Chapter

Determination of the Most Priority Conservation Areas Based on Population Pressure and Erosion Hazard Levels in Lesti Sub-Watershed, Malang Regency, Indonesia

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Abstract

In a watershed, the Erosion Hazard Level (EHL) is usually associated with erosion rate and existing soil solum. In Lesti Sub-Watershed, erosion rate increases every year due to erosivity factor, erodibility, the length and slope, as well as crop factor and land conservation action. Analysis of erosion associated with population pressure has not been much discussed in the Lesti Sub-Watershed. This topic needs to be explored given that the erosion rate that affects sedimentation in the Sengguruh Reservoir, as an outlet of the Lesti Sub-Watershed, cannot be separated from the population activity therein. The population activity and the choice of use of land suppress the land so that it affects the carrying capacity of the watershed. Measuring land strength is usually based on the value of existing population pressure and its effect on vulnerability or erosion hazard level. This study seeks to assess the relationship between erosion hazard level and population pressure, as well as to determine the priority conservation areas in the Lesti Sub-watershed. The research approach uses a mixed method. The results shows that from 12 sub-districts in Lesti Sub-watershed there is 1 sub-district which has high population pressure as well as severe EHL. This sub-district is the most priority area for environmental conservation.

Keywords: watershed, erosion, population, land

1. Introduction

The problem of watersheds is the problem of ecological balance related to the carrying capacity of the environment and its components [1–3]. The environment is defined as a region (region, etc.) as a boundary of economic activity, which influences the development of life in it [4, 5]. Dwelling or hydrological containers of economic activity based on environment are described as watersheds [4, 6].

The conversion of lands of an area of a watershed is due to population pressure on the land indicating there is a role for the community, both on a spatial scale and in general that affects the sustainability of natural resources [7–9]. Population pressure on this land is driven by the unbalanced rate of population growth with the availability of land resulting in increased activity and intensity on existing land or opening new land [10]. Conversion of lands without regard to topographic geological, and carrying capacity of ecosystems causes natural disasters such as landslides, floods and drought [11].

Land conversion is always associated with erosion [12]. Brantas watershed is one of the priority watersheds facing erosion problems [13, 14]. Lesti sub-watershed as part of the Brantas watershed plays a very important role in the preservation of the Sengguruh Reservoir. The Sengguruh Reservoir affects the supply of irrigation water for flood control, and generates most of the electricity in the East Java Province [15]. Erosion from upstream of the Lesti Sub-watershed sub-impacted a reduction in the storage capacity of the Sengguruh Reservoir resulting in an accelerated reduction of water storage from the original plan [16]. The interesting thing is that the upstream area of the Brantas watershed, especially the Lesti Sub-watershed is contributing a large river water flow to the downstream of the Sengguruh Reservoir [16–18].

Previous studies of erosion in the Lesti Sub-watershed show a significant upward trend in erosion rates. Yupi [19] has calculated the rate of erosion in the average of each hectare of land in the Lesti Sub-watershed, which is 30.57 tons/ha/year. The results of the Setyono and Prasetyo studies in 2012 stated that the average erosion rate in each hectare of land in the Lesti Sub-watershed was 105.763 tons/ha/year [20]. Meanwhile, the study of Ma'wa *et al.* [16] got an average erosion rate/hectare of 131,098 tons/ha/year. This research increasingly shows that areas with a high level of erosion hazard are also getting wider, especially in the current conditions.

Analysis of erosion associated with population pressure has not been much discussed in the Lesti Sub-watershed. This needs attention because the rate of erosion that affects sedimentation in the Sengguruh Reservoir as an outlet of the Lesti Sub-watershed cannot be separated from the activities of the residents therein. The activities of the population and the choice of how to use land in fact suppress the land so that it affects the carrying capacity of the watershed. Measuring land strength is usually known from the value of existing population pressures and their effects on vulnerability or the level of erosion hazard.

Research related to erosion in the Lesti Sub-watershed so far has only been influenced by physical factors of the watershed such as slope, vegetation, and soil erodibility [21]. Linkages between population pressures and the extent of the erosion hazard area in determining the most priority areas for conservation are rare [22–26]. The linkage and determination of the most priority areas for environmental conservation are interesting things to be studied further based on environmental science.

2. Materials and methods

2.1 Time and location

The time to complete the research was 12 months from conceptualization, data collection, data analysis and report writing. The research location is limited to the Lesti Sub-watershed as one of the upstream Brantas watersheds (**Figure 1**).

Administratively, the Lesti Sub-watershed is located in Malang Regency with the total area of the sub-watershed is 64,740.84 ha. The research sites cover 12 sub-districts, namely Poncokusumo, Tirtoyudo, Ampelgading, Turen, Wajak, Dampit,

