

SPATIAL ANALYSIS OF EROSION AND LAND CRITICALITY OF THE UPSTREAM CITARUM WATERSHED

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ABSTRACT: High soil sedimentation in the Upstream Citarum Watershed has reduced the capacity of aging Saguling Hydroelectric Power Plant in West Bandung, West Java, a supplier of electricity to Java and Bali. The purpose of this study is to assess the level of erosion danger and land criticality occurring at the Upstream Citarum Watershed to characterize conservation measures to reduce soil and water sediment transfer to reservoirs. To estimate the value of the actual distribution of soil erosion in the river basin, we use the model-based Arc-GIS USLE, which incorporates information on the spatial allocation of each parameter USLE. Cell grid systems available in GIS feature robust functionality; at each grid cell on the map overlay, results can be obtained for the value erosion rate per unit area grid cell, which can then be converted into the speed of erosion per hectare. Simulation results in various fields to control sedimentation caused by erosion in the soil have incorporated the fact that vacant land has been converted into plantations; land adjustment can be simulated with existing spatial planning and the installation of a check dam for sediment control. However, this approach is not optimal to reduce the impact of the age of the reservoirs. To optimize the Upstream Citarum Watershed requires management of various technical and non-technical aspects of the relationships among groups of users and the areas, and of sustainable conservation systems for agriculture.

Keywords: Watershed, River Basin, Sedimentation, Spatial Analyses, Erosion Control

1. INTRODUCTION

Erosion is processing of removal of topsoil by rainwater; this process is influenced by soil erodibility, erosivity, rain, land slope, the type of vegetation and crop management. The impact of erosion is the depletion of the surface layer of topsoil, which leads to land degradation. Another consequence of erosion is the declining ability of the soil to absorb water (infiltration). Erosion in the upstream area of a dam affects sedimentation in the reservoir area, reduces capacity in terms of flood control, and degrades reservoir functionality.

The system lacks integrated watershed management, which leads to high levels of soil erosion. This condition can result in the exacerbation of land criticality in Indonesia. In a land that does not fit this designation, farming techniques are inconsistent with the rules of conservation, and the high-intensity rainfall, topography, and slopes cause high rates of soil erosion [1], [2]. Soil erosion, as a natural process of movement of soil materials and transportation, can be caused by water, wind, gravity, and human disturbances [3], [4], [5].

Agriculture is the primary cause of high soil erosion. A high attrition rate primarily affects developing countries because of intensive cultivation, deforestation, plowing of marginal lands and the danger of extreme climate [6], [7].

Soil erosion is a worldwide environmental problem that threatens the lives of the majority of small farmers [8]. On the cultivation of land, soil conservation requires specific types of vegetation supported by an efficient strategy for controlling soil loss [9]. Approximately 80% of current agricultural land is degraded due to global soil erosion [10], [11]. The practice of sustainable agriculture is challenged by severe soil erosion and reduced on-farm productivity of the soil, resulting in food insecurity [12], [13], [14].

Erosion occurring at the Upstream Citarum Watershed must be treated quickly because the longer that sediment accumulates the greater reduction in water capacity at Saguling. To address sedimentation in the reservoir, the potential erosion of the land must be reduced through a variety of conservation efforts that integrate technical and non-technical approaches. One of the technical efforts is the use of a porous check dam. Porous check dams are the most commonly used mitigation approach because they possess a simple structure effective for soil and water conservation, flood mitigation and flood damage cost reduction. The main purpose of the check dam is to reduce the speed of water and sediment trapping in sewers and prevent additional river soil erosion [15]. A porous check dam releases some of the flow through the structure, reducing the head flow over the spillway along with the dynamic and hydrostatic forces on

the check dam. It is straightforward and inexpensive to construct.

[16] Reported that flood-slowing structures, such as check dams, can reduce the impact of the original sediment by 50% or more. In fact, the water velocity in the river decreases through a reduction of the effective gradient.

