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**Research Article**

# Prediction of soil organic carbon loss due to erosion in the Girindulu Watershed of Central Java

**D. Mey*, J. Sartohadi, D. Mardiatno, M. A. Marfai**

Postgraduate Program, Faculty of Geography, Gadjah Mada University, Bulaksumur, Yogyakarta 55281, Indonesia.

*corresponding author: djafar_mey@yahoo.com

**Abstract:**This research aimed to predict soil loss and soil organic carbon loss due to the erosion in the Girindulu watershed. The population of the research was all landforms in the Girindulu watershed. The research sample was representative in representing landform unit characteristic of the population. Data collection was conducted through soil surveys and laboratory analysis, and the sampling technique was purposive sampling. The collected data were the characteristics of the land, climate, and soil erosion and related carbon organic. The amount of soil organic carbon loss was predicted using the equation of COT= 2.1091(totSed)$^{0.025}$, and the total sediment transported by erosion was predicted using the equation of totSed = 0.6808+ 0,854Ch+0.435BO–2.125pL+1.98mL. The results showed that the Girindulu watershed area of 73,703.75 ha had a total soil loss due to erosion of 9,880,934.7 t/year, and total soil organic carbon loss due to erosion of 153,120.2 t/year. Soil and soil organic carbon loss affected pool of C stock on landform, climate condition (rainfall), geomorphologycal condition (the presence of a geological fault, length slope and land slope), soil characteristics (texture and organic matter), and human activity in agricultural society management. Soil conservation actions need to be taken through replanting of trees (reforestation) in marginal lands, incorporation of agricultural residues, mulching with organic matter from vegetation, and application of organic fertilizer on cultivated land.

***Keywords:*** *prediction, soil loss, soil organic carbon loss, watershed*

## Introduction

Erosion is an active geomorphologic process on the Earth's surface. Erosion can be the results of climate, topography, grass and human factors that work interactively. Rainfall is the most important climatic factor in accelerating erosion. High rainfall kinetic energy will be able to destroy and release soil materials and carry them away to rivers through run-off and deposited in water bodies/lakes/bays (Arsyad, 1989; Seta, 1991 Kartasapoetra et al., 2000; Suripin, 2002; Lal, 2003).

Destructive power of water flow over the soil surface grows with increasing steep and length of slopes. Run-off that is greater than infiltration and the destruction of land cover vegetation from land clearing are not in accordance with the principles of soil and water conservation. Soil organic carbon that is one of the essential nutrients for plant growth can be transported by run-off. This makes the decline of land capability to support the cultivation of agriculture. The decline is because of (a) the reduction of soil capability to hold water, (b) the hampered granulation and stabilization of soil aggregates, (c) the increase of plasticity and cohesion of clay, (d) the decrease of power absorption and cation exchange capacity, (e) the leaching of nitrogen, sulfur, and phosphorus elements, and (f) the decrease of quantity and metabolic activity of soil organisms that in turn inhibit the decomposition process in turn (Hakim et al., 1986).

Carbon dioxide ($CO_2$) is the greenhouse gas that affects the increase in atmospheric temperature. Hairiah and Murdiyarso (2008) pointed out that there has been an increase of $CO_2$ emissions from 1400 million Mg/year to 2900 million Mg/year in the last decade, despite the decline of $CH_4$ emissions of 37 million Mg/year to 22 million Mg/year, and the reduction of $N_2O$

emissions from 3.9 million to 3.8 million Mg/year. This increase in $CO_2$ emission has reached harmful level towards the earth's climate and ecosystem balance. One of its effects is that most of tropical areas have a surplus of water. If land cover vegetation and soil conservation are not performed, watersheds face the potential increase of surface run-off rate, erosion, soil loss and soil organic carbon loss, river flow rate, and sediment suspension. The availability of soil organic carbon is influenced by geomorphic and pedogenic processes. Pedogenic processes affect the amount of availability of organic carbon in the soil horizons through decomposition, humification, eluviation, iluviation, and alteration processes. Under geomorphic processes, soil organic carbon tends to be transported laterally through erosion and deposition processes. Soil organic carbon dynamic is related to land use conversion, tillage, erosion and surface water flow. This study was aimed to predict soil organic carbon loss from top of soils due to the erosion in the Girindulu watershed.