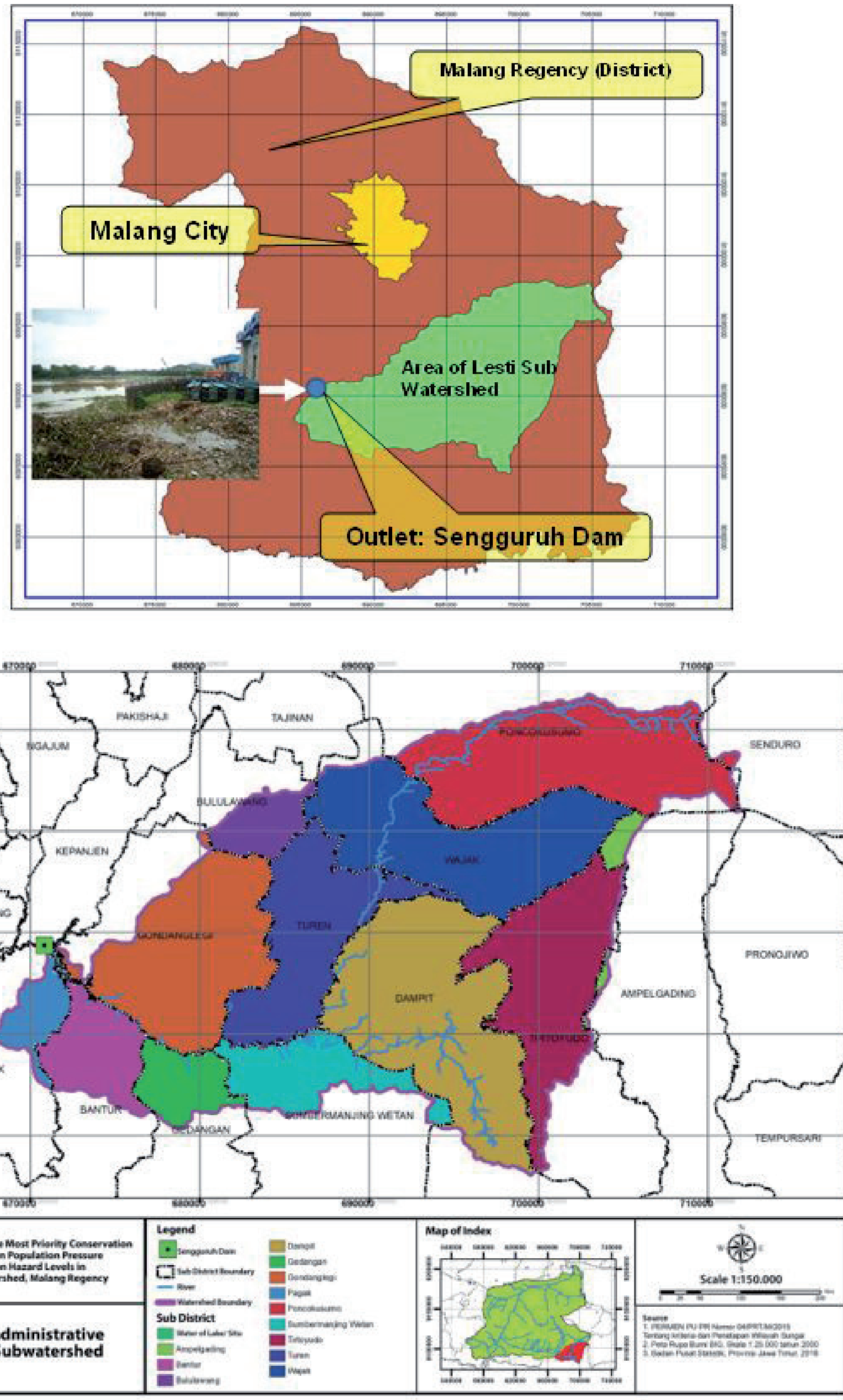

Figure 1.
Study location: Lesti sub watershed, Malang District – East Java Province, Republic of Indonesia.

Bululawang, Sumbermanjing Wetan, Pagak, Gondanglegi, Gedangan, and Bantur Sub-district. The limitation of the study area starts from the headwaters of the Lesti Sub-watershed in Poncokusumo Sub-district to the Sengguruh Reservoir outlet.

2.2 Materials and tools

This research uses several secondary data from related institutions such as: 1) rainfall data in the last 10 years; 2) the latest land use and soil data in 2018 issued by the Office for Watershed Management and Protection Forest Brantas [27] in East

Java, Indonesia; 3) contour spatial data (issued by Indonesia Spatial Information Board), soil type, slope and plant management factors and conservation measures. In addition, several tables were agreed upon by experts from previous researchers. Some secondary data related to the agricultural sector and population from agencies such as the Central Statistics Bureau (BPS) of Indonesiaand the Ministry of Agriculture of Indonesia are also needed, particularly to analyze population pressure in the Lesti Sub-watershed.

2.3 Research methods

The approach used is a mixed method with the population pressure analysis method using the Otto Soemarwoto [28] formula and the projected population growth using a geometric formula. The erosion rate calculation is analyzed using the MUSLE method with the support of Geographic Information System tools [29]. To calculate the erosivity of surface runoff as part of the MUSLE method, a modified rational formula is used. The software used is Arc GIS 10.3, and Microsoft Excel 2019. The level of erosion hazard is obtained by overlaying the erosion rate map analysis results with the soil solum map in the Lesti Sub-watershed in Office for Watershed Management and Protection Forest Brantas [27]. The choice of environmentally sound conservation priority areas based on the results of population pressure analysis >1 that intersects with the level of erosion hazard that is heavy/very heavy at the sub-district scale.

The definition of population pressure on land is a comparison of the number of people with a minimum area of land to live properly [28] (**Figure 2**).

Ideal population pressure is one that can still adjust the carrying capacity of the land. Carrying capacity of land itself is the ability of the environment to support life. The higher the percentage of land that can be used for agricultural land, the greater the carrying capacity of the land [28].