Since 1992, the sediment has exceeded the maximum limit of sedimentation allowed into Saguling, which is 4 million m³/year. The sedimentation peaked in 2010, reaching 4.71 million m³/year, and then declined (to 4.26 million m³/year in 2013). This condition must be addressed immediately for the aging reservoir to reach a dead storage of 167.7 million cubic meters. Poor land conditions and high rainfall have resulted in substantial amounts of sediment transported into the river.

The high sedimentation in the watershed land in Citarum has led to a reduction in the capacity of the aging Saguling Hydroelectric Power Plant (HEPP) in West Bandung regency, West Java, a supplier of electricity to Java and Bali.

The purpose of this study is to assess the hazard level of erosion and land criticality that is occurring in the upstream of Citarum, to evaluate conservation measures, to reduce soil and water sediment transport to reservoirs.

2. METHODOLOGY

2.1. Location Research

The Upstream Citarum Watershed section associated with the Saguling reservoir is located at 107° 15'46.27" – 107° 57' 1.99" E and 6° 43'8.65" – 7° 14' 32.09" ± LS with an area of 232,986.02 hectares. Based on the classification of the Citarum Land Rehabilitation and Soil Conservation Group, Upstream Citarum can be divided into 8 subzones, namely, Cihaur, Cikapundung-Cipamokolan, Cikeruh, Ciminyak, Cirasea, Cisangkuy, Citarik, and Ciwidey. The largest subzone is Cirasea (16.51%), followed by subzones Cisangkuy and Ciminyak. Subzone Cikeruh consists of only approximately 8.24% of the Citarum river basin upper section. Administratively, the Citarum river basin on the upstream side enters the following districts: Bandung, West Bandung, Bandung, Cimahi, and Sumedang; a small percentage enters District Garut.

The regional distribution of rainfall in the Citarum in the upper section is uneven. The annual precipitation varies between 1,502 to 2,680 mm with an average rainfall of 1,901 mm in this region. The lowest rainfall is in subzone Citarik and subzones Cikeruh, while the highest rainfall is in the upstream sub-basins and sub zone upstream of Cirasea Cikapundung. These variations in rainfall

occur due to the topography. The wettest month brings 300 mm of rain. In general, the Citarum upstream section is classified as a C-type climate according to the Schmith and Fergusson classification or type Am according to the classification of Koppen. It is classified as wet (> 200 mm) according to the Oldeman climate classification, which is based on the amount of rainfall.

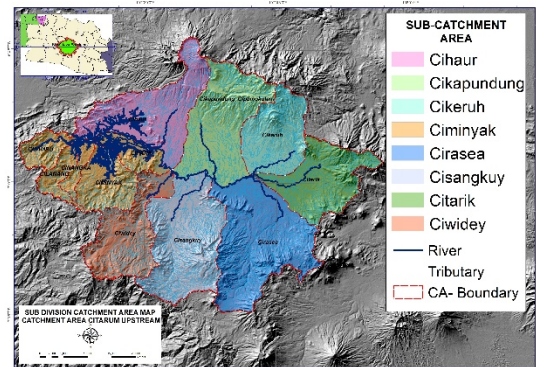


Fig.1 Catchment area of Saguling watershed

According to the shape of region, the Citarum upper section varies from plains to mountains. Upstream of Citarum is a watershed that forms a former lake basin terrain (Lacustrine Plain) as a base and is surrounded by hills and mountains. The Citarum upper altitude ranges from 578 m to 2,582 m above sea level.