## Materials and Methods

This research was conducted in the Girindulu watershed covering an area of 73,703.75 ha. Geographically, the area is located in the south of the equator between coordinates of $7^0$56’00”-$8^0$15’00”S;$111^0$48’12”-$111^0$24’35”E. This study used ecological approach that emphasized on the interaction between the physical appearances of the natural environment conditions. The study population was the entire landforms of the Girindulu watershed that composed of genetic factors, geological and geomorphic process levels, through the interpretation of Landsat-7 ETM imagery, SRTM imagery, geological maps, and map of RBI. The study samples were landform units representing the condition of the population. Based on genetic factors, geological and geomorphic process level, 28 landform units were selected as samples (Table 1). The spread of the landform units in the Girindulu watershed is presented in Figure1.

Table 1. Landform unit of The Girindulu Watershed

| Landform Unit | Landform Genetic *) | Geological Formation | Erosion Process | Area (ha) | Area (%) |
|---|---|---|---|---|---|
| F1 | FP | Alluvium | - | 5,080.74 | 6.89 |
| D1a | DH | Arjosari Formation | slightly eroded | 4,463.41 | 6.06 |
| D1s | DH | Semilir Formation | slightly eroded | 1,401.38 | 1.90 |
| D1t | DH | Andecite, Dacite Intrusive rock | slightly eroded | 1,135.08 | 1.54 |
| D1w | DH | Watupatok Formation | slightly eroded | 7,469.19 | 10.13 |
| D1wu | DH | Wuni Formation | slightly eroded | 74.31 | 0.10 |
| D2a | DH | Arjosari Formation | moderately eroded | 5,687.96 | 7.72 |
| D2t | DH | Andesite, Dacite Intrusive rock | moderately eroded | 1,079.51 | 1.46 |
| D2w | DH | Watupatok Formation | moderately eroded | 4,483.60 | 6.08 |
| D2wu | DH | Wuni Formation | moderately eroded | 799.84 | 1.09 |
| D3a | DH | Arjosari Formation | highly eroded | 10,472.32 | 14.21 |
| D3t | DH | Andesite, Dacite Intrusive rock | highly eroded | 412.27 | 0.56 |
| D3w | DH | Watupatok Formation | highly eroded | 3,900.00 | 5.29 |
| D4j | PP | Jaten Formation | - | 381.15 | 0.52 |
| K1wo | KH | Wonosari Formation | slightly eroded | 52.18 | 0.07 |
| K2wo | KH | Wonosari Formation | moderately eroded | 692.03 | 0.94 |
| K3wo | KH | Wonosari Formation | highly eroded | 295.39 | 0.40 |
| S1j | SH | Jaten Formation | slightly eroded | 1,057.34 | 1.43 |
| S2j | SH | Jaten Formation | moderately eroded | 1,248.30 | 1.69 |
| S2n | SH | Nampol Formation | moderately eroded | 124.16 | 0.17 |
| S3j | SH | Jaten Formation | highly eroded | 512.44 | 0.70 |
| S7.1d | BFH | Dayakan Formation | slightly eroded | 1,260.00 | 1.71 |
| S7.1n | BFH | Nampol Formation | slightly eroded | 389.07 | 0.54 |
| S7.2n | BFH | Nampol Formation | moderately eroded | 272.63 | 0.37 |
| S7.3j | BFH | Jaten Formation | highly eroded | 362.33 | 0.49 |
| SD1m | SDH | Mandalika Formation | slightly eroded | 6,197.04 | 8.41 |
| SD2m | SDH | Mandalika Formation | moderately eroded | 6,460.08 | 8.76 |
| SD3m | SDH | Mandalika Formation | highly eroded | 7,940.00 | 10.77 |
| **Total** | | | | **73,703.75** | **100.00** |

*) FP = Fluvial Plains, DH = Denudasional Hills, PP = Peneplain, KH = Karst Hills, SH = Structural Hills, BFH = Block Fault Hills, SDH = Structural Denudasional Hills

