Erosion hazard index analysis of several land uses in Watatu Village, Donggala Regency

Salapu Pagiu, Roland F. A, Abd Rahman and Ramlan
Faculty of Agriculture, Universitas Tadulako, Indonesia

Email Corresponden: salapupagiu@aol.com

Abstract. Watatu Village is one of the villages located in Donggala Regency and as the capital city of South Banawa Sub-District which has significant potential in the agricultural sector, including cocoa plantations, oil palm trees, and paddy fields. This research aims as a source of information correlated to land-use policies and the erosion hazard index in Watatu Village, South Banawa Sub-District, Donggala Regency. The research was carried out by using the descriptive explorative method, and the observed variables were carried out through a survey. Soil sampling was determined purposively (purposive sampling) based on the category of land use and slope at the research location. Intact and incomplete soil samples were taken as many as 21 samples at seven land-use units. Sample analysis was performed at the Soil Science Laboratory on the Erosion Hazard Index, namely (1) soil texture, (2) soil structure, (3) organic matter content, and (4) permeability, and (5) bulk density. The results of the Erosion Hazard Index analysis showed that the high erosion hazard index was found in Land use unit 2 (mixed gardens), Land use unit 4 (cocoa gardens), Land use unit 5 (mixed gardens), and Land use unit 7 (Shrub). Thereby, conservation actions needed to preserve the environment to prevent or inhibit the rate of erosion and maintain the stability of land use.

1. Introduction
One of the primary natural resources on earth is the land. The land described as a land space and is a part of the land that has many functions for life [1]. Erosion is one type of land degradation. Erosion is one indication that land is damaged [2]. Furthermore, erosion is the process of erosion and transport of soil or parts of soil by natural media in the form of water. Erosion is an indicator of gaps in land use in an area [3]. However, it should be noted that erosion can occur naturally also by human activities that use the land for various purposes such as land use for agriculture, settlement, and others.

Direct land use may cause damage in an area if not accompanied by land damage prevention measures [4,5]. It will result in visible land degradation marked by high levels of erosion and sedimentation and low levels of rainwater infiltration [6,7].

This research aims as a source of information correlated to land-use policies and the erosion hazard index in Watatu Village, South Banawa Sub-District, Donggala Regency

2. Methods
This research was conducted in Watatu Village, Banawa Selatan District, Donggala Regency, Central Sulawesi Province and soil analysis was carried out at the Laboratory of the Soil Science Unit of the Faculty of Agriculture, Tadulako University. This research was conducted from October 2019 to November 2019.

Several tools used in this research were including Meters, Plastic Bags, Label Paper, Clinometer, Hoes, Ring samples, soil drills, pH meters, Global Position System (GPS), compasses and physical and chemical analysis equipment in the laboratory. While the materials used were slope maps, land
use maps, land unit maps, whole and incomplete soil samples. Then the materials needed at the time of analysis in the laboratory.

The research was carried out by using the descriptive explorative method, through a survey to determine the predicted value of erosion in each land unit in Watatu Village, Banawa Selatan District, Donggala Regency, Central Sulawesi Province. Data collection was done by collecting primary data and secondary data. Primary data was including length data, slope class, permeability, texture, structure, organic matter, soil bulk density. Secondary data such as rainfall data for the last five years were obtained from the Meteorology, Climatology and Geophysics Agency (BMKG), Palu.

Taking soil samples from each land use unit (LUU) to obtain land characteristics: soil depth, slope length, slope, and image interpretation of land use. Sampling partial soil as many as 21 samples at seven land-use units. Each land use unit consisted of 3 samples, and then they were composited into 1 sample for each land unit. While for intact soil sampling, 21 samples were taken for each land unit, then averaged.

The erosion hazard index was processed using the USLE (Universal Soil Loss Equation) by entering primary data and secondary data into the USLE equation as follows:

\[ A = R \cdot K \cdot L \cdot S \cdot C \cdot P \]

Note:
- \( R \) = rainfall erosivity
- \( K \) = soil erodibility
- \( L \) = slope length
- \( S \) = slope
- \( C \) = crop management
- \( P \) = soil conservation action factors

2.1. Rain Erosivity Factor (\( R \)):

\[ R_b = 10.80 + 4.15 \cdot R_F \]

Note:
- \( R_b \) = Erosivity index
- \( R_F \) = Average Monthly Rainfall (cm yr\(^{-1}\))

\[ R_F = \frac{K \cdot 1.292 \cdot (2.1M^{1.14}10^{-4})(12-a) + 3.25 (b-a) + 2.5 (c-3)}{100} \]

