Hydrological responses of micro-catchments under different farming practices in Banjarnegara, Indonesia

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Abstract. Effects of two different farming practices namely mixed-cropping (i.e. agroforestry) and mono-cropping systems on hydrological responses were investigated based on a paired catchment method. Two catchments namely Tamansari catchment (16.4 Ha) and Penanggungan catchment (3.6 Ha), both are located in Banjarnegara district, Central Java, Indonesia, were studied. Based on drone mapping, the dominant land use of the Tamansari catchment was agroforestry where trees were combined with seasonal crops like cabbage, potatoes and carrots on the same unit of land, whereas the dominant land use of the Penanggungan was seasonal crops without any trees. For both catchments, meteorological data and discharge data were available from May 2017 to March 2018, so that made it possible to compare each other. Furthermore, the hydrological responses of the two catchments were compared for their water balance and the annual, seasonal and monthly Flow Duration Curves (FDC). The results showed that both catchments had their lowest rainfall in August and their highest rainfall in February. Based on the FDC, the Tamansari generally had a steadier flow and the range of discharge values was smaller than the Penanggungan, especially on February, the wettest month of the year. In the drier periods, the two catchments behave similarly, but in general, the Tamansari produced more discharge than the Penanggungan. Finally, based on the observation, it can generally conclude that a micro catchment mostly occupied with seasonal crops like in the Penanggungan catchment reacted more extreme to rainfall than a micro catchment mostly occupied with combined trees and seasonal crops in form of agroforestry like in the Tamansari catchment.

Keywords: discharge, agroforestry, water balance, flow duration curve, paired catchment

1. Introduction

Disaster events can largely impact the land use of an area. But it also works the other way around: the type of land use has an impact on disaster events, which influences the hydrological response of an area. The hydrological responses of the tropical area can be more extreme than in temperate areas. For tropical catchments there is a wet and a dry season, the total amount of rainfall is commonly higher than in temperate regions, the intensity of this rainfall is higher and the evaporation rates are higher [1].

Universitas Gadjah Mada (UGM) is currently doing fieldwork in two micro-catchments, Tamansari (16.4 Ha) and Penanggungan (3.6 Ha), both are located in the Banjarnegara district, Central Java, Indonesia (Figure 1). Erosion is a big problem in the area and also downstream of these two
catchments. Floods are also a problem downstream. In these two micro-catchments, local farmers practiced both agroforestry and monocropping systems to cultivate their crops. Agroforestry is defined as a land-use system in which woody perennials (trees, shrubs, etc.) are grown in association with agricultural crops, pastures, or livestock, in a spatial arrangement, a rotation or both [2]. Monocropping consists of cultivating one type of crop on the same land. Agroforestry, which is the land use of Tamansari, is thought to solve both the erosion and flooding problem. However, the impact land use change will have on the hydrology of the areas, is unknown. To look into the difference in hydrological response on different land use practices, a paired catchment study between a micro-catchment occupied by agroforestry (i.e. Tamansari catchment) and micro-catchment occupied by monocropping system (i.e. Penanggungan catchment) will be performed.

Findings of this study would be beneficial to water management decisions, and specifically for UGM in their ongoing corporation with the farmers to solve erosion and water quantity problems downstream of Tamansari and Penanggungan catchments.

![Figure 1](image_url)

**Figure 1.** Location of the study area (1. Karangkobar sub-district in Banjarnegara district, 2. Tamansari catchment, 3. Penanggungan catchment)

### 2. Method

First, based on drone mapping, the dominant land use of the two catchments were determined. This process included geometric correction to avoid distortion on map coordinates of the drone images. In the image geometric correction, RBI map (1:25,000) produced by Badan Informasi Geospasial, the Geospatial Information Agency of Indonesia, including contour map (contour interval equal to 12.5 m) have been used to extract Ground Control Points (GCPs). For this study, in total hundreds of GCPs were collected and used to carry out image correction resulting ground RMSE is about 5 m. Furthermore, head-up digitizing based on visual interpretation has been applied to delineate land cover and land use in the study area. Second, other catchment physical characteristics such as elevation, mean slope and soil type were also identified based on the secondary data from Karo Karo [3]. Third, hydrological and meteorological conditions of both catchment were assessed and analysed. For both catchments, meteorological data and discharge data are available from May 2017 to March 2018, so that made it possible to compare them to each other. After a data quality check to identify missing and unrealistic values (outliers), to check the minimum, maximum, and mean values, to identify trends in
the data, and to calculate the water balance; adjustments to the data were made, to improve the quality. In addition, the calibrated water levels were converted to discharges using discharge rating curves from Karo Karo [3] for Tamansari and from Putra [4] for Penanggungan. Furthermore, the hydrological responses of the two catchments were compared for their annual, seasonal, monthly and daily flow duration curves (FDC), following procedures from Searcy [5].

3. Results and Discussion
Based on the drone mapping, the dominant land use of Tamansari catchment is agroforestry, where trees are combined with seasonal crops like cabbage, potatoes and carrots on the same unit of land, whereas the dominant land use of Penanggungan catchment is seasonal crops without any trees, see Table 1 for the land cover distribution. Figure 2 shows land use in the Penanggungan that agriculture is the dominant land use of the area. There are two types of agroforestry in the Tamansari, a mixed cropping between trees and agricultural crops, and agricultural crops with trees at the borders. Figure 3 shows example of a mixed cropping and trees along border systems, respectively, in the Tamansari catchment.

