Soil degradation level under particular annual rainfall at Jenawi District– Karanganyar, Indonesia

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Abstract. The study of the climatic elements such as rainfall is vital for the sustainable development of agriculture at a region. The aims of the study were to evaluate the soil degradation based on the annual rainfall and to determine the key factors which responsible for the soil degradation at in Jenawi Sub-District. The mapping of soil degradation potency is an identification of initial soil condition to discover the potential of the land degradation. The mapping was done by overlaying the map of soil, slope, rainfall and land use with the standard procedures to obtain the value and status of Soil Degradation Potency (SDP). The result showed that SDP in Jenawi District categorized in very low (SDP I) 0.00 ha (0.00%); low (SDP II) 109.01 ha (2.57%); moderate (SDP III) 1,935.92 ha (45.63%); high (SDP IV) 1,959.54 ha (46.19%) and very high (SDP V) 238.08 ha (5.61%). The rainfall is the factor which has the strong correlation with the SDP ($r = 0.65$, $P < 0.01$, $n = 306$). The changes in the rainfall as the impact of climate change need to be anticipated to minimize soil degradation. The result can be adapted to the rainfall changes in various ways based on local soil-land characteristics.

1. Introduction

Global warming is currently one of the world’s most challenging issues. The effect of anthropogenic changes to the land and atmosphere on climate change is being pursued as a dynamic multi-disciplinary problem. Increases in atmospheric greenhouse gases, i.e. water vapor, carbon dioxide, methane, nitrous oxide and ozone are considered the major reason for global warming. The land is a part of the resources that important on the biomass production, so its sustainability must be maintained to keep the function, and stay sustain for life that goes both above and below the earth surface. The importance of land is not only for its function as an anchorage for plants and the supplier of important resources and footholds, but also as a part of the ecosystem [1]. The process of land to produce biomass cannot be separated from the existences of the soil damage, which caused by several factors both natural and human activities. The soil damage may result in the decrease of land productivity. Rain is one of the main factors in triggering soil erosion and thus leads to the soil damage. The soil eroded by the effects of rainwater, especially on cropland will cause the decreasing on the quality of physical, chemical, and biological properties of the soil; also reduce the nutrients and organic matter, as well as decline the productivity.

In recent decades the impact of global climate change has also affected the increase of annual rainfall as the result from rising air temperature due to global warming. That will lead to more water...
evaporating into the air, so that the potential for heavy rainfall will also highly increase [2]. According to the Regulation of the Indonesian Minister of Environment No. 7 of 2006 who stated that the higher the rainfall the higher potential of soil damage. The aims of the study were to evaluate the soil degradation based on the annual rainfall and to determine the key factors which responsible for the soil degradation at in Jenawi Sub-District. This result will be an information to identify areas with high rainfall and need more attention and anticipation to prevent land damage.

2. Materials and Methods
The research was conducted in Jenawi district, Karanganyar regency which consists of 9 villages namely Anggrasmanis, Balong, Gumeng, Jenawi, Lempong, Menjing, Seloromo, Sidomukti, and Trengguli. The materials used were thematic maps, i.e.: land map, rainfall 1: 50,000 [3], slope [4], and land use 1: 25,000 [4]. The tools used included a set of survey tools and ground investigations, computers and software ArcView GIS 3.3 [5]. The land maps were made with transect method survey followed by a soil profile investigation and then completed with the analysis of soil samples in the laboratory [6][7][8].

The mapping of land damage potential based on the land units from the uniformity resulted from overlaying rainfall, slope, and land use map using ArcView GIS 3.3. The overlay land units were scored based on the multiplication of the soil weight and the land rating (See Table 1), the slope (See Table 2), the rainfall (See Table 3), and the land use (See Table 4). The scoring results were then classified to obtain several classes of the land damage potential (See Table 5). The type of the land use under study is an effective area for biomass production in the form of forests, rice fields, gardens, shrubs, grasslands, and moorlands. The mapping of potential land damage following standard procedures in [9][10].

The correlations between factors of the potential soil degradation were determined using the correlation analysis and the Pearson’s correlation coefficient was calculated as well. All statistical analysis was performed with SPSS Statistics 17.0 software.