2.2. Land Erosion Rate Analysis

The erosion estimation model containing the universal soil loss equation (USLE) is an empirical model developed at the Center for Data Flow and Erosion Surface National, Agricultural Research Service, United States Department of Agriculture (USDA) in collaboration with Purdue University in 1954 [17]. Descriptively, the USLE model is formulated as follows:

$$A = R \times K \times LS \times C \times P \quad (1)$$

Where:

- A = the amount of soil loss (tons/ha/year)
- R = erosivity factor rainfall data from rainfall station Arso
- K = soil erodibility index K sourced from the soil type map
- LS = length and slope index (dimensionless)
- C = crop management index (dimensionless)
- P = soil conservation index (dimensionless)

2.2.1. Land Erosion Mapping

To use the USLE model to estimate the value and the actual distribution of soil erosion in a river basin, we use a GIS system (Institutional Strengthening for Integrated Water Resources Management (IWRM) in the 6Ci's River Basin Territory), which incorporates information about the spatial distribution parameters of each USLE parameter. Various spatial characteristics of each parameter obtained from available maps are digitally inserted in the form of thematic maps and in overlays in the GIS system. Cell grid systems available for the GIS functions are overlaid on each grid cell on the map, allowing estimation of the erosion rate per unit area grid cell, which is then converted into the speed of erosion per km². The map layers used in the analysis of the erosion rate are as follows:

- Map Erosivity R of Thiessen polygon analysis and analysis of rainfall
- Soil type map of the Watershed Management Agency of Citarum
- Map of the digital elevation model (DEM) from SRTM (28.5 m resolution)
- Land use maps of Watershed Management Agency Citarum-Ciliwung

2.2.2. The rate-of-erosion USLE Analysis Method Based on GIS

The analysis of soil erosion conducted using USLE is modeled using the GIS model. This analysis yield results in the form of soil map erosion in the study area. The modeling of erosion mapping consists of several stages as follows:

- Raster Fill Process: Raster fill is used to identify the depth and surface repair. The input data for raster fills are taken from the SRTM digital elevation map of 2000.
- Feature to Raster Process: This feature is used for converting raster feature available data (shape files) into raster data. Input data for the feature to raster process are in the form of iso-erodent (R) and soil (K) maps.
- LS Calculation Process: The slope characteristic factor is calculated using the formula proposed by Wood and Dent (1983) in [18]. The slope characteristics strongly influence the amount of erosion that occurs; this factor is associated with the energy that causes the erosion itself. The LS raster calculation scheme is presented in the figure below.
- The combination process Grid Cell: To calculate the CP factor requires a combination of grid cells between the land use and slope. For groups of different slope, CP factors are obtained that differ

according to each type of land use planning, both factors need to be combined.

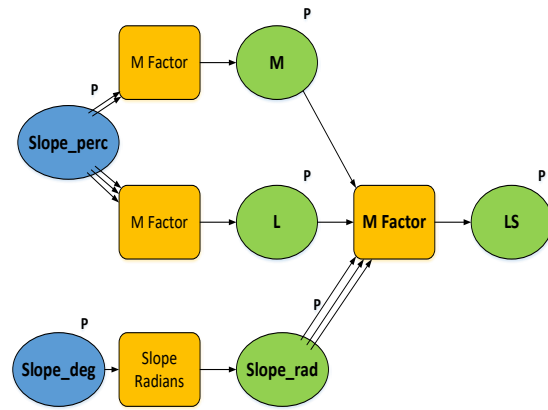


Fig.2 LS Calculation scheme

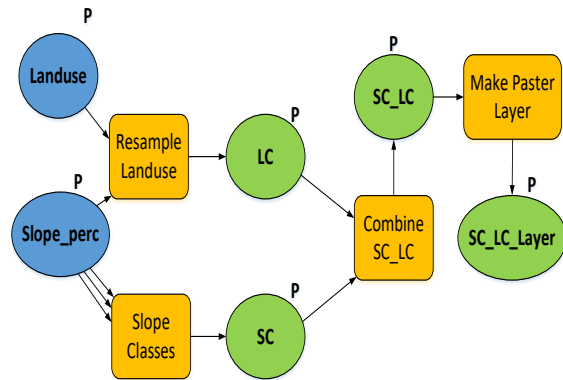


Fig.3 Scheme combination of land use and slope

The C factor represents the ratio of soil loss from a field with specified cropping and management to that from the fallow condition, and P factor of soil loss from the field with conservation practices.