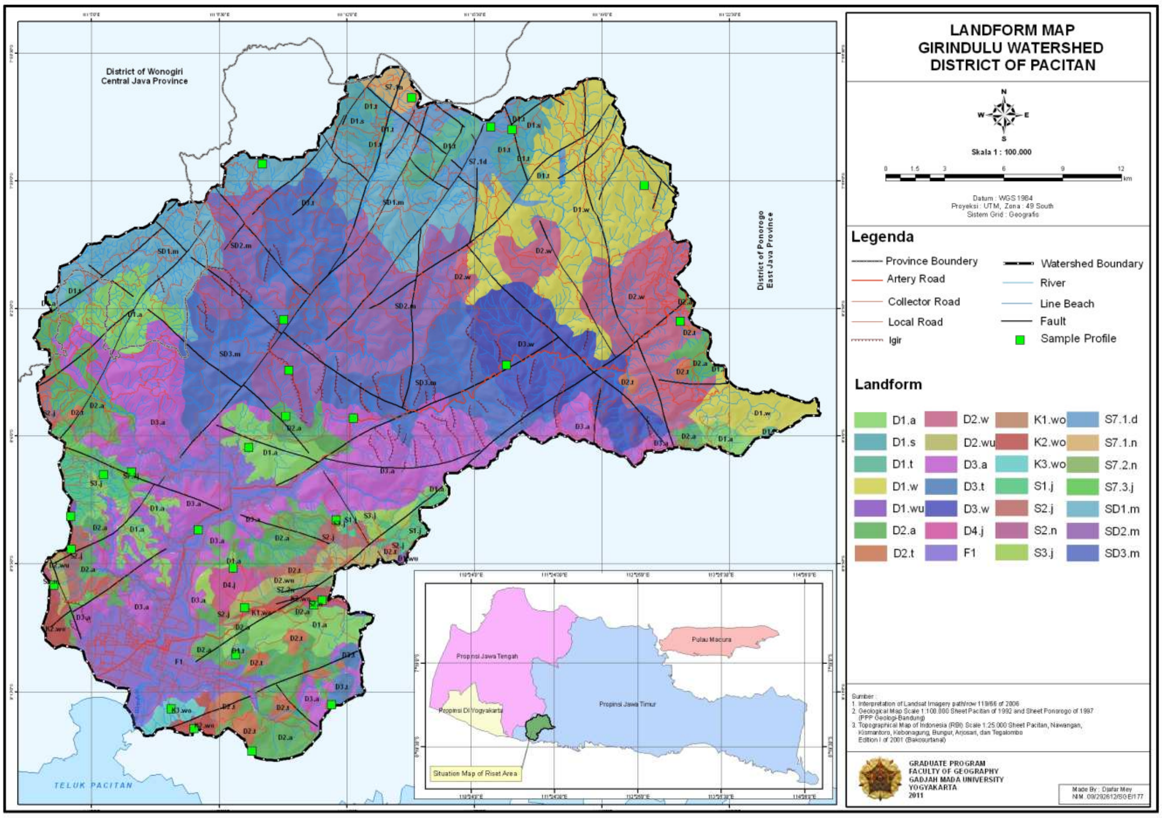


Figure 1. Landform map of The Girindulu Watershed

Data were collected through soil surveys and laboratory analyses, with a purposive sampling technique. The data collected were soil and land characteristics, climate related erosion, and carbon. Land characteristics data included slope and length of slope, erosion, vegetation / land use, and soil conservation techniques. The soil characteristics of the data included texture, structure, permeability and organic carbon. Climate data included precipitation (11 years), for the analysis of climatic conditions (polygons theisen) of the study area that were recorded at Arjosari, Pacitan, Tegalombo, Nawangan, Tahunan, and Kebonagung climate stations. Atmospheric temperature data were recorded at the Pacitan climate station. Total soil organic carbon loss due to erosion was predicted using the equation: $COT = 2.1091(totSed)^{0.025}$, where: COT is soil organic carbon loss (kg/t), totSed is total sediment transported (t), 2.1091 and 0.025 are statistical constants. Total sediment transported due to erosion was predicted using the equation:

$$totSed = 0.6808+0.854Ch+0.435BO-2.125pL+1.980mL$$

where: totSed is total transported sediment (t/ha), Ch is rainfall total average (cm), BO is organic matter (%), pL is lenght of slope (m), mL is land slope (%), 0.6808, 0.854, 0.435, 2.125 and 1.980 are statistical constants.

## Result and Discussion

### *General situation of the study area*

In general, research area is in the administrative area of Pacitan District in East Java Province, with the following boundaries: South side with the Indonesian Ocean; North side with District of Wonogiri-Central Java, West side with District of Wonogiri-Central Java, and East side with District of Ponorogo-East Java. The Girindulu watershed is characterized by 1941-2882 mm annual rainfall, D (medium) and C (rather wet) climate types, 29.8°C air temperature, and 32.2°C soil temperature.