Ariani *et al.,* 2012, stated that the Population Pressure value <1 indicates that there was no population pressure or that the area was still able to meet the population's living needs in more than adequate numbers. TP value equal to 1 means that the area is still able to meet the living needs of its inhabitants appropriately. TP value is greater than 1, meaning that there has been a population pressure on the

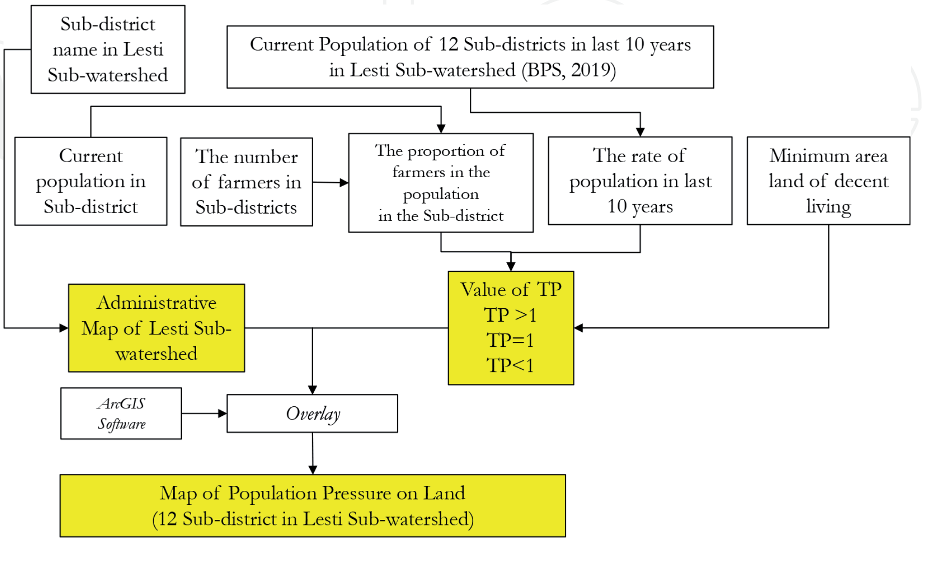

Figure 2.
Flow analysis of population pressure on land in Lesti sub-watershed, Malang District – East Java Province, Republic of Indonesia.

land in an area so that it is unable/able to meet the living needs of its residents properly.

Population pressure on land is calculated by the formula Otto Soemarwoto [28] as follows:

$$TP = Z \text{ x } \frac{\text{f } Po \ (1+\text{r})^{\text{t}}}{\text{L}} \tag{1}$$

where
TP = Population Pressure
L = Total area of agricultural land
Z = Minimum land area per farmer to be able to live properly
Po = Total population of the initial year
F = Proportion of farmers in the population (%)
T = Time span in years
R = The average population growth rate per year

The minimum land area of each farmer to be able to live properly (Z value) is calculated based on the formula as follows:

$$Z = \frac{(0.25\, LSI_2) + (0.5 LSI_1) + (0.5 LST) + (0.76 LLK)}{(LSI_2 + LSI_1 + LST + LLK)} \tag{2}$$

where
Z = Minimum land area per farmer to be able to live properly (ha)
LST = The area of rain-fed rice fields (ha)
LLK = Dry land area (ha)
LSI_1 = The area of irrigated rice field once a year harvest (ha)
LSI_2 = The area of Irrigated rice field from twice a year harvest (ha)

The proportion value of farmers in the population (f) is obtained from the formula submitted by Soemarwoto [28], namely:

$$\text{f} = (\text{Number of farmers / Total population}) \text{ x } 100\% \tag{3}$$

The population growth rate is calculated using the geometric formula as follows:

$$\text{Pt} = \text{Po}(1+\text{r})^{\text{t}} \tag{4}$$

where
r = Population growth rate
t = The time period, which is stated in years
Pt = Total population in the year t
Po = Total population of the initial year

In order for calculating the rate of erosion using the formula of the MUSLE (Modify Universal Soil Loss Equation) in **Figure 3** and below

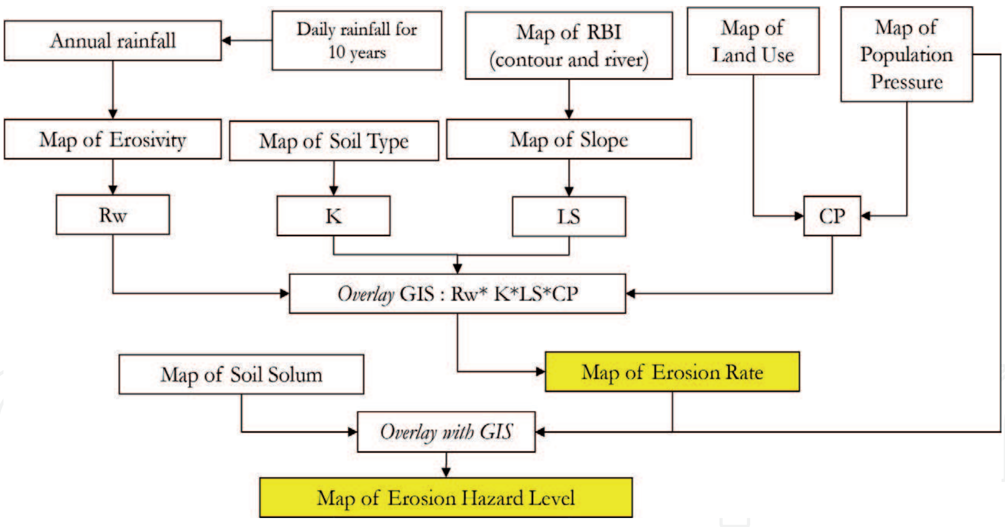

Figure 3.
Flow analysis of erosion rates and erosion Hazard levels in Lesti sub-watershed.