Table 1. The assessment of SDP based on the soil types

| Soil types         | SDP      | Scores | Status | Weight score (score x status) |
|--------------------|----------|--------|--------|------------------------------|
| Vertisols          | Very low | 2      | 1      | 2                            |
| Oxisols            | Low      | 2      | 2      | 4                            |
| Alfisols, Mollisols, Ultisols | Moderate | 2    | 3      | 6                            |
| Inceptisols, Entisols, Histosols | High  | 2      | 4      | 8                            |
| Spodosols, Andisols| Very high| 2      | 5      | 10                           |

Table 2. The assessment of SDP based on the land slope

| Slope (%) | SDP      | Scores | Status | Weight score (score x status) |
|-----------|----------|--------|--------|------------------------------|
| 1-8       | Very low | 3      | 1      | 3                            |
| 9-15      | Low      | 3      | 2      | 6                            |
| 16-25     | Moderate | 3      | 3      | 9                            |
| 26-40     | High     | 3      | 4      | 12                           |
| >40       | Very high| 3      | 5      | 15                           |
3. Results and Discussion

The dominant annual rainfall was 3,000 - 4,000 mm/year with the status of 4 (high damaged potential) in the north-central area (Jenawi Village, Trengguli, Sidomukti, Balong, south-east Lempong, Menjing and Seloromo), and eastern part of Gumeng. The rainfall which was > 4,000 mm/year is categorized in the status of 5 (very high potential damage) which is located in Anggrasmanis Village and the west of Gumeng. The rainfall in a small part of the northern area of Seloromo, Menjing, and Lempong villages was 2,000 - 3,000 mm/year which is categorized in the status of 3/moderate (potentially damaged).

In affecting the soil damage, both rainfall intensity and pattern play an important role. The different patterns of the rainfall intensity are: (1) increase; (2) increase then decrease; (3) decrease, and (4) decrease then increase. All the patterns contributed different effects on soil damage [11]. The increase rainfall intensity resulted in the highest sediment, total runoff and sediment concentrations.

The soil type at research site consists of 3 types, namely Alfisols, Inceptisols, and Andisols. According to Table 1, Alfisols with status 3(moderately damage potential) (3) spread in the middle-north of research site. Inceptisols with high potentially damaged status (4) distributed in the north and the middle-south. Andisols with a very high potential damage status (5) are located in the southern area which is on the hillside to the top of Mount Lawu. The slope varies from 0 to 40%, and the top area of Mount Lawu has a slope > 40% with a very high damaged potential status (5). Below the top of Mount Lawu the central part-the south area has a slope of 16 - 40% with potential damage status between 3 - 5 (moderate-high). The central-north area has a slope of 0-25% with a potentially damaged status between 1 - 3 (very low - moderate). Land use type which is effective for biomass production are: (1) forest, the area was 552.07 ha with the status of potential damage 1 (very low); (2) garden, the total area is 877.22 ha with the status of potential damage 2 (low); (3) grass, with total area 1.38 ha with the status of potential damaged 2 (low); (4) paddy field has an area of 544.94 ha with the status of potential damage 1 (very low); (5) the shrubs have an area of 1086.87 ha with the status of potential

### Table 3. The assessment of SDP based on the rainfall

| Rainfall (mm/year) | SDP      | Scores | Status | Weight score (score x status) |
|--------------------|----------|--------|--------|------------------------------|
| < 1.000            | Very low | 3      | 1      | 3                            |
| 1.000-2.000        | Low      | 3      | 2      | 6                            |
| 2.000-3.000        | Moderate | 3      | 3      | 9                            |
| 3.000-4.000        | High     | 3      | 4      | 12                           |
| > 4.000            | Very high| 3      | 5      | 15                           |

### Table 4. The assessment of SDP based on the land use

| Land use                        | SDP      | Scores | Status | Weight score (score x status) |
|---------------------------------|----------|--------|--------|------------------------------|
| Natural forest, paddy field, pure fertile reed | Very low | 2      | 1      | 2                            |
| Mix farm, shrub, savanna        | Low      | 2      | 2      | 4                            |
| Production forest, dry land     | Moderate | 2      | 3      | 6                            |
| Dry land (annual crop)          | High     | 2      | 4      | 8                            |
| Open field                      | Very high| 2      | 5      | 10                           |

### Table 5. The SDP classes based on the final score

| Symbol | SDP      | Weighting score (final score) |
|--------|----------|-------------------------------|
| SDP I  | Very low | < 15                           |
| SDP II | Low      | 15 - 24                        |
| SDP III| Moderate | 25 - 34                        |
| SDP IV | High     | 35 - 44                        |
| SDP V  | Very high| 45 - 50                        |
damage 2 (low); and (6) the moor has an area of 1,183.55 ha with potentially damaged status of 4 (high).