![Figure 2. Agricultural crops at Penanggungan catchment](image1)

![Figure 3. Trees as a border of the farmland (a) and Trees in between the crops (b) in Tamansari catchment](image2)
Table 1. Land cover distribution in hectare (percentage)

| Catchment  | Total area | Trees | Crops | Crops with tree border | Mixed cropping | Built-up area |
|------------|------------|-------|-------|------------------------|----------------|---------------|
| Penanggungan | 3.58       | 0.11 (3%) | 3.48 (97%) | -                     | -              | -             |
| Tamansari  | 16.39      | 3.58 (22%) | 2.64 (16%) | 4.11 (25%)           | 5.75 (35%)     | 0.32 (2%)     |

Other characteristics of the micro-catchments include the elevation and mean slope are shown in Table 2. The soil type in both micro-catchments is similar. Tamansari and Penanggungan are classified as Dystropepts, Eutropepts, Tropudalfs. These subgroups fall in the Inceptisols order [6].

Table 2. Elevation and mean slope of Penanggungan and Tamansari catchments

| Catchment  | Lowest elevation (MSL) | Highest elevation (MSL) | Average slope (degrees) |
|------------|------------------------|-------------------------|-------------------------|
| Penanggungan | 1462.5                | 1512.5                  | 17.1                    |
| Tamansari  | 1150                   | 1225                    | 18.2                    |

Based on the annual FDC in Figure 4, the sharp turns identifying the high, mean and low flows of the discharge in Penanggungan were located around 10 mm per day for the high flows and 0.5 mm per day for the low flows, with the exceedance frequencies of 0.03 and 0.95 respectively. For Tamansari, the sharp turns were located around 7 mm per day for the high flows and 0.5 mm per day for the low flows, with the exceedance frequencies of 0.04 and 0.93 respectively. The line in the mean flow regime was more horizontal, which meant that the mean flows in Tamansari were steadier than the mean flows of Penanggungan.

Figure 4. Annual FDC Penanggungan (April 2017 – March 2018) and Tamansari (July 2017 - April 2018)

Based on the seasonal FDCs, for the dry season a low variation in the discharge and a similar shape can be observed in Figure 5a. It is observed that a turn towards the higher flows and a small drop towards the lower flows. The discharges in the dry season are lower for Penanggungan than Tamansari, contrary to the wet season. For the wet season, Figure 5b, the high and low flows were distinguishable. For Penanggungan, the sharp turns of discharge were located around 13 mm per day for the high flows and 1.1 mm per day for the low flows, with the ratios of exceedance of 0.05 and 0.93 respectively. For Tamansari, the sharp turns were located around 6.3 mm per day for the high flows and 0.4 mm per day for the low flows, with the ratios of exceedance of 0.07 and 0.91 respectively. It was observed that the sharp turns of discharge were sharper in Penanggungan than
Tamansari. The discharges in the wet season are higher for Penanggungan than Tamansari, contrary to the dry season.

The results showed that both catchments had their lowest rainfall in August and their highest rainfall in February. Based on the monthly FDCs, on August (Figure 6a), the month with the lowest rainfall, both catchments showed a similar FDC shape: a steady and almost horizontal mean and low flow and a slight turn into the higher flows, where Penanggungan had a slightly steeper change into the higher flows than Tamansari. While on February (Figure 6b), the month with the highest rainfall, the shape of the FDC of Penanggungan shows the high and low flow regime better than the FDC of Tamansari, as the flows are more extreme for Penanggungan. However, both shapes are not completely horizontal and show some bumps, which makes it hard to locate sharp turns from the mean flows into the high and low flows. A notable difference is that the range of high flows is larger for Penanggungan than for Tamansari.

Figure 5. (a) Dry season FDC Penanggungan (May 2017 - September 2017) and Tamansari (July 2017 - September 2017); (b) Wet season FDC Penanggungan (November 2017 – March 2018) and Tamansari (November 2017 – March 2018)

Figure 6. (a) Driest month FDC Penanggungan (August 2017) and Tamansari (August 2017); (b) Wettest month FDC Penanggungan (February 2018) and Tamansari (February 2018)
However, it should be noted that for the Tamansari figures are not based on 12 complete months of data; half of the dry season is missing. Therefore, conclusions may not be valid for the whole year or dry season. As for general conclusions, this study can only conclude based on one year of data, and thus conclusions should not be interpreted as a hard truth for every year.

4. Conclusion

Based on the observations, it can generally be concluded that a micro-catchment mostly occupied with seasonal crops like in the Penanggungan catchment reacted more extreme to rainfall than a micro-catchment mostly occupied with combined trees and seasonal crops in form of agroforestry like in the Tamansari catchment. The results of the FDCs supported this observation, by showing the Tamansari generally had a steadier flow and the range of discharge values was smaller than the Penanggungan, especially during the wet season and February, the wettest month. In drier periods, the two catchments behave similarly, but in general, the Tamansari produced more discharge than the Penanggungan. These conclusions are in line with Brown et al. [7], Bruijnzeel [8] and Mwangi et al. [9].

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