Note:
- \( K \) = soil erodibility
- \( M \) = particle size (% dust + fine sand) (100 -% clayey)
- \( a \) = Percent of organic matter (C \times 1.724)
- \( b \) = Soil texture class
- \( c \) = Soil permeability class ggg

2.2. Slope length and slope factors (\( LS \))

\[ LS = L^{1/2} (0.0138 + 0.00965 S + 0.00138S^2) \]

Note:
- \( L \) = Length of slope (m)
- \( S \) = Slope independence (%)

2.3. Plant management factors and soil conservation factors (CP)
The CP factor value was determined based on the form of land use adjusted to the C factor value for various forms of land use.

2.4. Tolerable Erosion (\( T \))
Tolerable erosion level measured by the equation put forward by [8], as follows:
\[ T = \left( \frac{DE - D_{\text{min}}}{\text{UGT}} \right) + \text{LPT} \times \text{BD} \]

Note:
- \( T \) = The amount of erosion allowed (ton ha\(^{-1}\) yr\(^{-1}\))
- \( DE \) = Depth equivalents (effective depth x sub orders)
- \( D_{\text{min}} \) = Minimum depth of particular plant growth (mm)
- \( \text{UGT} \) = Land lifespan (400 years)
- \( \text{LPT} \) = The rate of soil formation (1.5 mm yr\(^{-1}\))
- \( \text{BD} \) = Bulk Density (g m\(^{-3}\)).

2.5. Erosion Hazard Index (EHI):

\[ \text{EHI} = \frac{A}{T} \]

Note:
- \( A \) = amount of potential erosion (ton ha\(^{-1}\) yr\(^{-1}\))
- \( \text{TSL} \) = Tolerable erosion (ton ha\(^{-1}\) yr\(^{-1}\))

| Table 1. Erosion hazard index (EHI) classification. |
|----------------|----------------|
| Value          | Value classification |
| <1.0           | Low              |
| 1.01 – 4.00    | Moderate         |
| 4.01 – 10.00   | High             |
| >10.01         | Very high        |

3. Results and Discussions

3.1. Rain Erosivity Index (R)

| Table 2. Rain Erosivity Index for the Last 5 Years (2015-2019). |
|----------------|----------------|----------------|
| Month          | Rainfall        | R              |
|                | Mm    | Cm    |            |
| January        | 300.10 | 30.01 | 135.34      |
| February       | 206.80 | 20.68 | 96.62       |
| March          | 253.40 | 25.34 | 115.96      |
| April          | 203.00 | 20.30 | 95.04       |
| May            | 230.12 | 23.01 | 106.29      |
| June           | 478.52 | 47.85 | 209.38      |
| July           | 170.58 | 17.05 | 81.59       |
| August         | 135.40 | 13.54 | 66.99       |
| September      | 187.00 | 18.70 | 88.40       |
| October        | 132.50 | 13.25 | 65.78       |
| November       | 226.24 | 22.62 | 104.68      |
| December       | 197.60 | 19.76 | 92.80       |
| Total          |        |       | 1258.92     |

From the calculation of the rain erosivity index (R) was using the average monthly rainfall data for the last five years at the BMKG station at Mutiara Sis-Aljufri Airport, Palu, the Watatu Village area (Table 2). It has a rain erosivity value of 1258.92 cm/year, the highest monthly erosivity (R) was in June, about 209.38 cm/month, so in that month there was a possibility of soil erosion with a considerable enough potential. Then, the lowest R-value was in October, about 65.787 cm/month, at that month the chance of erosion was relatively low.

3.2. Soil Erodibility (K)
3.4. Plant Management and Conservation Measures (CP)

Table 3. Soil Erodibility (K).

| Land use unit | Land used      | BO  | KST | KPT | Textures (%) | K | Classification |
|---------------|----------------|-----|-----|-----|--------------|---|----------------|
| 1             | Paddy field    | 2.67| 4.00| 5.00| 15.0         | 39.0 | 33.2 | 0.15 | Low    |
| 2             | Mixed garden   | 2.10| 3.00| 5.00| 20.8         | 44.3 | 25.5 | 0.11 | Low    |
| 3             | Mixed garden   | 2.31| 2.00| 5.00| 17.7         | 30.1 | 12.4 | 0.07 | Very low |
| 4             | Cacao plantation | 2.65| 4.00| 5.00| 1.9          | 86.2 | 3.4  | 0.15 | Low    |
| 5             | Mixed garden   | 3.03| 2.00| 5.00| 12.4         | 52.5 | 28.1 | 0.07 | Very low |
| 6             | Mixed garden   | 2.32| 3.00| 5.00| 19.1         | 33.3 | 20.4 | 0.11 | Low    |
| 7             | Shrub          | 2.91| 2.00| 5.00| 15.0         | 21.3 | 21.3 | 0.07 | Very low |

