LAND USE CHANGE AND FLOOD MITIGATION IN CITARUM AND KALIGARANG WATERSHEDS

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ABSTRACT

Along with the rapid changes of land use from forest to agriculture and from agriculture to industrial and urban areas, flood and erosion events and intensities have been increasing. Upper Citarum Watershed in West Java, where Bandung an urban of around 2 million people is located and Kaligarang Watershed in Central Java that is house of 1.4 million people have been chosen as study area for rainfall, land use change and flood relationship. Flood tended to increase over time in both areas, mainly due to rapid changes in their land use although there were slightly increase of rainfall. Many hydrological as well as rainfall long-term data were not available for these large size watersheds, however by assumption and prediction from hydrological data collected as well as from soil characteristics measured showed the land use, rainfall and flood relationships. In both watersheds, areas of

paddy field and forest that have important functions in flood mitigation continue decreasing. The decrease of paddy field area ranged from 0.2 to 0.3% annually, meanwhile urban area that has negligible water retaining capacity developed 2 to 4.5% annually.

INTRODUCTION

Along with the rapid changes of land use from forest to agriculture and from agriculture to industrial and urban areas (Agus et al., 2004), flood and erosion events and intensities have been increasing. These changes have been perceived by stakeholders as the main cause of flood and erosion.

The main cause of the flood is still debatable, whether due to the anomaly of the climate (Putuhena et al., 2004; Pawitan, 2004), or reduced capacity of soil to retain rainwater (Agus et al., 2003), or siltation in the rivers and dams, but all agrees that flood tends to be more frequent and more serious in catchments undergoing rapid land use changes.

This study focused on finding the main cause of floods in several important watersheds. Long-term hydrological studies on medium to large size watersheds relating to peak flow with land use or peak flow with rainfall are voluminous (Putuhena et al., 2004; Pawitan, 2004), but the integration of both rainfall and land use change data in this kind of study is rare. As such, watershed management may have not targeted the main issues and there was a tendency of blanket recommendation. Therefore, a study to analyze the relationship of land use systems and management techniques on water yield is required. The main objective of this study was to evaluate the main cause of floods on several rapidly changing watersheds for further solutions to mitigate the flood in downstream as well as reduce the erosion rate in the upland.

MATERIALS AND METHODS

Area description

This study included literature review on dominant factors causing flood and actions so far that have been taken to mitigate floods. The second part of the study was the collection and analysis of secondary data from 2 watersheds. Watersheds studied were:

a. Upper Citarum Watershed in West Java Province, and

b. Kaligarang Watershed in Central Java Province.
The Upper Citarum Watershed is located in the upstream of Saguling dam, one of the three main dams, covers 1674.50 km² area. Bandung, a 2.13 million populated people, municipal city as the capital city of West Java Province as well as some part of Bandung district area are located within this study area. Annual rainfall in this mountainous area ranged from 1600 to 2500 mm.

Kaligarang Watershed was the second study area of 189.80 km², situated at the upper stream of Semarang, the municipal city of Central Java, which house of 1.35 million people. The annual rainfall of this watershed was 2500 mm.

Soils in the Upper Citarum and Kaligarang Watersheds were mostly developed from volcanic and deposited materials. Forest was predominant in the upper stream area followed by forested, estate plantation or either mixed garden or upland annual crops. Vegetable crops were planted in the volcanic sloped area in both northern (Lembang) and southern (Pangalengan) mountainous area in the Upper Citarum Watershed. Paddy was planted in terraced paddy in the sloping area when sufficient water is available in all of the watersheds. Flat irrigated paddy area was found in Bandung plain, where flood were frequently happened in the last decade.

Data collection and analysis

Secondary data was collected from several institutes in Bandung, Semarang and Solo. Field measurements of infiltration rate and soil sampling for soil pore distribution from each designated dominant land use were conducted in Upper Citarum and Kaligarang Watersheds. Only secondary data was collected from Upper Solo Watershed. Data and sources are given in Table 1.

Table 1. Data collection and sources

<table>
<thead>
<tr>
<th>Data</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial data (Maps)</td>
<td>Soil Research Institute, Bakosurtanal</td>
</tr>
<tr>
<td>Rainfall</td>
<td>Stasiun Klimatologi Bandung dan Semarang, Puslitbangair, BPHP Dinas Pertanian Semarang, P2TK Gambung</td>
</tr>
<tr>
<td>River discharge</td>
<td>Puslitbangair, BP2TP DAS Solo, BPDAS Pemali Jratun</td>
</tr>
<tr>
<td>Infiltration rate</td>
<td>Field measurements</td>
</tr>
<tr>
<td>Soil physical properties</td>
<td>Laboratory measurement</td>
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</tbody>
</table>
The trends of rainfall on each river as a function of time were analyzed to have rainfall pattern in both watersheds. Changes in land use system were evaluated using aerial photo or remote sensing techniques. Ground checking and land use history collection were performed to validate data obtained from aerial photo or remote sensing. Land use systems were compared with relevant years of flood occurrences. Land uses were delineated for certain years of observation to see the pattern of land use change.

