC + 0.700 logBd- 0.652 logAv, or

$$LD = 0.1499 \times R^{1.000} \times K^{0.0026} \times LS^{0.0933} \times C^{0.133} \times P^{1.000} \times Bd^{0.700} \times Av^{-0.652}$$

The high explanatory power of this model indicates that the combined effects of rainfall erosivity (R), soil erodibility (K), topography (LS), land cover (C), soil conservation practices (P), soil bulk density (Bd), and vegetation age (Ac) play a critical role in controlling erosion-driven land degradation. Similar findings have been reported in tropical and subtropical regions, where modifications of the RUSLE framework by incorporating local soil and vegetation parameters significantly improved prediction accuracy (Dlamini & Chaplot, 2016; Cao, Lu & Yue, 2017; Meng, Cao & Wang, 2021). The inclusion of soil bulk density and vegetation age as explanatory variables highlights the importance of soil physical properties and land use history in land degradation processes. High bulk density is commonly associated with soil compaction, reduced porosity, and decreased infiltration capacity, which in turn increase surface runoff and erosion rates (Widiatiningsih, Mujiyo, & Suntoro, , 2018; Mujiyo, Hardian, Widijanto, & Herawati, 2021). Conversely, increasing vegetation age contributes to improved canopy cover, higher organic matter content, enhanced aggregate stability, and stronger root systems, all of which reduce soil detachment and transport (Frouz, Dvorscik & Dousova, 2015; Cao, Lu & Yue, 2017). Furthermore, the corrective model developed using a correction factor (fk = 0.2158) addresses the tendency of the conventional RUSLE approach to overestimate soil loss in complex tropical environments. The substantial difference between soil loss estimated from field indicators (80.31 tons/ha/yr) and the RUSLE method (372.10 tons/ha/yr) underscores the necessity of local calibration. This finding is consistent with earlier studies emphasizing that erosion models developed in temperate regions require adjustment when applied to tropical watersheds characterized by high rainfall intensity, steep slopes, and heterogeneous land use patterns (Renard *et al.*, 1997; Dlamini & Chaplot, 2016). The results demonstrate that the integration of field-measured land degradation indicators with RUSLE-based factors produces a robust and context-sensitive assessment model. Such an approach is particularly suitable for small island environments like Maluku, where limited spatial extent, steep terrain, and rapid land use change demand erosion prediction models that are both accurate and locally adaptive.

4. CONCLUSION

The study is part of a series studies conducted in Maluku in order to develop a suitable land degradation assessment model for small islands in the tropical region in Maluku, Indonesia ((Talakua, Osok, 2017, Talakua, Osok, 2019, and Talakua *et al.*, 2024). These current results demonstrated the results of using the Stocking dan Murnaghan's land degradation field indicators assessment and the RUSLE predicted method to estimate annual soil as a main cause of land degradation in small-scaled watershed in Ambon Island, Maluku. This study found that the average annual soil loss by the RUSLE predicted model is 372.10tons/ha/yr, which is much higher than the field indicators 80.31tons/ha/yr. However, at the land degradation categorization rates, both methods show a similarity and difference in annual soil loss rates.

At the lowest degraded land rate, the average annual soil loss is 4.40 – 19 15tons/ha/yr or 1.47 mm/yr (field assessment), and 0.11 – 16.92tons/ha/yr (RUSLE), and at the moderate degraded land rate, the average annual soil loss is 22.20 – 49.75tons/ha/yr or 3.51mm/yr (field assessment), and 21.04 – 33.22tons/ha/yr (RUSLE). At the high degraded land rate, the average soil loss is 50.34 – 187.73tons/ha/yr or 9.33mm/yr (field assessment), and 63.82 – 159.44tons/ha/yr (RUSLE). However, at the very high degraded land rate, the RUSLE provided much higher the average annual soil loss, which is 287.63 – 4207.41tons/ha/yr compared to 202.84 – 675.62tons/

ha/yr or 22.26mm/yr by field assessment. Best model of land degradation assessment in Wai Ruhu Watershed is : $LD = 0.1499 \times R^{1.000} \times K^{0.0026} \times LS^{0.0933} \times C^{0.133} \times P^{1.000} \times Bd^{0,700} \times Av^{-0.652}$.

The results of this current study promote the importance fact that the Stocking and Murnaghan's land degradation field assessment indicators could be considered as a suitable land degradation assessment model for the specific local condition of small islands in Maluku.

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