$$\mathbf{A} = \mathbf{R}_W \times \mathbf{K} \times \mathbf{LS} \times \mathbf{CP} \qquad (5)$$

$$\text{where } R_W = 9{,}05\left(V_O \times Q_p\right)^{0{,}56}$$

Note:

- A = Erotion Rate (ton/ha/tahun)
- R_W = Surface runoff erosivity index *(run-off)*
- K = Soil erodibility factor
- LS = Slope factor
- CP = Factors of land use and land management
- V_O = Surface runoff volume (m^3)

Runoff discharge (Qp) is calculated in relation to the surface runoff erosivity (Rw) as part of the MUSLE method erosion estimation formula. In order to get runoff discharge data, several steps are needed, namely: 1) Determining the Flow Coefficient (C); 2) Determine the Concentration Time (Tc), Reservoir Coefficient (Cs) and Rainfall Intensity (I); 3) Calculate runoff discharge and describe it in the form of Run-off Discharge Distribution Maps (surface runoff) in various times with ArcGIS 10.3.

The next step is the calculation of runoff discharge. Determination of the amount of runoff discharge is done through overlays with ArcGIS software. This analysis is done through geoprocessing analysis on ArcGIS 10.3 software. The data used are in Lesti Sub-watersheds (Coefficients Cs and I), land use maps (for C Coefficient). The formula used is the modified rational runoff equation, namely:

$$Q = 0{,}00278.\ Cs.\ C.\ I.\ A \qquad (6)$$

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Sub-districts in Lesti sub-watershed	Total population	Number of farmers	Proportion of farmers	Growth rate population	Minimum land area decent life	Agricultural land area (Ha)	Value of population pressure	Criteria
Poncokusumo	26.221	24.460	0,93	1,53	0,17	4.226,381	0,97,542	< 1
Wajak	74.121	66.292	0,89	1,20	0,19	4.621,481	0,87,528	< 1
Dampit	108.914	89.087	0,82	1,50	0,19	8.361,963	**361,627**	**> 1**
Tirtoyudo	44.121	28.991	0,66	1,44	0,17	3.029,741	0,86,021	< 1
Sumbermanjing Wetan	24.739	15.099	0,61	1,47	0,19	1.548,180	0,55,234	< 1
Turen	107.607	61.445	0,57	1,68	0,16	3.713,927	**368,583**	**> 1**
Bululawang	12.282	4.927	0,40	0,72	0,16	209,196	0,00427	< 1
Gondanglegi	82.052	57.984	0,70	1,50	0,16	5.444,617	**195,847**	**> 1**
Ampelgading	14.823	9.084	0,69	1,24	0,16	307,824	0,13,464	< 1
Gedangan	12.032	5.043	0,42	0,19	0,26	1.329,656	0,00001	< 1
Bantur	20.384	13.051	0,64	0,66	0,26	1.757,160	0,01192	< 1
Pagak	7.683	7.123	0,93	1,49	0,26	1.082,391	0,38,289	< 1

Source: Analysis Result, 2019.

Table 1.
Level of population pressure on land (bold values showed Area with high populationpressure in Lesti-Sub-Watershed).

3. Results and discussion

Based on the existing formula related to calculation analysis for population pressure, the results are as shown in **Tables 1** and **2** and **Figures 4–6**. These results are a combination of spatial calculations with Arc GIS and calculations using Microsof Excel.

The conditions shown in **Table 1**. indicate that there are 3 sub-districts that have level of population pressure on high land, namely Dampit Sub-district, Turen

Number.	Sub-sub watershed	Area (ha)	Result of erosion rate (A) (ton/ha/year)
1	1	2244,760	60,897,267
2	2	1272,640	223,693,161
3	3	2585,000	66,900,000
4	4	4662,400	1,487,060,443
5	5	171,960	7416,818
6	6	3090,400	659,022,308
7	7	317,520	34,850,582
8	8	2945,280	833,252,748
9	9	140,480	3113,887
10	10	2574,120	11,963,945
11	11	4081,720	17,377,677
12	12	2224,800	1,056,466,594
13	13	1464,680	586,835,010
14	14	1653,560	85,246,379
15	15	2388,720	108,713,978
16	16	280,080	6605,734
17	17	1828,480	71,480,000
18	18	4787,960	35,165,209
19	19	1360	521,939
20	20	4800	933,119
21	21	2781,720	648,610,551
22	22	192,040	19,518,057
23	23	1613,120	429,947,887
24	24	1898,440	254,515,524
25	25	1412,760	81,638,228
26	26	2285,200	182,243,500
27	27	2224,520	14,097,787
28	28	1674,480	998,110,000
29	29	4468,480	283,810,000
30	30	2922,560	776,230,000
31	31	4546,800	915,280,000
Total		64,740,84	9,961,518,329

Table 2.
Calculation result related to erosion rate (generated by GIS) of Lesti subwatershed, Malang District – East Java Province, Republic of Indonesia.