Some undisturbed soil samples from different land use were collected and analyzed to evaluate the potential of water retention capacity within related land use systems. Selected soil physical properties were compared within the similar soil and topo-sequence but different land use to evaluate the effects of land use.

**RESULTS AND DISCUSSION**

**Rainfall changes and their relationship to the downstream discharge**

A long term rainfall data (30 years) for the upper Citarum Watershed indicates that there was a slight increase in the amount of rainfall that occurred in the watershed (Figure 1). Similar trend was also observed for the Kaligarang Watershed based on data from 1986-2000 (Figure 2). In contrast, annual rainfall in the Upper Solo Watershed tended to decrease (Figure 3). Reduction in the amount of rainfall that occurred in the Upper Solo Watershed might be the cause for the decrease in the amount of runoff coming out from the watershed.

\[ y = 7.6158x - 12912 \]

\[ R^2 = 0.0451 \]

![Figure 1. Annual rainfall trend in Upper Citarum Watershed](image-url)
Figure 2. Annual rainfall trend in Kaligarang Watershed

Figure 3. Annual rainfall and runoff trend in Upper Solo watershed

Maximum discharge was shown differently. In all watersheds studied maximum discharge increased over time. Figure 4 shows an example of the trend of 1973-1998 maximum discharge for the Upper Citarum Watershed measured at Nanjung AWLR observation. The lowest maximum discharge observed in 1997 was due to El Nino phenomena that caused drought over the year. The trend for the
increase in maximum discharge over time was observed due to the high siltation that has been occurred in the river. The siltation raised the river floor, which also raised the surface of water flow as indicated by flow discharge data.

The high siltation along the river reflected the high erosion rate in the watershed. The increased maximum discharge in downstream might be probably due to the reduction in the retention capacity of upstream soils and vegetations on rainfall.

\[
y = 1.0808x - 1843.3 \\
R^2 = 0.0434
\]

Figure 4. Qmax (maximum discharge) trend at Nanjung 1973-1998

**Land use changes in Upper Citarum and Kaligarang Watersheds and their effects on water yield**

Pattern of land use change over 30 years (1960-2002) in Upper Citarum and Kaligarang Watersheds over 60 years (1939-2000) are given in Figures 5 and 6. Figure 5a showed that paddy, forest and mixed garden areas decreased over time in Upper Citarum, while upland, shrubs and developed area increased. Similar trend in land use change was observed in Kaligarang Watershed (Figure 5b).

As the consequence for the change in land use was the negative impact on the environment. Paddy field conversion to other uses might increase flood occurrence and siltation on the river. Tarigan and Sinukaban (2001) indicated that paddy field plays important role in filtering sediment and storing water, therefore reduces siltation and runoff.
Paddy field acts also as a determinant factor of watersheds hydraulic condition. Irianto et al. (2001) stated that the increase of 20-25% paddy field area might reduce maximum discharge 5-11%. In addition, water retention of paddy field was almost similar to forest. Result on estimation of paddy field water buffering capacity which based on soil pore and plant canopy interception reached 0.08 m, while for forest was 0.15 m (Tala’ohu et al., 2001). Eom & Kang (2001) found that water storage capacity of paddy field was estimated to be 0.24 m. The water storage capacity of paddy field depends on the depth of ponding confined by the bunds.

Figure 5. Land use changes in (a) Upper Citarum, and (b) Kaligarang watershed
In relation to hydrograph, curve that represents the stream time response of the watershed to precipitation pattern, forest has the maximum lag time while on the other hand urban land has minimal lag time (Cassels et al., 1983). An intensive annual crop transmits rainfall into runoff more readily and was shown at observation on 0.9 ha watershed with 46% upland slope (Agus et al., 2003).

Until 2000, paddy field was the predominant land use in Upper Citarum Watershed (paddy field reached more than 30% of watershed area). But, after 2000 annual upland crop area was more than paddy. Most of paddy field area shifted to developed area (industrial, housing and road) and in small portion to annual upland crop area. Using construction levees that captures rainfall on paddy field in Japan, Ohnishi & Nakanishi (2001) observed peak runoff between two watersheds. They found that peak runoff was smaller and the runoff rate lower in the watershed with the larger paddy area. It was assumed that paddy fields in hilled rural areas catch and reserve rainfall water from their surroundings for cultivation purpose, they reduce the runoff rate and peak runoff discharge.