- Classification Process CP: The value factor of CP land management refers to the referenced Java Erosion Model - USLE 30m. The CP management factor is a function of land use, and the group slope value is classified based on the land management level. The CP raster classification scheme is presented, (Fig. 4).
- Erosion rate calculation process: The value and the actual distribution of erosion of soil erosion can be determined by clicking on the fourth overlay raster layer that has been obtained, i.e., the R raster, raster K, raster and raster LS CP. The product of the four raster grid cells provides the soil erosion rate value, as illustrated by the scheme below.

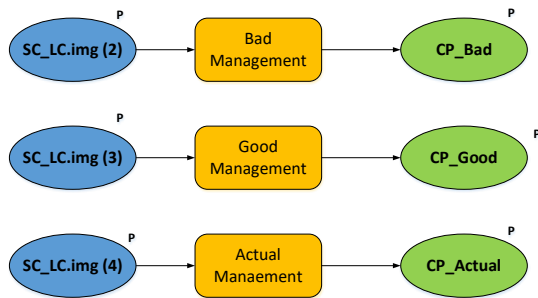


Fig.4 CP Classification scheme

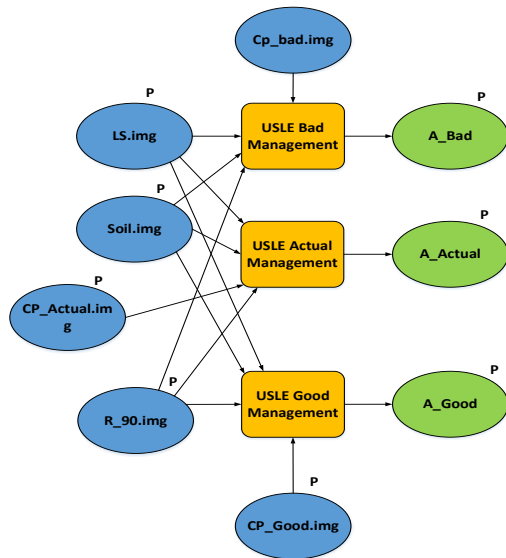


Fig.5 Erosion Rate Calculation Scheme

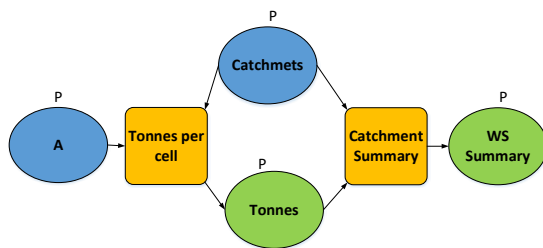


Fig.6 Resumption of the erosion rate calculation

3. RESULTS AND DISCUSSION

3.1. Land Cover Condition

Land use in the watershed upstream of the Citarum, in general, is dominated by rice fields, dry land farming and residential areas, although in some sub-watershed areas, forest plantations and secondary forests still dominate, including the 3rd largest land area in the sub-basins. For example, sub-watersheds Ciwidey and Ciminyak still have plant forest lands of 15.13% and 17.11%, or approximately 0.14% and 0.079% of the area of

Citarum Hulu, respectively. Sub-watersheds Cisangkuy and Secondary Cirasea consist of 11.34% and 14.33% land, or approximately 1.05% and 2.46% of the Citarum upstream watershed area, respectively. However, they are also highly dominated by sub-watershed settlements. Sub-watershed Cihaur settlement Cikapundung contains over 40% land, or approximately 5.1-5.8% of the total area of Citarum Hulu. Dry land agriculture and paddy essentially dominate in every sub-watershed in the upper Citarum river basin except in Cikapundung and Cihaur, (Fig.7).