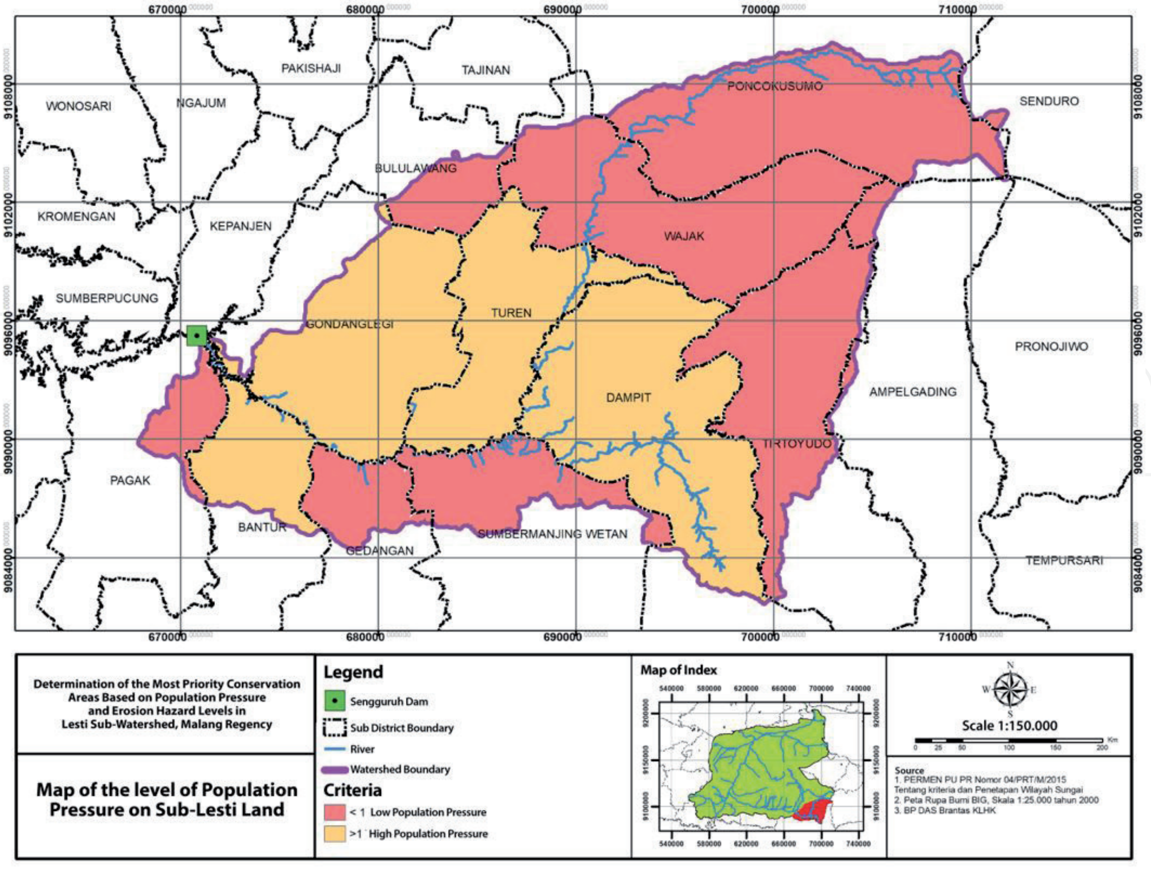

Figure 4.
Map of population pressure conditions in 12 sub-districts of Lesti sub-watershed, Malang District – East Java Province, Republic of Indonesia.

