Land Degradation Identification to Rehabilitate Upper Citarum Sub Watershed for Increasing Water Supply

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Abstract. Land degradation in Upper Citarum gives problem not only for erosion and sedimentation in downstream, but also for decreases the infiltration due to higher surface runoff. The surface runoff from upper Citarum contributed to the flooding downstream, such as Bandung city and West Bandung District. The degraded areas could be determined through analysis of land vulnerability to erosion. The aim of this study is to identify areas vulnerable to erosion and to design a rehabilitation plan to reduce erosion and increase infiltration. It is expected that by doing the land rehabilitation, the surface runoff is decreased and the groundwater is increased.

The land vulnerability is identified by overlaying land cover, land system and precipitation. The result shows that more than 50% of the total areas of Upper Citarum are vulnerable to erosion, 26% are very vulnerable and the rest are moderate to not vulnerable. The recommended activities for land rehabilitation in the vulnerable and very vulnerable areas are determined according to their functions: forest and non-forest. In the non-forest function, the suggested activities are infiltration well, ponds, and planting forest trees; while in the forest function, especially in the protected forest, enrichment planting completed with water trap.

1. Introduction
The Citarum watershed is one of the largest watersheds in Indonesia where there are important reservoirs for power plants and water suppliers, namely the Jatiluhur, Saguling and Cirata reservoirs. The area of the Citarum watershed is 6,614 km2 with the length of the main river 269 km, while the Upper Citarum is only 233,000 ha. The Upper Citarum River originates from springs on the slopes of Mount Wayang, flowing through several districts/cities, namely 1) Regency of Bandung and West Bandung, 2) City of Bandung, 3) City of Cimahi, 4) Regency of Subang, 5) Regency of Garut.

Citarum river, one of the most potential rivers for water supply in West Java, Indonesia, with river basin area of 6,080 Km2. The river flows from Mt. Wayang of 1,700 m above mean sea level and drains into Java Ocean with the annual rainfall between 2,000 up to 5,000 mm per year and the temperature between 180 up to 240 C [1]. The Citarum watershed supplies approximately 7,650 million cubic meters of water per year (m3/year). Currently, approximately 78% of the extracted water is used for irrigation, 14% for industrial activities and electricity generation, and 8% for domestic consumption[2].

Watershed services provided by forest ecosystems are said to provide a range of watershed services, including hydrological regulation in the form of low-flow augmentation, flood control and groundwater recharge, water quality enhancement, and soil conservation[3]. Conversion of natural forest to plantations generally leads to increased evapotranspiration (ET) and therefore to reductions in total
flows, groundwater recharge and dry season flows [4], [5]. In USA, 53% of the water supply originates on forested land, which covers only 29% of the surface area [6]. Forests are also the source of the highest quality runoff, therefore forests play an extremely important role in the provision of water in the U.S. [7]. Forest reduction have affected water yield in the downstream of Upper Citarum Watershed [8].

Since Citarum is claimed to be one of the degraded watersheds, many studies are done there. Fajar et al. [9] made a study about the dynamics of land use change in Citarum watershed. The result shows that the impact of land use change could be used to identify areas prone to flood due to land use change. While Tarigan [10] identified land degradation in Citarum using the scoring method. The study showed that the scoring method was not accurate in a certain location, such as plantation or terraced agriculture area. He suggested to combine the scoring method and inconsistency of land use with land capability classes.

The aims of the paper are to identify areas vulnerable to erosion and to design a rehabilitation plan to reduce erosion and increase infiltration. This activity will increase water availability in the lower part of the catchment especially during dry season.

2. Material and method

2.1. Location and time
This study was done in the upper of Citarum watershed. It is selected due to the erosion and sedimentation in addition to the flooding downstream. Upper Citarum sub watershed comprised of 4 large regencies and 2 smaller regencies. The study was done during 2015-2016.

2.2. Materials
Maps used in this study were: topographic map and RePPPRoT from BIG (1:250,000), land cover and forest function maps from Ministry of Environment and Forestry (1:250,000) and DEM from SRTM (Shuttle Radar Topography Mission) 1 Arc-Second Global downloaded from USGS services.