The soil falls into ustic moisture regime, and isohypertermic temperature regime because the average soil temperature is greater than 22°C, the partial cross section of the soil is dry for 90 cumulative days in normal years, and the different soil temperatures in dry and rainy seasons is less than $6^{0}$C. The geological formations are arjosari formation, watupatok formation, mandalika formation, jaten formation, semilir formation, dayakan formation, wonosari formation, wuni formation, nampol formation, alluvium, andesite and daciterock intrusive. The soil sub groups are Ustorthents, Ustipsamments, Haplustepts, Haplustalfs, and Haplustults (USDA, 1999).

Generally, the Girindulu watershed has land use type of mixed garden with the soil conservation technique of terrace and contour cultivation. There is also local shelf mulching from local plant foliage litter. The hilly areas are planted with agricultural crops such as bananas (*Musa sp*), coconut (*Cocos nucifera*), cassava (*Manihot utilisima*), maize (*Zea mays*), gnetum gnemon (*Gnetum gnemon*), papaya (*Carica papaya*), mango (*Mangifera indica*), rambutan (*Nephelium lappaceum*), paddy rainwater (*Oriza sativa* L), potato (*Ipomoea batatas*), taro (*Colocasia esculenta*), peanuts kedele (*Arachis sp*), and forest trees such as teak (*Tectona grandis*), pine (*Phinus mercusii*), Acacia (*Accacia sp*), sengon (*Albizia valcataria*), and angsana (*Pterocarpus indica*). In the lowland areas, available water is sufficient for cultivating rice (*Oriza sativa* L). There are also non-cultivated herbs such as jambu-jambu (*Myrtaceae*), bamboo (*Bambusa* sp), komba-komba (*Chromolaena odorata*), reeds (*Imperata cilindrica*), and nuts (*Colopogonium* sp) found in the area.

### *Prediction of soil and soil organic carbon losses due to erosion at the Girindulu Watershed*

Based on the research model used for this study, total of soil loss and soil organic carbon loss due to erosion in the Girindulu watershed are presented in Table 2, and the spread in the Girindulu watershed is presented in Figure 2.

Table2. Soil and soil organic carbon losses due to erosion in the Girindulu Watershed

| Landform Unit | Area (ha) | Soil Loss (t/ha/year) | Soil Loss (t/year) | Soil Organic Carbon Loss (t/ha/year) | Soil Organic Carbon Loss (t/year) |
|---|---|---|---|---|---|
| F1 | 5,080.74 | -37.20 | -189,175.80 | -1.75 | -8,901.00 |
| D1a | 4,463.41 | 211.70 | 944,745.50 | 2.41 | 10,760.60 |
| D1s | 1,401.38 | 120.60 | 168,968.30 | 2.38 | 3,331.80 |
| D1t | 1,135.08 | 207.40 | 235,431.10 | 2.41 | 2,735.40 |
| D1w | 7,469.19 | 155.50 | 1,161,457.60 | 2.39 | 17,869.60 |
| D1wu | 74.31 | 179.30 | 13,325.20 | 2.40 | 178.40 |
| D2a | 5,687.96 | 152.70 | 868,364.20 | 2.39 | 13,598.20 |
| D2t | 1,079.51 | 259.00 | 279,621.70 | 2.42 | 2,615.60 |
| D2w | 4,483.60 | 162.00 | 726,480.50 | 2.39 | 10,738.10 |
| D2wu | 799.84 | 129.40 | 103,493.20 | 2.38 | 1,905.00 |
| D3a | 10,472.32 | 111.10 | 1,163,567.10 | 2.37 | 24,842.70 |
| D3t | 412.27 | 171.30 | 70,627.40 | 2.40 | 988.60 |
| D3w | 3,900.00 | 170.90 | 666,498.30 | 2.40 | 9,353.60 |
| D4j | 381.15 | -133.80 | -51,009.90 | -2.38 | -908.60 |
| K1wo | 52.18 | 202.80 | 10,580.60 | 2.41 | 125.60 |
| K2wo | 692.03 | 206.60 | 142,975.40 | 2.41 | 1,667.20 |
| K3wo | 295.39 | 229.50 | 67,793.70 | 2.42 | 713.70 |
| S1j | 1,057.34 | 181.60 | 192,050.20 | 2.40 | 2,539.80 |
| S2j | 1,248.30 | 167.80 | 209,437.90 | 2.40 | 2,992.50 |
| S2n | 124.16 | 245.30 | 30,456.20 | 2.42 | 300.40 |
| S3j | 512.44 | 206.80 | 105,948.00 | 2.41 | 1,234.90 |
| S7.1d | 1,260.00 | 154.10 | 194,140.10 | 2.39 | 3,014.10 |
| S7.1n | 389.07 | 119.90 | 46,638.80 | 2.38 | 924.90 |
| S7.2n | 272.63 | 196.60 | 53,600.30 | 2.41 | 656.10 |
| S7.3j | 362.33 | 172.70 | 62,591.80 | 2.40 | 869.20 |
| SD1m | 6,197.04 | 133.80 | 828,959.30 | 2.38 | 14,771.90 |
| SD2m | 6,460.08 | 77.80 | 502,732.90 | 2.35 | 15,191.30 |
| SD3m | 7,940.00 | 160.00 | 1,270,635.20 | 2.39 | 19,010.50 |
| **Total** | 73,703.75 | 4,315.20 | 9,880,934.80 | 58.18 | 153,120.10 |
| **Average** | 2,632.28 | 154.11 | 352,890.53 | 2.08 | 5,468.58 |