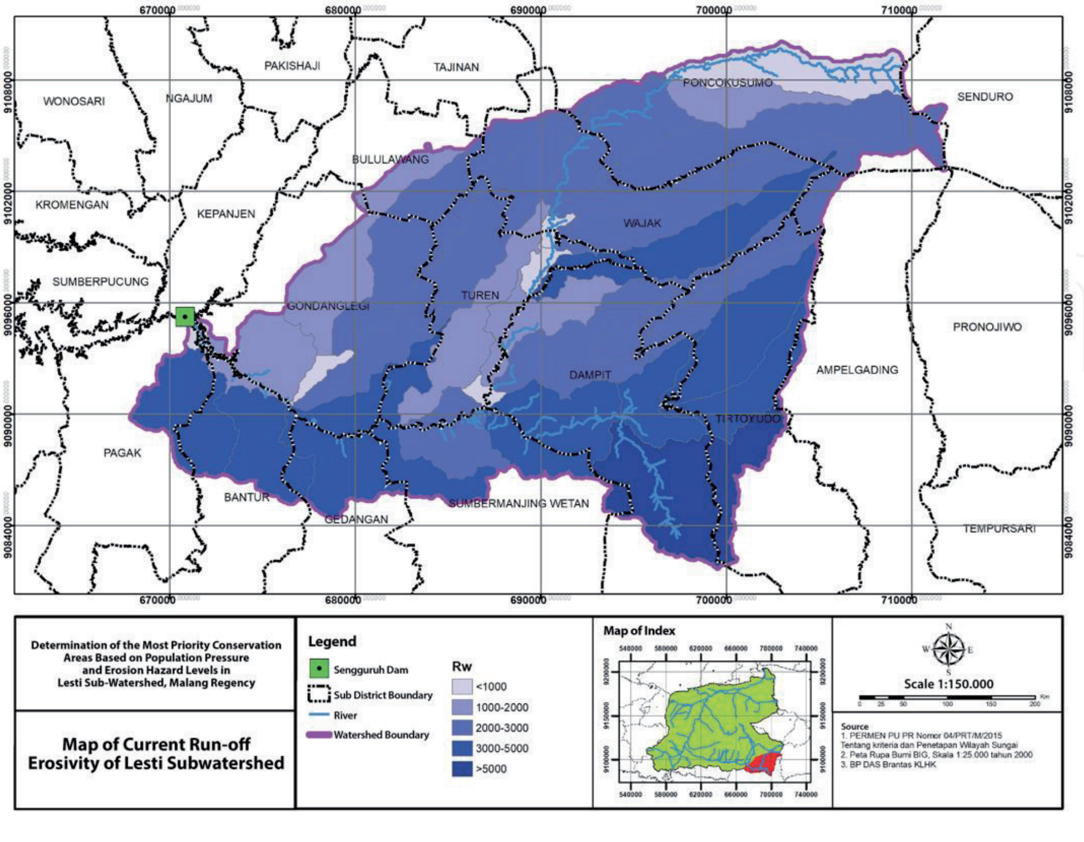

Figure 5.
Map of current run-off Erosivity of Lesti subwatershed, Malang District – East Java Province, Republic of Indonesia.

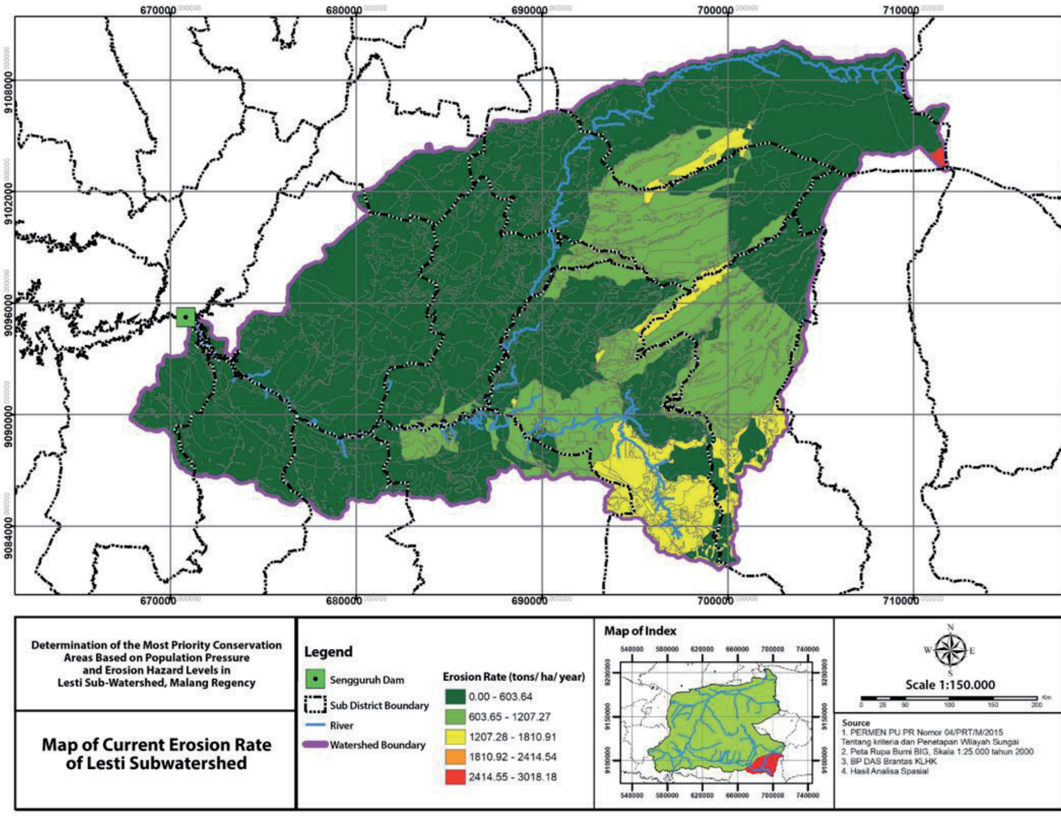

Figure 6.
Map of current erosion rate of Lesti subwatershed, Malang District – East Java Province, Republic of Indonesia.

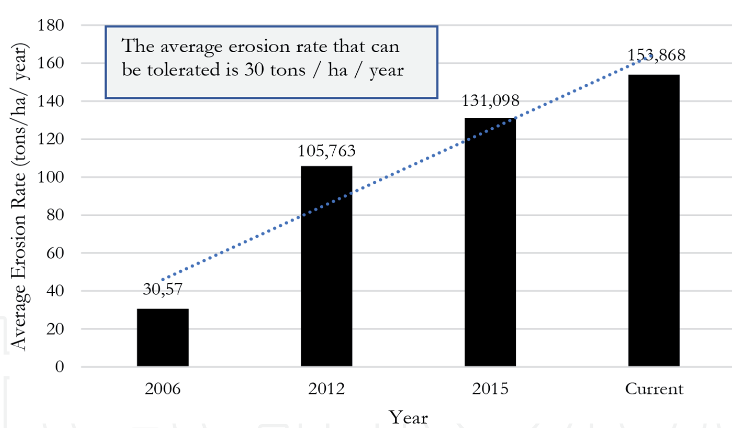

Figure 7.
Average erosion rate of Lesti sub-watershed from 2006 – Present.