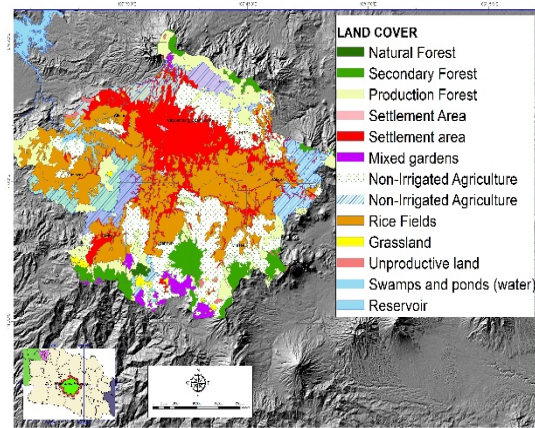


Fig.7 Land cover map (the year 2013)

3.2. The slope of the upstream Citarum Watershed

Topographic characteristics were obtained from SRTM DEM 30 using a cell size (raster) of 25 m \times 25 m for all sub-watersheds. To determine the slope of the land, we used a map of the DEM slope and processed the data using Arc GIS (revealing a slope of 10.1) so that each sub-watershed upstream of Citarum could be analyzed.

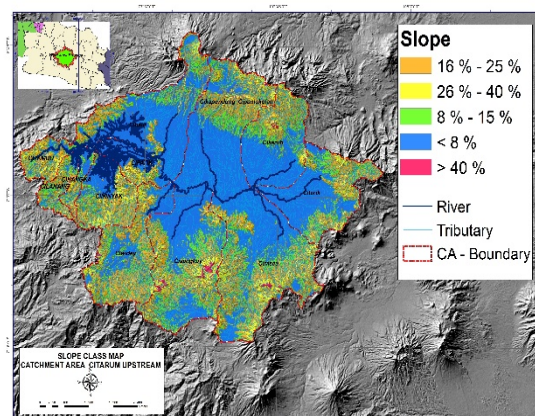


Fig.8 Slope map of the upstream Citarum watershed

The slope in the Upstream Citarum watershed generally ranges between 2% and 15% across an area of 135 million hectares or 57.95% of the Citarum watershed upstream; the slopes greater than 15% are often much higher (i.e., >20%). The slope factors greatly affect the speed and volume of runoff and the runoff is very high for steep slopes greater than 15%. A flat slope (less than 2%) allows rainwater to infiltrate into the soil, decreasing the runoff volume. The reduction in runoff also reduces the tendency for water to erode and carry the soil.

3.3. Soil Type in the Watershed Areas

There are 4 types of soil in the Citarum watershed, namely, latasol, andosol, regosol, and yellow and red pedosol alluvial. The type of soil in upper Citarum river basin is dominated by latosol soil scattered in mountainous areas. Andosol black exists in flat area of Lembang, while developing soil in the Lembang fault is latosol soil. Alluvial soil exists in the river valley. Low-permeability latosol and very low-permeability alluvial soil are highly susceptible to erosion; the kinetic energy of rain can easily erode these soils. The river basins with the highest alluvial soil content are the Cihaur, Cikeruh, and Cikapundung watersheds. These areas are also characterized by the presence of sand mines licensed by the Ministry of Energy and Mineral Resources. These areas are also characterized by high erosion.

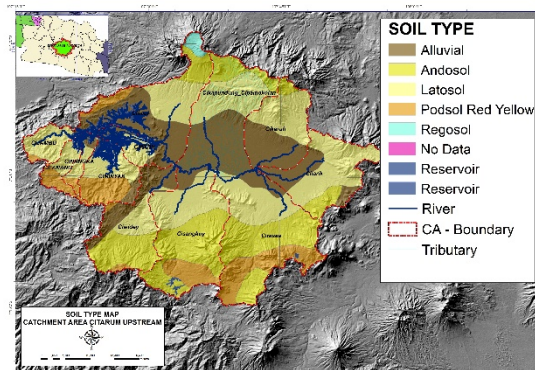


Fig.9 Soil type map (2013)

3.4. Soil Erosion Rate of the Upstream Citarum Watershed

The values of actual soil erosion distribution can be visualized by clicking on the fourth overlay raster layer, that is, the R raster, raster K, raster and raster LS CP. The product of the four raster grid cells provides the soil erosion rate value.