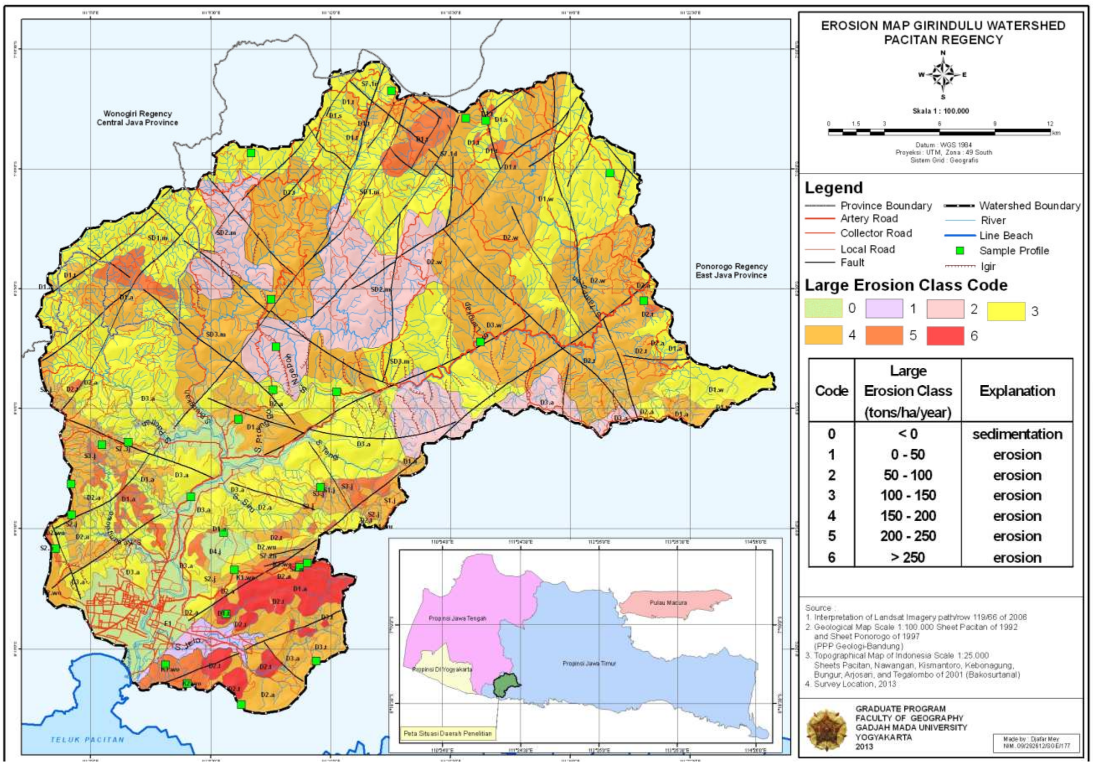


Figure 2. Erosion map of the Girindulu Watershed

Data presented in Table 2 show that the Girindulu watershed area of 73,703.75 ha had the total average soil loss of 134.1 t/ha/year, which was equivalent to 9,880,934.7 t/year. The total soil organic carbon loss was 2.08 t/ha/year, which was equivalent to 153,120.2 t/year. The highest total soil loss of 259t/ha/year occurred on denuded hills landform unit of andesite intrusive rock over the moderately eroded (D2t) area of 1,079.51 ha. The sedimentation of 133.8 t/ha/year occurred on the peneplain landform unit of jaten rocky formations (D4j) area of 318.15 ha. The sedimentation of 37.2 t/ha/year occurred in fluvial plains landform unit area of 5,080.74 ha.