Sub-district and Gondanglegi Sub-district. If looked at the current land use, several sub-districts identified as having a Population Pressure (TP) > 1 are on open land.

Based on the results of the above calculations, it is known that the total recent erosion rate in the Lesti sub-watershed is 9,961,518,329 tons/ha/year. Considering that the value of the sediment delivery ratio in the Lesti sub-watershed is 8.247%, the amount of sediment in the sub-watershed is 821,556.3 tons/ha/year.

Meanwhile, with the Lesti sub-watershed area of 64,740.84 ha, it can be calculated that the current average erosion rate in each ha of land in the Lesti sub-watershed is 153,868 tonnes/ha/year (exceeding the tolerable erosion rate of 30 tonnes/ha/year). Previous research results from Yupi [19] stated that the average erosion rate in the Lesti sub-watershed was 30.57 ton/ha/year, and Setyono and Prasetyo's research (2012) was 105.763 tonnes/ha/year. Meanwhile Ma'wa et al. In 2015, the average erosion rate was 131.098 ton/ha/year. **Figure 7**. Based on the results of calculations carried out by the author which states that the current erosion rate is 153.868 tonnes/ha/year, it can be said that there has always been an increase in the erosion rate of the Lesti Sub-watershed since the last 14 years so that better conservation management is needed.

The erosion rate calculation in the Lesti Sub-watershed is used as a basis for obtaining the extent and information on the Erosion Hazard Level Category (TBE) **Tables 3** and **4**. The values estimate the maximum soil loss that will occur on a land. Spatially, the TBE map makes it easy to see the condition of certain areas as conservation priority areas. TBE map is obtained by overlaying the current erosion rate map, behavior map and population pressure map with the soil solum map in the Lesti Sub-watershed **Figure 8**.

Some of the sub-districts identified as having the highest area of Erosion Hazard Levels marked in red on the map are in Wajak Sub-district, Tirtoyudo Sub-district, Dampit Sub-district, Sumbermanjing Wetan Sub-district, Gedangan Sub-district and Bantur Sub-district. As is known Dampit Sub-district, Turen Sub-district and Gondanglegi Sub-district have TP values >1, which means that there has been a population pressure on the land in an area so that it has not been able to meet the needs of its population properly **Figure 9**.

From the standpoint of environmental science, it can be said that erosion which is usually seen from the aspect of carrying capacity of the environment, also has a strong connection with social and economic aspects in the form of pressure. Based on TBE and TP analysis, it was found that 1 sub-district had slices, namely Dampit Sub-district. It is recommended that environmental conservation directives focus

No	ID Solum	Depth	Class of Solum soil	Area (m^2)	Area (Ha)	Percentage (%)
1	A	> 90 cm	Deep	561,419,204,2	56,141,92,042	86,72
2	B	60–90 cm	Medium	68,067,150,77	6806,715,077	10,51
3	C	30–60 cm	Shallow	9,930,132,548	993,0132548	1,53
4	D	< 30 cm	Very shallow	7,991,912,474	799,1,912,474	1,23
Total				647,408,400,00	64,740,84	100,00

Source: Analysis Result, 2019.

Table 3.
Data of solum soil depth in Lesti sub-watershed.

No	Erosion hazard level	Area (m^2)	Area (Ha)	Percentage (%)
1	Very light	115,142,109	11,514,21	17,79
2	Light	113,345,070	11,334,51	17,51
3	Medium	97,183,967	9718,40	15,01
4	Heavy	69,542,700	6954,27	10,74
5	Very heavy	252,194,553	25,219,46	38,95
Total		**647,408,400**	**64,740,84**	**100,00**

Source: Analysis Result, 2019.

Table 4.
Percentage of erosion hazard level of current Lesti sub-watershed.