Figure 1. Map of annual rainfall, Jenawi District

Figure 2. Map of soil degradation potency, Jenawi District
The mapping result of the soil damage potential (See Figure 2) shows that most of the areas in the study site are categorized in the high damaged potential with the total area of 1,959.54 ha (46.19%) which is dominant in Gumeng and Anggrasmanis. The medium damage potential with the total area of 1,935.92 ha (45.63%) is distributed throughout the study site and small part in Gumeng. The very high damaged potential status of the total area of 238.08 ha (5.61%) is located in Gumeng, Anggrasmanis, and a small part at Jenawi. While the rest of the total area which is 109.01 ha (2.57%) is categorized as low damaged potential status located in Balong, Lempong, Seloromo, Trengguli, Sidomukti and Menjing. The area with very low damage potential was not found in the study site.

The correlation test showed that slope is the most affected factor on soil damage \( r = 0.76, \ P < 0.01, \ n = 306 \) as it causes the soil erosion. The steeper the slope, the more soil splashes by rainfall [12]. If the steepness of the slope increases twice, then the erosion will rise 2 - 2.5 times. The increasing slope will raise the soil loss \([13][14]\). This is also supported by the results of [15] who stated that the loss of soil will be higher if the slope becomes steeper, especially in uncultivated soil. The second factor affecting the soil damage potential is rainfall \( r = 0.65, \ P < 0.01, \ n = 306 \) as it can increase the surface runoff, soil loss and soil particle displacement [12]. The rain which directly falls on the soil surface and the flow of the surface will accelerate the erosion as the water is not infiltrated into the soil [16].

The third factor which affects the soil damage potential is soil type \( r = 0.61, \ P < 0.01, \ n = 306 \) as the soil damage occurs due to rainfall in certain soil conditions [17]. The soil properties such as texture, organic matter and calcium content will affect the extent of soil damage through its effect on the surface flow [18]. The fourth factor is the type of land use \( r = 0.39, \ P < 0.01, \ n = 306 \). Land use will also promote the surface flow which then leads to soil erosion [19]. The open agricultural system causes big erosion as when the surface flows, most of the C- organic are eroded [20]. On the other hand, the forest land has a higher C-organic content resulted by the accumulation of organic matter on the bottom layer of the forest [21]. Paddy field has a low SDP as it commonly lies on the flat area and the conservation method by the farmer resulting both of paddy bund and terrace maintenance [22].

Rainfall is one of the important factors that affect the soil damage potential. As shown in Figure 1 and Figure 2, there is a similar trend between the rainfall levels and the soil damage potential. The areas which have high potential damage are those with high annual rainfall (\( > 4,000 \) mm/year). The lower rainfall found in the upper and middle areas, the less soil damage occurred. The increasing rainfall intensity will rise soil loss, and thus increase the soil damage potential [13][14]. The changes and differences in the rainfall within a region can cause different levels of soil damage potential. Rain is an external factor of the land damage that cannot be controlled globally. The changes in rain properties are affected by global climate conditions, which also effects the environment and organism. The anticipation on land damage due to rain properties changes is urgent, and shall be supported by observing the landforms such as the slope, soil type, and land use. The conservation-based land management can be implemented to minimize the potential of land damage, especially those caused by rainfall.

Table 6. The Area with the SDP status in Jenawi

| No. | Soil Degradation Potency | Area (ha) | Area (%) |
|-----|--------------------------|-----------|----------|
| 1.  | Very low                 | 0.00      | 0.00     |
| 2.  | Low                      | 109.01    | 2.57     |
| 3.  | Moderate                 | 1,935.92  | 45.63    |
| 4.  | High                     | 1,959.54  | 46.19    |
| 5.  | Very High                | 238.08    | 5.61     |
|     | Total                    | 4,242.55  | 100.00   |

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This study needs a further study to identify the actual soil degradation through detail verification in the field and soil samples analyzed in the laboratory. Similarly with soil water regimes, soil surface roughness, tortuosity, and soil management practices also contribute to the surface flows and soil erosion [23][24][25]. Therefore, the adaptation to the climate change, particularly to rainfall can be carried out in various ways to increase water use efficiency; reduce evaporation, surface runoff, seepage and filtration losses; increase water storage capacity and available moisture range of soils [26].

4. Conclusion
The soil damage potential (SDP) at Jenawi district can be categorized to several classes, namely: very low (SDP I) 0.00 ha (0.00%); low (SDP II) 109.01 ha (2.57%); medium (SDP III) 1,935.92 ha (45.63%); high (SDP IV) 1,959.54 ha (46.19%); and very high (SDP V) 238.08 ha (5.61%). Annual rainfall strongly affected the SDP. The higher the annual rainfall, the more soil degradation occurs. The changes in rainfall properties as resulting by climate change phenomenon need an anticipation to minimize soil degradation based on local soil-land characteristics.

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