According to Table 3 above, it can be seen from the classification of soil erodibility values at land use unit of 1 – 6, which were categorized as low soil erodibility. Meanwhile, land use unit 3, 5, and 7 were categorized as very low soil erodibility values. The difference in soil erodibility values on land use in Watatu Village was caused by soil properties, such as texture, permeability, structure, and organic matter.

Then, the permeability and organic matter can change over time as a result of changes in land use management. These soil properties influence each other in determining the level of soil erodibility in a land unit. The presence of organic matter on the soil surface can inhibit the surface flow rate and provide a more ample opportunity for water to be infiltrated; as a result the surface runoff becomes small [9]. Soil with a fine sand structure also has a high infiltration capacity, but if there is a runoff, the fine grains will easily be caught [10]. Fine sand and dust are soil particles affect the sensitivity of soil to erosion [11].

3.3. Slope Length (L) and Slope (S)

Table 4. Calculation of Slope Length (L) and Slope (S).

| Land use unit | L (m) | S (%) | LS |   |
|---------------|-------|-------|----|---|
| Paddy field   | 26    | 0.03  | 0.37 |   |
| Mixed garden  | 83    | 0.05  | 1.19 |   |
| Mixed garden  | 43    | 0.05  | 0.61 |   |
| Cacao plantation | 58   | 0.07  | 0.84 |   |
| Mixed garden  | 137   | 0.06  | 1.97 |   |
| Mixed garden  | 28    | 0.41  | 0.52 |   |
| Shrub         | 27    | 0.51  | 0.52 |   |

Table 4 shows the highest LS value was found in mixed garden land of land use unit 5 about 1.97, with a slope of 0.06% and a slope length of 137 m. At the same time, the LS value was low in the paddy field with a slope of 0.03 and a slope length of 26 m. The greater slope of the slope, the greater the number of soil grains that splashed down the slope by the collision of raindrops [12,13]. If the slope of the soil surface becomes twice as steep, the amount of erosion per unit area will be 2.0 to 2.5 times as much.

3.4. Plant Management and Conservation Measures (CP)

Table 5. Calculation of Plant Management and Conservation Measures (CP).

| Land use unit | Land used | C   | P | CP |
|---------------|-----------|-----|---|----|
| 1             | Paddy field | 0.01 | 0.04 | 0.004 |
| 2             | Mixed garden | 0.2 | 1  | 0.2 |
| 3             | Mixed garden | 0.2 | 1  | 0.2 |
| 4             | Cacao plantation | 0.08 | 0.05 | 0.004 |
| 5             | Mixed garden | 0.2 | 1  | 0.2 |
| 6             | Mixed garden | 0.2 | 1  | 0.2 |
| 7             | Shrub       | 0.3  | 1  | 0.3 |
In Table 5, it can be seen that the paddy field (land use unit 1) and cocoa plantation (land use unit 4) have the same CP value, was about 0.004. Then, at mixed gardens (land use unit 2, 3, 5 and 6) had the same CP value about 0.02 of each. Whereas at land use unit 7 (shrub) had a value of 0.3. The impact of vegetation on surface runoff is the interception of rainwater, reducing the speed of surface flow, and the destructive power of rain and surface flow, the influence of roots, organic matter from plant debris that falls on the ground, biological activities related to vegetation growth [14–16]. Also, it affects the stability of the structure of soil porosity and respiration, which results in reduced groundwater content [17].