2.3. Method
a. Identification of land degradation
The land vulnerability areas were determined using method developed by Paimin et al. [11]. By overlaying land system, land cover and rainfall maps, the areas vulnerable to erosion could be determined. Parameters used for this study is presented in Table 1.

| Land system          | Water, buildings | Protected forest, conservation forest | Production forest, plantation | Ricefield, grass field, shrub/bush | Settlement | Dryland, stoney land |
|----------------------|------------------|--------------------------------------|-------------------------------|-----------------------------------|------------|----------------------|
| Swamp, beach         | (1)″             | (1)″                                 | (2)″                          | (3)″                              | (4)″       | (5)″                 |
| Alluvial plains and  | 1                | 1                                    | 1                             | 1                                 | 1          | 1                    |
| valleys              | (2)″             |                                      | (1,5)                         | (1,5)                             | (2)        | (2,5)                |
| Plains               | 1                | 2                                    | 2,5                           | 3                                 | 3,5        | 4                    |
| Fans and lahars,     | 1                | 2                                    | 2,5                           | 3                                 | 3,5        | 4                    |
| teraces              | (3)″             |                                      | (1,5)                         | (1,5)                             | (2)        | (2,5)                |

*Note: The values in the table represent the weighting factors assigned to each land use type for erosion vulnerability assessment.*

Table 1. Parameters used to determine the vulnerability to erosion
Land system | Water, buildings (1) | Protected forest, conservation (2) | Production forest, plantation (3) | Ricefield, grass field, shrub/ bush (4) | Settlement (5) | Dryland, stoney land (6)
--- | --- | --- | --- | --- | --- | ---
Mountain and hilly | 1 | 3 | 3.5 | 4 | 4.5 | 5

*Note *): numbers in the brackets shows the score for each parameter

b. Land Rehabilitation
Priority of land rehabilitation based on the rate of vulnerability especially in the upper part of the watershed. The land rehabilitation in the upper watershed will improve infiltration rate and consequently the water availability will increase. The land rehabilitation not only planting the trees but also building soil and water conservation measurements.

3. Results and Discussion

3.1. Location
Upper Citarum is located in 6 regencies and cities; which are Bandung, West Bandung, Garut, Subang and Sumedang regencies; and Bandung and Cimahi cities. Figure 1 shows the administrative boundaries of Upper Citarum. Figure 1 shows that Bandung and West Bandung regencies were the biggest areas, while Subang only contribute 0.02% of the total Upper Citarum areas (see Table 2)

![Figure 1. Administrative boundary of Upper Citarum Sub Watershed](image)

**Table 2. Areas of each regency in Upper Citarum sub Watershed**

| Regency/city | Area (ha) | % |
| --- | --- | --- |
The biggest contribution to the upper Citarum sub watershed is Bandung regency (59.6% from the total of sub watershed). The position of Bandung regency in the upper area of Citarum makes all activities and land conservation in Bandung Regency affects the condition of Citarum watershed.

3.2. Rainfall
The average yearly rainfall data derived from 22 rainfall stations in Citarum watershed is presented in Figure 2. It shows that on average more than 2,000 mm rain fell in Citarum watershed yearly. Those amounts of water became flood during rainy season.

![Figure 2. The annual rainfall in Citarum Watershed](image)

The graph shows that conserving rain water during rainy season could be used during dry season. Rehabilitate the upper watershed by put as much water as possible into the ground could reduce the volume of flood. Based on the above rainfall data, Citarum watershed is not in the condition of water shortage. Unfortunately, the abundant precipitation turned into runoff and end up as flood before they have the opportunity to infiltrate into the soil. Therefore, the water availability is not sufficient during the dry season.

3.3. Land cover
The land cover in Upper Citarum is dominated by rice field (27.9% of the total area), while forest areas only cover less than 20% (production forest, secondary forest and plantation). The rice field was spread in Bandung and West Bandung, where the areas are often flooded. Figure 3 and Table 3 shows the distribution of land cover in Upper Citarum.

|          |                |      |
|----------|----------------|------|
| Bandung (regency) | 138,899.8 | 59.6 |
| West Bandung     | 62,783.3   | 26.9 |
| Bandung (city)   | 15,223.2   | 6.5  |
| Sumedang         | 13,157.4   | 5.6  |
| Garut            | 3,053.4    | 1.3  |
| Subang           | 51.0        | 0.02 |
| **Total**        | **233,168.1** | **100** |
Figure 3. Land cover map in Upper Citarum sub watershed