The highest loss of total soil organic carbon of 2.42 t/ha/year occurred on denuded hills land form unit of andesite intrusive rocky over the moderately eroded (D2t) area of 1,079.51 ha, structural hills land form units, nampol rocky formations over the moderately eroded (S2n) area of 124.16 ha, and karst hills landform unit of wonosari rocky formations over the highly eroded (K3wo) area of 295.39 ha. The addition of 2.38 t/ha/year occurred in peneplain landform unit of jaten rocky formation (D4j) area of 381.15 ha.

### *The soil loss in the Girindulu watershed*

The Soil loss (erosion) in The Girindulu watershed is a process of destruction of soil material by rain water and soil materials which then transported/redistributed from one place by the strength of the surface flow either naturally or by human intervention, and deposited else where (Arsyad, 1989; Kartasapoetra et al., 2000; Suripin, 2002; Lal, 2003). Results of this study showed that the landform characteristics in the Girindulu watershed had great influence on soil loss due to erosion which is caused by rainfall, length and steep of slope, organic matter content, soil texture, land use and soil conservation techniques.

Landform units of K3wo andD2t had lower of annual rainfall average of 1,941-2,882 mm than landform units of D4j and D2wu of 2,192-2,227 mm. The high rainfall in D2t and K3wo landform units made the capability of erosion rainfall became large and thus causing high soil erosion (Morgan, 1995). Rainfall is potential for destructing, removing, transporting and depositing soil materials (Arsyad, 1989, Suripin, 2002; Lal, 2003). Results of this study showed that the direct influence of rainfall on the soil loss in The Girindulu watershed was 31.9%. This showed that the effectiveness of rainfall in accelerating erosion in the study area is also influenced by other factors such as the condition of the slope, soil physical and chemical characteristics. The collision of the raindrops destroys soil surface material and mostly are then transported from the place of origin to place further up by the kinetic energy of the water flow surface, where the materials or larger aggregates were first deposited on the micro-relief, and material of fine sized aggregates were deposited further away to get into the Girindulu river's body.

During the process of the soil materials transport, parts of soil materials got back into the ground water infiltration and percolation covering the soil pores. As a result, the capacity and ground water infiltration rate decreased, the pressure of surface runoff increased, and erosion and washout of soil particles became more intensive. This condition was accelerated by human activity in land use to meet their needs, especially on steep sloping land regardless of soil conservation techniques. Landform units of D2t and K3wo had average slope lengths of 15.32 m and 34 m, respectively. These slopes were 32% and 27% shorter and steeper than that of D4j landform unit with an average slope length of 157.0 m and an average slope of 4.0%, and that of D2wu landform unit with average slope length of 59.5 m. The slope was almost similar to that of the K3wo landform unit of 32.5%. The slope conditions and tilt increased the rate of number and surface flow in the K3wo and D2t landform units that resulted in the expanding of grinding power and water carrying capacity.

This erosion process was supported by the loam soil texture on the K3wo landform unit with small clay fraction (11.15%) and high sand (46.95%) causing soil aggregates to become brittle, the reduction of capability of the soil to store water, and the reduction of resist the shear zones and power conveyance of water, so that erosion became large. In landform units of D4j and D2wu, the rate of runoff was reduced by slight slope coupled with moderate soil organic matter content (3.56% and 3.37%). This caused the improvement of soil aggregates stability, soil structure, and soil ability to store water, and thus reducing soil erosion.