The total value of soil erosion rate that occurs in each sub-watershed requires summary calculations

that provide information about the values of maximum erosion or average rate and the total amount of erosion in each sub-watershed. The conversion of the grid cell values in GIS system is based on the fact that every grid cell has a size of $25 \times 25 \text{ m}^2$. Thus, the total rate of erosion in tons / year is the erosion rate \times number of cells in each sub-watershed \times width \times cell size sub-watershed.

Almost all existing sub-watersheds upstream of the Citarum feature is moderate (50-125 t/ha/y) to severe (125-330 t/ha/y) erosion. Starting in 1990, the condition of all sub-watersheds was moderate; in 2003, there were 3 sub-watersheds with heavy erosion rates: Ciwidey, Cisangkuy, and Cirasea. In 2013, Citarik joined this list. Shown here is a map of the erosion rate (tons / hectares / year) for the Upstream Citarum Watershed:

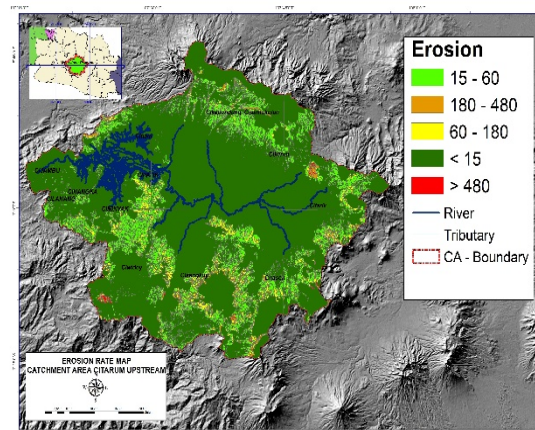


Fig.10 Map of Citarum watershed upstream erosion rate

The result estimation of erosion in this research has been validated with the result of research from Maimun Rizalihadi (2015) and Arman Manalu (2012) on the same condition of land and re-calculated by Citarum River Basin Management Agency Cisanggarung.

Based on Ministerial Regulation 4 of 2009, the poor erosion criteria included data 5 mm/year. The watershed conditions upstream of Citarum since 1990 have approached an unfavorable level and are expected to be classified as poor next year (Table 1).

Table 1 The erosion rate upstream of the Citarum watershed

Year	The Erosion Rate of Citarum Upstream		
	(t/y)	t/ha/y	mm/y
1990	14,462,686.53	62.04	4.34
2003	26,190,717.98	112.41	7.86
2006	27,923,226.15	119.85	8.38
2013	32,073,995.34	137.66	9.63

Source: Analysis Result

Figure 11 shows the developing erosion rate of past few years. Where the maximum limit of the sediment allowed entering the Upstream Saguling reservoir is 4 million m³ per year.

Generally, the erosion rate has continually increased every year, although decreases have occurred in certain sub-watersheds due to reforestation efforts from 2003 to 2008 to improve the condition of vegetation land; the results are detectable for several years,

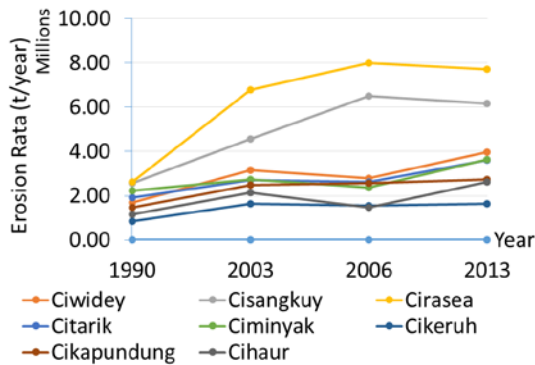


Fig. 11 Resume the erosion rate calculation

However, after 2013, we observe encounter land degraded which shown by an increased rate of erosion. Thus, any improvements were temporary.

3.5. Erosion Danger Levels Upstream Of The Citarum Watershed

Overlay results maps of rainfall, soil type, slope grade, and land cover and distribution maps of the Erosion Hazard Level (EHL) results upstream of the Citarum watershed are shown in Figure 12. Figure 6 indicates that the Citarum river basin is still largely classified at a class EHL 1 level of erosion danger.