The conversion of paddy area to settlement/urban area affects rainfall absorbance by increasing the area of impervious soil (Agus et al., 2001).
estimated that the growth of urban area in Citarik sub watershed was 4.5% annually during 1969-2000, while 2.0% during 1939-2000 for Kaligarang watershed (Wahyunto et al., 2001). Most of the rainfall becomes a direct runoff that filled the streams or rivers. Sarief (2004) estimated that a rainfall intensity of 125 mm h\(^{-1}\) that fall into Bandung area would produce about 35 million m\(^3\) of runoff when 30\% of Bandung area covered with impermeable layer.

Figure 6 also indicates an increase in the area of upland crops at Upper Citarum. Most likely that forest conversion contributes to the increase of upland area. Until 1962 forest area was around 23\% while in 2000 only 14\% of the total watershed area. Forest conversion was higher than paddy field, but the converted area was about the same which totally 22,000-24,000 ha. An immediate effect of reducing the density of canopy cover will be a reduction in the amount of gross precipitation intercepted by the forest vegetation.

Until 1998, mixed garden was a predominant practice in Kaligarang watershed but after 2000 developed area was dominance. Forest and paddy conversion were lower than mixed garden. The effectiveness of mixed garden to intercept rainfall is estimated to be 80\% due to its multi-storey characteristics. Therefore, the conversion of mixed garden to settlement complex would significantly increase direct runoff by reducing water infiltration and canopy absorbance.

Tala’ohu et al. (2001) reported that in Citarik sub watershed (26,000 ha), based on the 1969-2000 land use conversion, the predicted water buffering capacity value decreased from 24.4 million m\(^3\) to 20.3 million m\(^3\) (16.8\%). While in Kaligarang watershed, the predicted water buffering capacity value decreased from 17.6 million m\(^3\) to 15.0 million m\(^3\) (14.8\%) during the 1939-2000 period. The reduction in the water buffering capacity of both watersheds is responsible for the water yield reduction in the downstream area.

**Effects of land use change on infiltration and pore distribution**

Land use change affects watershed hydrological characteristics by altering the canopy interception and soil absorbance to rainfall. Rainfall reaches the ground by vegetative interception and through fall. Some of the water used in evapotranspiration process and the rest of rainfall fall unto soils. Amount of water absorb by soil was depend on soil physical condition. Land use change affects soil physical condition by altering porosity that in turn changes the capacity of water absorbance.
Observation showed that land use was the dominant factor affecting infiltration rate, pore distribution and total pore space (Figure 9, 10, and 11) the second factor was soil type. In Upper Citarum watershed, in every land use soil order of Andisols showed better physical properties than Alfisols in all land uses observed. Similar observation was found in Kaligarang watershed where Andisols, Inceptisols and Ultisols were predominant (Figure 9). In each land use observed Andisols were better properties in term of hydrologic role followed by Inceptisols and Ultisols.

Forest and tree crops based farming (estate and mixed garden) had better soil physical properties than annual upland crop system. Terraced upland crops tend to have better soil properties than un-terraced soils. The worst soil be specific based on the observation were housing or residential area. The infiltration rate, drainage pore percentage and pore space were less than others land used.

Even though paddy field had smaller value or less than upland soil be specific (infiltration, BD or porosity) but ponding capacity of paddy resulted in better water buffering capacity.

Figure 8. Soil infiltration rate on several land use in two different soil orders at Upper Citarum Watershed
Figure 9. Soil infiltration rate on several land use in three different soil orders at Kaligarang Watershed

Figure 10. Drainage pore percentage on several land use in two different soil orders at Upper Citarum watershed
CONCLUSIONS

The main cause for the increase of flood frequency and intensity in Upper Citarum and Kaligarang Watersheds is due to the rapid changes of land use although there is a slightly increase of rainfall. With the available data we gathered in these large size catchments we studied, there is a general trend of increasing water discharge. Land use conversion reduced the capacity of both plant canopy and soil to retain rainwater.

In both watersheds paddy field, shifted 0.2-0.3% annually, as well as forest acts as water retention function. Urban area, developed 2-4.5% annually, increases stream discharge. Dominant land use changes are the decrease of forest, paddy field and mixed garden/multistrata area and the increase of annual upland crop and developed area (housing, industrial and roads).
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REFERENCES


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