Slope angle controls gravity geomorphic processes. Slope or relief affects erosion, transport and deposition. The runoff that flows from the top slope to the foot slope carries soils and sediments. The slope and slope length can affect soil erosion processes by influencing the amount of rainfall that is absorbed and water storage in the soil top soil displacement that is accelerated by erosion and the direction of movement of materials in suspension or solution from one place to another (Hakim et al., 1986). Although the D2wu landform unit had a rather steep slope (32,5%), but its slope length of 59,5m, medium organic matter content (3,37%) and clay soil texture (50,59% clay, 36,95% silt, and 12,47% sand) made the soil to have stable soil aggregates, compact soil structure, and high soil water capacity, so that the soil loss due to erosion remains small. This happens because the clay-textured soils have high cohesive forces between particles of soil (Seta, 1991), so that ability of the soil to defend itself from the water surface erosivity is strong. Therefore, soil that is dominated by clay has strong bonds among soil particles, which makes the soil not easily eroded (Asdak, 2002). The low soil loss due to erosion in this D2wu landform unit was supported also by the use of a mixture of garden that made the soil to have medium density. Plant canopy can reduce the strength of grain mashed of rain. Soil conservation techniques of terraces with rice and corn crop rotation can reduce haul age flow so that the surface erosion gets smaller. Plant canopy can prevent spark erosion due to rainfall passing directly through the water (Asdak, 2002), and reduce the rate of erosion by reducing the destructive force of the rain that falls and the number of damaged power of flow surface (Suripin, 2002). Terrace soils can capture run-off (Suripin, 2002), and minimize run-off that allows water to seep into the soil (infiltration) (Seta, 1991).

Results of soil loss prediction showed that sedimentation occurred on the F1 and D4j landform units. This sedimentation occurred because the F1 and the D4j landform units had long slopes (112.4 m and 157 m), 2% and 4% slope levels with 2192-2882 mm rainfall. These conditions led slightly to a reduction in run-off with slope, which was also supported by the organic matter content of the medium, causing more stable soil aggregates, better soil structure, and better ability of soil to water storage which in turn reducing soil erosion. Nevertheless, results of this study showed that erosion had occurred in certain areas of the F1 landform unit having rainfall condition of 2882 mm. This indicates that the erosion in the study area was mainly controlled by the occurrence of rainfall.

***Soil organic carbon loss in the Girindulu watershed***

Soil organic carbon loss in the Girindulu watershed was influenced directly by the process of erosion. Results of this study showed that the D2t, S2n, and K3wo landform units had highest total soil organic carbon loss, while the lowest was observed in the D4j landform unit. The D2t and K3wo landform units had enrichment factor value of 0,930, and that of the D4j landform unit was 0,602. This condition indicates that the soil organic carbon layer above the water surface traversed by the landform unit of K3wo was more transported to the river than the one stored in the soil at each rain event. Soil organic carbon loss due to erosion in the Girindulu watershed began with the degradation process of organic carbon from the repository in the soil body. It was then disclosed due to power grinding of surface water flow from one place to another with the flow on the surface of a deposited (micro-relief) and into the river body water through centralized water flow (gully erosion). Soil erosion affects the dynamics of soil organic carbon through its impact on the following processes: (i) slacking or disruption of soil aggregates, (ii) the removal of carbon by runoff, (iii) mineralization of soil organic matter in place, (iv) the mineralization of soil organic carbon waste lands and redistribution over the landscape and transported on a river, (v) re-aggregation soil through the formation of organo-mineral complexes in the deposition site, and (vi) the accumulation of carbon in the sediments at the site of deposition, floodplains, reservoirs and seabed (Lal, 2003).

Soil erosion is controlled by erosivity of erosion agent, soil erodibility, slope of the land, and natural cover crops (Morgan, 1995). The erosion agent in this case is water run-off from rainfall. In general, the Girindulu watershed has rainfall ranging from 1,941 to 2,882 mm, with the condition of land topography >90% hilly-mountainous. These conditions caused intensive run-off that eroded the soil surface. The kinetic energy of rain is the cause of increased power sliding surface runoff, making the soil aggregate exposed evenly along organic carbon. This results in concentrated organic carbon in the soil surface with a low density, making it easily washed away by runoff when it rains, because it has a relatively low density (<1.8 $mg/m^3$) (Lal, 2003; 2005).