3.5. Prediction of Erosion in Watatu Village (A)

| Land used       | R      | K      | LS     | CP      | A    |
|-----------------|--------|--------|--------|---------|------|
| Paddy fields    | 1258.92| 0.15   | 0.37   | 0.004   | 69.87| 0.28 |
| Mixed garden    | 1258.92| 0.11   | 1.19   | 0.02    | 164.79| 32.96|
| Mixed garden    | 1258.92| 0.07   | 0.61   | 0.02    | 53.76| 10.75|
| Cocoa Plantation| 1258.92| 0.15   | 0.84   | 0.004   | 158.62| 0.63 |
| Mixed garden    | 1258.92| 0.07   | 1.97   | 0.02    | 173.60| 34.72|
| Mixed garden    | 1258.92| 0.11   | 0.52   | 0.02    | 72.01| 14.40|
| Shrubs          | 1258.92| 0.07   | 0.52   | 0.02    | 45.82| 13.75|

Based on Table 6, the analysis results obtained the potential erosion value and the actual erosion value. The highest potential erosion was found in mixed garden land use (land use unit 5) with a value of 173.60 ton ha⁻¹ yr⁻¹ and the lowest was in shrubs (land use unit 7) about 45.82. Whereas the highest actual erosion was found in mixed garden land (land use unit 5) with a value of 34.72 tonnes ha⁻¹ yr⁻¹ and the lowest was in paddy field (land use unit 1) with a value of 0.28 tonnes ha⁻¹ yr⁻¹. This may occur due to various factors that influence the erosion, one of which is the absence of plant management and conservation measures (CP). Rachman, et.al (2003) stated that soil and plant management that accumulates plant debris has a good effect on Soil quality, such as improve the soil aggregate stability, soil resistance, and soil resistance to the destructive power of raindrops [18].

3.6. Tolerable Erosion (T) and Erosion Hazard Index (EHI)

| Land         | Dmin | De  | RL | LPT | BD | T  |
|--------------|------|-----|----|-----|----|----|
| Paddy fields | 250  | 1000| 400| 1.5 | 1.47 | 23.93|
| Mixed garden | 500  | 2145| 400| 1.5 | 1.57 | 27.66|
| Mixed garden | 500  | 1365| 400| 1.5 | 1.53 | 25.11|
| Cocoa Plantation | 500 | 975 | 400| 1.5 | 1.47 | 23.24|
| Mixed garden | 500  | 2145| 400| 1.5 | 1.41 | 25.26|
| Mixed garden | 500  | 1170| 400| 1.5 | 1.49 | 24.03|
| Shrubs       | 150  | 975 | 400| 1.5 | 1.52 | 24.86|

Note: T = allowed amount of erosion (ton ha⁻¹ yr⁻¹); De = Depth of the equivalence; LPT = Formation Rate (g/cm) of soil; Dmin = minimum depth of certain plant growth (mm); BD = Bulk Density

| Land use   | A   | T    | EHI   | Classification |
|------------|-----|------|-------|----------------|
| Paddy field| 69.87| 23.93| 2.91  | Moderate       |
| Mixed garden | 164.79| 27.66| 5.95  | High           |
| Mixed garden | 53.76| 25.11| 2.14  | Moderate       |
| Cacao plantation | 158.62| 23.24| 6.82  | High           |
| Mixed garden | 173.60| 25.26| 6.87  | High           |
| Mixed garden | 72.01| 24.03| 2.99  | Moderate       |
| Shrub      | 45.82| 24.86| 1.84  | Moderate       |

| Average    | 24.87| 4.21 | High  |

Table 8. Erosion Hazard Index (EHI).
Based on Table 7 and 8, which has been described, the results of the classification of the erosion hazard index in Watatu Village were high and moderate. The highest classification of erosion hazard index was found in the mixed garden (land use unit 2), cocoa garden (land use unit 4), and mixed garden (land use unit 5), while the classification of moderate erosion hazard index was found in paddy field (land use unit 1) and mixed garden (land use unit of 3, and 6) and shrubs (land use unit 7).

Land-use patterns and soil management measures cause the difference in the erosion hazard index, so it is essential to take conservation actions to overcome the occurrence of more significant erosion. The potential for erosion that occurs in the Palu watershed in the existing conditions is 19,241,205.99 tonnes yr\(^{-1}\) or 10,689,558.88 m\(^3\) yr\(^{-1}\) or around 62.09 tonnes ha\(^{-1}\) yr\(^{-1}\) categorized of class III erosion hazard (moderate) with a loss of soil layer thickness of 3.45 mm yr\(^{-1}\) and after controlling the amount of erosion decreased by 14,829,860.24 or 8,238,811.34 m\(^3\) yr\(^{-1}\) or by 47.85 tonnes of ha\(^{-1}\) yr\(^{-1}\), with a classification of erosion hazard level II (mild) and the loss of soil layer decreased to 2.66 mm yr\(^{-1}\) [19].