Table 2 The Erosion Rate Upstream Of The Citarum Watershed

EHL (t/h/y)	Year (ha)		
	1990	2006	2013
Light (15-60)	178,673	184,495	155,824
Medium (61 – 180)	27,342	32,877	24,845
Weight (181 – 480)	21,888	13,057	28,329
Very Heavy >480	5,081	2,555	23,985
Total	232,986	232,986	232,986

Source: Analysis Result

The Area with heavy EHL (180-480 t/ha/y) increased from 1990 value of 21,000 hectares to

28,000 hectares in 2013, and areas with very heavy EHL (> 480 t/ha/y) increased from 5,000 hectares became 23,900 hectares.

3.6. Critical Land in the Upstream Citarum watershed

Land cover changes such as vegetation is one causes of land reaching a critical status. Declines in forest covers occurred due to the opening of forest lands for dry farming land and the proliferation of illegal logging. Forest clearing for dry land agriculture occurs because of the agricultural conversion land into settlements,

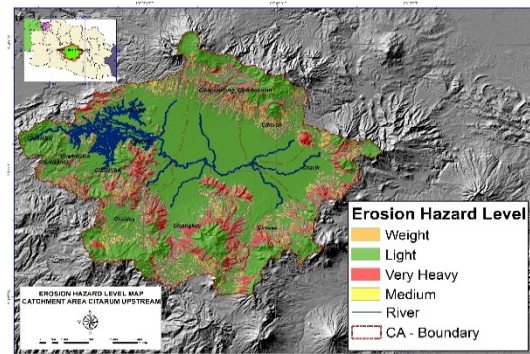


Fig.12 Erosion hazard level map (year 2013)

which are later cleared for agriculture. The critical potential is huge increasing year by year, reaching 37.49%, and the area mostly consists of 87,450 hectares forest.

Based on pictures and tables, the Citarum upstream forests are most important at the Ciwidey Watershed, reaching above 20% with an area of over 45 hectares of critical land and 87 hectares of watershed land. The population of this watershed increased between 2-fold and 3-fold in the last 20 years and the residents have begun clearing forests for agriculture because the most productive farmland has been used for residential, commercial industrial and service purposes. Similarly, in other areas of residential land occur. The map sections indicate the areas of priority.

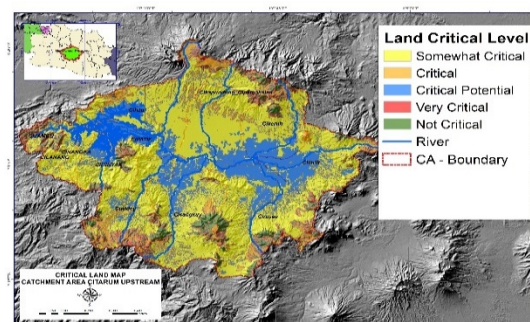


Fig.13 Critical Land Map (Years 2013)

Because of a decrease in forest cover resulting in an increasing trend of maximum discharge, the overall function of the forest as a buffer runoff has declined, causing a decrease in infiltration, percolation and increased runoff. Forest degradation can be prevented by prohibiting the conversion of forest land to other uses or repaired by replanting (rehabilitation) scrub and bush land PLK mixed with other types of forestry plants.

3.7. Erosion Rate Reduction Efforts

To reduce the high sedimentation at Saguling, it is necessary to lessen the soil erosion rate that has occurred in the reservoir catchment area. Efforts to reduce the erosion rate include attempts to address raindrop kinetic energy and hydraulic gradients in the ground to reduce or prevent transport of land by water.