Table 3. Land cover distribution in Upper Citarum sub Watershed

| Land cover                  | Area (ha) | %   |
|-----------------------------|-----------|-----|
| Ricefield                   | 64,944.8  | 27.9|
| Dryland                     | 44,745.6  | 19.2|
| Settlement                  | 41,417.8  | 17.8|
| Dryland mixed with bush     | 31,044.4  | 13.3|
| Production forest           | 27,900.4  | 12.0|
| Secondary forest            | 13,025.1  |  5.6|
| Plantation                  |  4,736.0  |  2.0|
| Water bodies                |  2,256.1  |  1.0|
| Shrubs                      |  1,686.3  |  0.7|
| Bare land                   |  1,221.2  |  0.5|
| Airport                     |   190.3   |  0.1|
| **Total**                   | **233,168.1** |     |

Table 3 shows that forest cover only occupy 17.6% of the total upper Citarum sub watershed, this situation is contradictory to the Law 41/1999 which stated that forest area should occupy 30% of the watershed. Therefore, soil conservation with tree enrichments should be prioritized to reach the minimal forest coverage.

3.4. Regional forest function
The Regional Forest Function is determined based on slope, sensitivity to erosion and rainfall. There are 5 (five) forest function in Upper Citarum: protection forest, production forest, restricted production
forest, KPSA and other used area. More than 77% of the total Upper Citarum is other used areas. It means that forest areas are less than 30%. Figure 4 and Table 4 shows the forest function areas in Upper Citarum.

![Forest function map in Upper Citarum Sub Watershed](image)

**Figure 4.** Forest function map in Upper Citarum sub watershed

| Forest function              | Area (ha) | %   |
|------------------------------|-----------|-----|
| Other used areas             | 180,446.3 | 77.4|
| Protection forest            | 36,014.7  | 15.4|
| KPSA                         | 13,043.6  | 5.6 |
| Production forest            | 2,549.7   | 1.1 |
| Restricted production forest | 1,113.8   | 0.5 |
| Total                        | 233,168.1 |     |

Source: Regional Forest Function map, MEF (2015)

3.5. **Land vulnerability**

Land vulnerability to erosion map derived from overlaying land system, land cover and rainfall maps. The very vulnerable area is located in Bandung regency (16.6%), while the vulnerable to erosion is in Bandung and West Bandung (29.5 and 12.5% respectively). When comparing the area of Bandung regency which is nearly 60% of total upper Citarum area, 46.6% are vulnerable to very vulnerable to erosion. It means that most areas in Bandung regency need to be rehabilitated. Figure 5 shows the distribution of land vulnerability in upper Citarum sub watershed.
3.6. Land rehabilitation for regulating water balance

Land rehabilitation is directed and prioritized in areas that have the highest level of vulnerability as shown in Figure 5. Based on the land cover map (Figure 3), the forest area in the Citarum watershed is only 19.6% of the watershed area. This is still less than what is required in Law 41/1999 concerning Forestry which requires the forest area in a watershed or island to be at least 30% of the watershed or island. Furthermore, for maintaining water flow the plantation area should be less than 40% and forest area should more or same 30% of the watershed area [12].

On the other hand, based on the Regional Function Map as seen in Figure 4, it turns out that the most vulnerable areas are mostly outside the forest area (Other Used Areas). These areas cannot be directly reforested but must be done with an agroforestry pattern because these lands are owned by farmers and most of the owners are small farmers. Their lives are very dependent on their farm land. The pattern of agroforestry is expected to increase the infiltration of rainwater so that it can reduce flooding and increase the yield of water beneath it during the dry season.

To increase water yield during the dry season, besides planting, it can also be done with water conservation treatment. Water conservation in forest areas or gardens with rorak (silt pit), while on farms with ponds, and on residential land with infiltration wells.

During dry years, water conservation on terrace gives important water for tree cultivation [13]. Furthermore, application of tillage system increases water aggregate content from 1.3 to 13.6% of 0–30 cm depth [14].

The Upper Citarum sub watershed which functions as a water producer for urban areas such as Bandung and Jakarta, the management of the Citarum watershed must pay attention to land improvement in the upstream area. Land rehabilitation in the upstream area will get 3 benefits at once, which are reducing flood hazards, increasing water yields, and increasing people's income. The conservation planning for the Upper Citarum sub watershed is presented in Figure 6.
4. Conclusions
Some important findings found during this study are summarised below:
- Identification of the vulnerability of land in the Citarum watershed can help to determine the priority of land rehabilitation.
- Land rehabilitation in the Citarum watershed can reduce flooding in the rainy season and increase water yield in the dry season.
- In addition to land rehabilitation, water conservation in upstream areas can also increase water yield in the dry season.
- Water conservation in forest areas and gardens using water traps, in arela agriculture with ponds, and in residential areas with infiltration wells.

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