4. Conclusions
The classification of the erosion hazard index in Watatu Village was high and moderate. The highest classification of erosion hazard index was found in the mixed garden (land use unit 2), cocoa garden (land use unit 4) and mixed garden (land use unit 5), while the classification of moderate erosion hazard index was found in paddy field (land use unit 1), mixed garden (land use unit 3 and 6), and shrubs (land use unit 7). It is necessary to carry out agricultural land conservation efforts, must pay attention to land conservation principles following the conditions of the agricultural land. Thus, the erosion occurred does not get bigger. Besides, expected to plant crops and carry out land management that is suitable for sloping areas

References
[1] Makhrawie 2012 Evaluasi Kerusakan Tanah Untuk Produksi Biomassa Pada Areal Lahan Kering Di Kota Tarakan Media Sains 4 185–96
[2] Yudhistira Y, Hidayat W K and Hadiyarto A 2011 Kajian dampak kerusakan lingkungan akibat kegiatan penambangan pasir di Desa Keningar daerah kawasan Gunung Merapi J. Ilmu Lingkung. 9 76–84
[3] Anwar M R, Pudyono P and Sahiruddin M 2012 Penanggulangan Erosi Secara Struktural pada Daerah Aliran Sungai Bango Rekayasa Sipil 3 51–63
[4] Foley J A, DeFries R, Asner G P, Barford C, Bonan G, Carpenter S R, Chapin F S, Coe M T, Daily G C and Gibbs H K 2005 Global consequences of land use Science (80-. ). 309 570–4
[5] Lu H, Xie H, Lv T and Yao G 2019 Determinants of cultivated land recuperation in ecologically damaged areas in China Land use policy 81 160–6
[6] Komaruddin N 2008 Penilaian tingkat bahaya erosi di sub daerah aliran sungai Cileunsgi, Bogor Agrikultura 19
[7] Matano A-S, Kanangire C K, Anyona D N, Aboum P O, Gelder F B, Dida G O, Owuor P O and Ofulla A V O 2015 Effects of land use change on land degradation reflected by soil properties along Mara River, Kenya and Tanzania Open J. Soil Sci. 5 20
[8] Hammer W I 1981 Soil conservation consultant report Center for Soil Research LPT Bogor. Indones.
[9] Harrys M, Utomo W H and Prijono S 2017 mplementasi Pemeliharaan Lahan pada Tanaman Ubikayu: Pengaruh Pengelolaan Lahan Terhadap Hasil Tanaman dan Erosi J. Tanah dan Sumberd. Lahan 1 79–84
[10] Asdak C 2010 Hidrologi dan Pengelolaan Daerah Aliran Air Sungai: Edisi Revisi Kelima Yogyakarta Gadjah Mada Univ. Press Yogyakarta
[11] Rusdi R, Alibasyah M R and Karim A 2013 Degradasi lahan akibat erosi pada areal pertanian di Kecamatan Lembah Seulawah Kabupaten Aceh Besar J. Manaj. Sumberd. Lahan 2 240–9
[12] Arsyad 2010 Konservasi Tanah dan Air (Bogor: IPB Press)
[13] Fu Y, Li G, Wang D, Zheng T and Yang M 2019 Raindrop energy impact on the distribution characteristics of splash aggregates of cultivated dark loessial cores Water 11 1514
[14] Dunnett N, Nagase A, Booth R and Grime P 2008 Influence of vegetation composition on runoff in two simulated green roof experiments Urban Ecosyst. 11 385–98
[15] Jiang M-H, Lin T-C, Shaner P-J L, Lyu M-K, Xu C, Xie J-S, Lin C-F, Yang Z-J and Yang Y-S 2019 Understory interception contributed to the convergence of surface runoff between a Chinese fir plantation and a secondary broadleaf forest J. Hydrol. 574 862–71
[16] Van Dijk A and Bruijnzeel L A 2001 Modelling rainfall interception by vegetation of variable density using an adapted analytical model. Part 1. Model description J. Hydrol. 247 230–8
[17] Yazdanpanah N, Mahmoodabadi M and Cerdà A 2016 The impact of organic amendments on soil hydrology, structure and microbial respiration in semiarid lands Geoderma 266 58–65
[18] Rachman A, Anderson S H, Gantzer C J and Thompson A L 2003 Influence of long-term cropping systems on soil physical properties related to soil erodibility Soil Sci. Soc. Am. J. 67 637–44
[19] Zainuddin R 2015 Prediksi Erosi dengan Bantuan Program Sistem Informasi Geografi Arcview 3, 3 di Daerah Aliran Sungai Palu Fak. Perton. Univ. Tadulako. Palu