The simulation of vacant land that is moor and scrubs converted to tree plantations causes' erosion rate was decreased. Empty land results in changes in areas without vegetation; thus, plantations occupying 31.63% of the land tend to reduce erosion by 18.48%. This reduction greatly affects the condition of reservoir sediment occurring, reducing the dead storage amount in reservoirs. An illustration to estimate the erosion reduction will be occurred due to recent land changes is shown in the picture below:

The rate of erosion of the existing conditions in 2013 was 36.08 million/year. The shrub land and moor areas associated with forest land erosion reduced by 8%. If land use is conducted properly, then the erosion of the entire sector can be reduced up to 50%, a substantial amount. The picture above clearly shows that the simulation is conducted on very limited land because the land is vacant to a certain extent anyway. Thus, the reduction of sedimentation in Saguling does not meet the targets.

For other simulations conducted on the spatial pattern plan upstream of the Citarum Watershed, we obtained a sediment value of 4:36 million tons/ year or 0.11 mm/year. The interest area in terms of Citarum Watershed planning, the vegetation is in the critical region. The conditions are adjusted to the Spatial Pattern Standard of 2009; the land states in simulations used of land use in 2013 are adapted to the Spatial Pattern Standard of West Java for 2029.

In addition to simulation of land use, changes can also be simulated in check dam sediment control. [16] in their research noted that check dam sediments such as check dams could reduce the results of the first sediment by 50% or more. In fact, the speed of the water flowing in the river is decreased by decreasing the effective gradient. Many challenges exist; focusing on our efforts of

physically reducing erosion that results in sedimentation in reservoirs. Many solutions proposed to reduce erosion, the most important factor is the human factor; if the land is not altered due to population, a growing number of hectares of farmland and forest in interest could be monitored through efficient management. In the calculation of erosion rate, effective management is predicted to decrease actual erosion by more than 50%. However, a permanent solution is preferred over continuous management.

Studies indicate that the reduction of the erosion rate in a watershed requires a comprehensive handling of various aspects both technical and non-technical; in terms of agriculture, the management of agricultural systems and sustainable conservation is necessary. In addition, public social factors strongly influence the sustainability of the system and the possibility of achieving solutions. [19] Noted negative perceptions regarding the functions, duties, and responsibilities, and authority of relevant institutions. These institutions have overlapping authority but remain effective; their roles and responsibilities have not yet been plotted in terms of management of the Upstream Citarum Watershed. The Upstream Citarum Watershed requires sustainable management of inter-sector, inter-group, and inter-regional users.

4. CONCLUSION

From the various analyses that have been done in this study, it can be concluded that the conditions in the Upstream Citarum Watershed are as follows:

1. The USLE method based on Ar-Gis can determine the rate of erosion at any point located throughout the sub-watershed of the upstream Citarum Watershed. Almost all existing sub-watersheds upstream of Citarum are moderate-erosion (50-125 t/ha/y) to severe-erosion (125-330 t/ha/y) areas. In 1990, the condition of all sub-watersheds was moderate; by 2003, there were 3 sub-watersheds with heavy erosion rates: Ciwidey, Cisangkuy, and Cirasea. In 2013, this list grew to include Citarik.
2. The erosion rate conditions and potential in all parts of the upper Citarum Watershed and the critical level of land can be determined directly from GIS. Areas with heavy EHL (180-480 t/ha/y) increased from 21,000 hectares in 1990 to 28,000 hectares in 2013; the EHL very heavy areas (> 480 t/ha/y) increased from 5,000 hectares become 23,900 hectares over the same period. This land area is vast, and the critical potential increases from year to year, reaching 37.49%; the area is generally located in a forest area of 87,450 hectares. The level of erosion shows the critical condition of the land can be

directly determined to be priority handling in terms of soil and water conservation activities.

3. The results of the simulations in the field to control sedimentation caused by erosion depend on land use (e.g., vacant land vs. plantations). Land adjustment simulation with existing spatial planning and the installation of a check dam to provide sediment control are also factors. All simulations above can be done, but it is not optimal to reduce the reservoirs age impact.
4. Citarum upstream watershed management requires a thorough handling of various aspects both technical and non-technical, and management calls for an ongoing dialog between sectors, groups of users and regions.

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