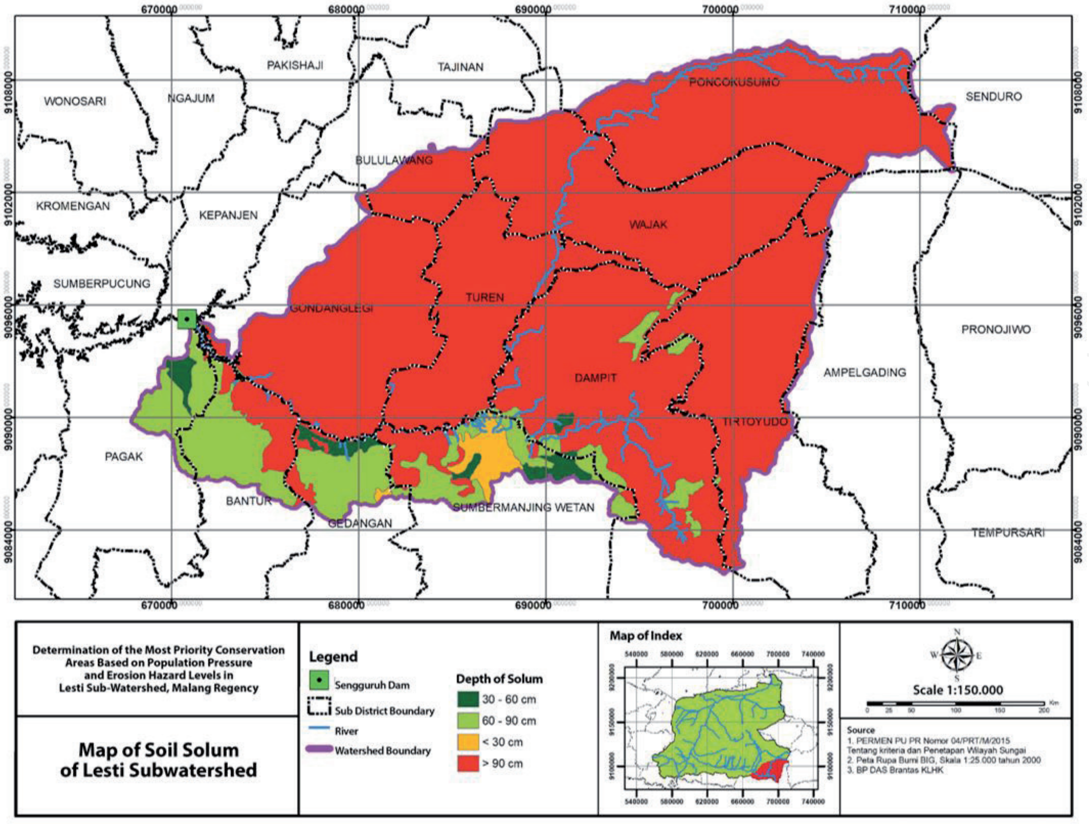

Figure 8.
Map of soil solum of Lesti subwatershed.

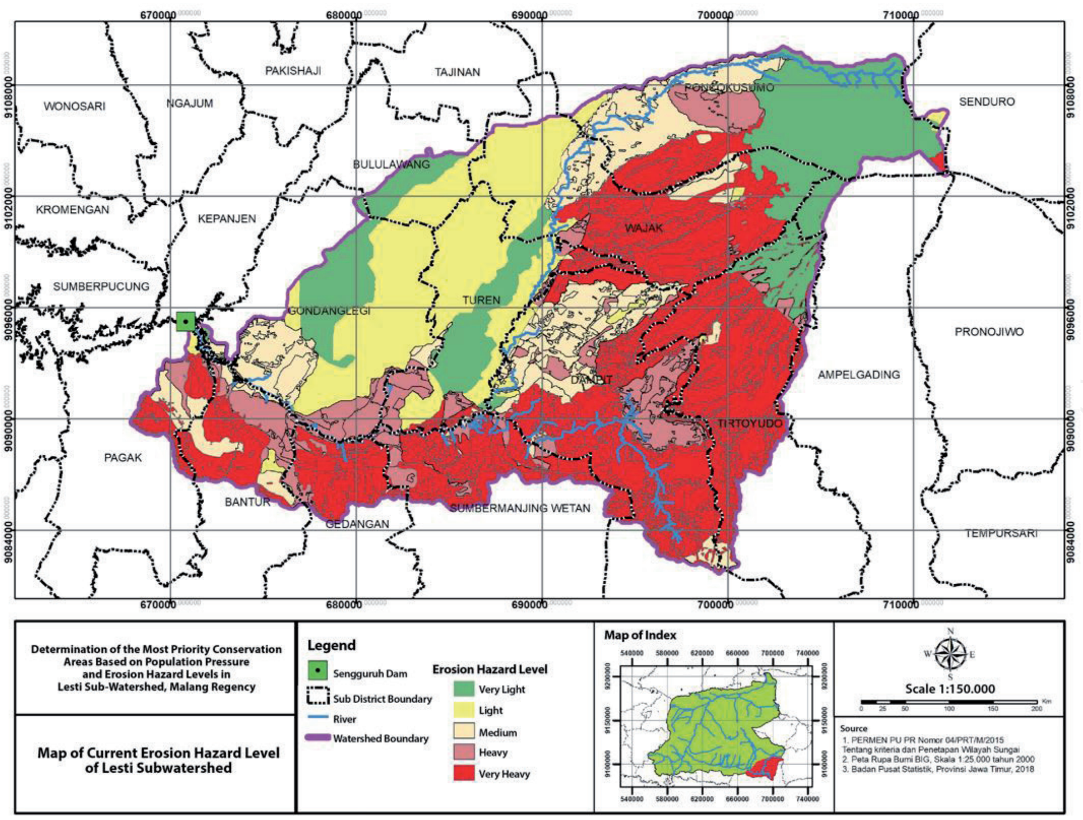

Figure 9.
Map of current erosion hazard levels of Lesti sub-watershed.

on the sub-district through the application of technical, vegetative, agronomic, land and water civil conservation as well as a combination involving the community and in accordance with local conditions.

4. Conclusion

Based on the results of data analysis and discussion, it can be concluded that the Lesti Sub-watershed, there is a correlation between population pressure and the current choice of land use, which results in erosion vulnerability. At high population pressure (> 1) in general is directly proportional to the erosion-prone land use conditions such as settlements, dry land fields and open land. Based on environmental science, the government needs to balance economic, social and environmental needs in several regions. Priority for conservation is prioritized in Dampit Sub-district because it is an area with high TP slices and heavy TBE.

The recommendation that can be given to this sub-district is the provision of subsidies or incentives by the government for people who want to carry out agricultural efforts with conservation principles. This is to reduce the income gap because in some cases of agricultural output will decrease when applying the principle of environmental conservation. In the social aspect, efforts are needed to involve the community with their local wisdom to carry out conservation efforts, both technical civil, agronomic and vegetative so that there is a sense of ownership of government programs undertaken to prevent erosion in the upstream watershed.

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