Soil organic carbon loss is exacerbated by the presence of soil degradation and erosion accelerated. The fate of soil organic carbon transported by erosion process is not easy to understand as well. Lal (2003) explained that the fate of the soil organic carbon (SOC) transported along the eroded sediments may:(i) deposited into the nearest whole land, (ii) deposited into the soil prior eroded and barren regions, (iii) is brought into fresh water bodies, and (iv) oxidized and released into the atmosphere. The impact of erosion on soil organic carbon movement path depends on the specific processes involved such as detachment or deposition (Lal, 2005).The amount of soil organic carbon loss on D2t and K3wo D2t and K3wo landform units caused by high rain fall was also influenced by the condition of the sloping topography, especially slopes. Slope angle controls gravity of geomorphic processes. The slope or relief influences erosion, transport and deposition of soil organic carbon. The medium contents of soil organic carbon (3.56% and 3.37%) on the D4j and D2wu landform units contributed to the reduced rate of soil organic carbon loss because along with the soil texture of containing high clay caused soil compaction and it was easily eroded. Transport processes of soil organic carbon in a landscape are influenced by stable aggregate size of soil eroded. Carbon is the most stable fraction (fine silt and clay), the highest possible only represent 8% of the total soil carbon losses from soil watershed into the aquatic ecosystem. Thus, only the largest aggregate is transferred at a short distance during a rainfall. Large aggregate that is accumulated on soil surface, will be affected by re-precipitation, solar radiation, extreme temperature variations, dramatic variations in water content, agricultural equipment, and other destructive processes that can cause more than the aggregate interference occurs when a single rainfall.

Effect of combination of processes on destructive surface can weaken the protection of physical SOC on aggregate to the soil and can cause an increase in carbon dioxide emissions (Lal, 2003). In general, the land in the study area has been used by farmers as cultivated agricultural land. This condition would disrupt of soil organic carbon balance, especially by the activities of agricultural cultivation that enlarge soil depletion such as land clearing, plowing, drainage and other disorders. These activities then result in a reduction in the quantity of root biomass and crop residues, which returned to the soil, the distribution of the elements and the water cycle and changes in energy balance. As a result, the SOC pool shrank by an increase in the rate of oxidation and loss due to erosion and leaching (Lal, 2003).

### *Impacts of soil and soil organic carbon losses in the Girindulu watershed*

Erosion process that caused soil and soil organic carbon losses affected the reduction of the soil organic carbon content in the Girindulu watershed. Soil erosion was mainly influenced by the geomorphology condition of the Girindulu watershed that was dominated by structural and denuded hills, sloping topography and, in some places, there was a fault. When it rains, the fault serves as a gathering place for water runoff and flow into the waters of the Girindulu river body. Erosion process except the stream sediment, also participated in soil organic carbon flow along the surface run-off sediment suspension, especially organic carbon in the form of fine-sized particles.

The carbon removal process occurred during high rainfall. Types of organic carbon can be transported in the form of particulate organic carbon (POC) and dissolved organic carbon (DOC), from the top layer of soil slopes (hills) to floodplain (fluvial plains), to enter into the body of the river along the river sediment. Carbon value transported by erosion process is determined by a complex series of interactions processes, mainly influenced by rainfall, length and slope. Results of this study showed that the combination of processes that was a destructive surface caused by erosion in the study area physically affected soil organic carbon content of the protection of soil aggregates.

The decrease of soil organic carbon content made the decrease of the capacity of the soil to hold water. This made agricultural lands in the Girindulu watershed were shortage of water in the dry season. In addition, soil cracks occurred in some areas resulting in crop failure. To reduce the rate of soil erosion and soil organic carbon loss in the Girindulu watershed, soil conservation measures that need to be conducted are replanting trees (reforestation) on less productive land, incorporating agricultural residues, mulching, bench terracing, and using organic fertilizer on farmland of 2.0-2.5 t/ha/year. The use of organic fertilizers such as manure on agricultural land is recommended, as the source was locally available. In addition, the application of soil organic carbon storage is also able to increase the fertility of the soil, enhance the humus content, improve soil structure, and encourage the life of microorganisms. Organic matter is a source of micronutrients needed by the plants that improves the balance of nutrients in the soil.

## Conclusion

In the Girindulu watershed area of 73,703.75 ha, there has been soil loss due to the erosion of 9,880,934.7 t/year. This occurrence had an implication for the soil organic carbon loss of 153,120.2 t/year. Soil loss and soil organic carbon loss in the study area were influenced by factors of climatic (rainfall), geomorphologic conditions (presence of faults, and length of slope), soil characteristics (texture and organic matter), and human activity in managing agricultural land.

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