The Impact of Land Use Change on Water Resources in The Southern Foot Plain of Merapi

Suhadi Purwantara, Slamet Suprayogi, M Pramono Hadi and Ig L Setyawan Purnama

Department of Geography and Environment Gadjah Mada University,
Kampus Bulaksumur, Yogyakarta
suhadi_p@uny.ac.id, suhadi.purwantara@gmail.ac.id, ssuprayogi@ugm.ac.id, mphadi@ugm.ac.id, igiwan@ugm.ac.id

Abstract. Population growth has resulted in the increase of settlements. Settlements in urban areas are getting crowded, including many hotels that require abundant water supply. Groundwater needed by the population is huge. Settlement constructions cannot be stopped. The next target area is land outside the urban areas. Some areas outside the northern urban areas are water catchment areas, the southern slopes of Merapi. Based on these problems, the major changes of land and river flow coefficient, one of the rivers on the southern slope of Merapi are studied.

The sample of the research is the river flow area of Code. The Code catchment area shape extends from the south to north. The flow coefficient is calculated based on the comparison of annual water volume between 2003 and 2012. This year sampling considers data completeness, land use data, rainfall data, and current data in Pogung Automatic Water Level Recording (AWLR).

The results show that a change in land use over the past 10 years has occurred. The total volume of river water in 2003 was 15.3 cubic meters, while the volume of flow in 2012 was 41.7 cubic meters. The value of the flow coefficient in 2003 was 0.262, while the flow coefficient in 2012 was 0.636. This research suggests that it requires to be built 180,400 recharge wells. The artificial recharge model is adapted to the topography, groundwater depth, and infiltration of each region.

Key words: settlement, groundwater, recharge

1. Introduction

Merapi volcano is located in the center of Central Java Province. 30 km to the south of the mountain lies the city of Yogyakarta. The urban area of Yogyakarta today has expanded into the countryside. The expansion of the city to the north part has caused many problems such as the increasing number of population, wider settlement, greater groundwater usage which leads to local floods, and groundwater shortage in many different regions. The areas that experience groundwater shortage include areas which are located next to big hotels, malls, and other buildings which require abundant water supply.

Based on the previous research conducted by Hendrayana, H. and Vicente, V. A. S., (2013), the southern slopes of Merapi can be divided into catchment areas, transition areas, and discharge areas [4]. The catchment areas located at the top of the Merapi volcano slope has become the main source of water recharge because most of the rainwater enters into the ground water. The transition area is an alternating area between discharge and recharge areas. In this case, some parts of the area are recharge areas, but many are shallow springs. Indischarge areas, most groundwater conditions are very shallow. Both in the transition and...
discharge areas, settlement constructions are rapidly growing in the last few decades. The greater of the land change from the land into the building areas, the more problems will be. During the rainy season, floods often occur in urban areas. In addition, the increase of river water discharge in the rainy season occurs in many different rivers including Gajah Wong, Code, and Winongo rivers.

The higher of the river discharge is probably due to the decrease of rainwater that seeps in the area of rainwater or groundwater recharge. Rainwater recharge functions to insert rainwater directly into groundwater body. Thus, its function and sustainability can be maintained. On the other hand, rainwater does not totally become run-off. Furthermore, rainwater will not cause flash floods, if they seep into the soil. The greater of the groundwater decrease which is indicated by the deeper wells in urban areas, the more frequent floods occurring in urban areas will be. This is the impact of non-environmentally-oriented development carried out on the recharge areas which function as groundwater sources.

The recharge areas a relocated in the southern slopes of Merapi Volcano, ranging from 700 to 2970 meters high. The areas located at an altitude between 700 meters and 200 meters are categorized as transition areas, while below 200 meters are included as groundwater discharge areas. Transition areas consist of recharge and discharge areas. The functions of these areas begin to decrease along with the development process, the increasing number of paving, settlement expansion, the decreasing of yard. Do these have no effect to groundwater storage?

Based on the background of the study, the main problem is the alteration of the surface flow height which is probably caused by the land changes, especially the decrease of the water recharge spaces. The recharge space decreases due to the development of settlements and the alternation of open space into a built-up area. How great is change of land use to water resources? Based on this problem, research investigates the area of settlement in different year, the monthly water volume in different year, the different of flow coefficient, and the estimation of the number of recharge wells which are needed.

2. Water Recharge

Rainwater that falls on earth's surface partially seeps into the soil becoming an infiltration. Then, they percolate or become groundwater recharge. According to Seiler and Gat (2007), groundwater recharge is an infiltration component that enters the groundwater through the unsaturated zone, river or lake[5]. In this case, the water recharge happens naturally. The non-natural recharge is called an artificial recharge. Rainwater recharge media can be natural and artificial. Natural recharge media include forest land, bare land, grassland, paddy fields, yard, and etc. Meanwhile, artificial infiltration media consist of rainwater recharge well (shallow), deep water recharge wells, as well as artificial puddles such as reservoirs and artificial puddles. There are many types of groundwater recharge, namely porous infiltration which lets the water flow easily. In addition, there is a groundwater recharge in which the water passes hardly and results in very slow infiltration.

The effectiveness of groundwater recharge is influenced by high capacity of infiltration and the type of unconfined aquifer which is supposed to be 2 to 3 meters deep from ground level. Thus, if the depth of ground water is more than 3 meters, artificial recharge can be made [4].

Artificial recharge functions to sustain the groundwater as a living resource, inhibit the reduction of groundwater level, reduce the decrease or drowning of land. Some methods of making artificial recharge includes making puddles or shallow basins (Java: jogangan) in the soil surface, moat, recharge wells, ditches, pools, and irrigation. Different methods with
various formulas have been applied in many different countries such as in Los Angeles, Arizona United States, Israel, Australia and the results are satisfying [7].

According to Gale et al. (2002), the main purpose of artificial recharge development performed in many developing countries is to store water primarily for the sake of irrigation[1]. Other objectives include preventing sea water intrusion in coastal areas, reducing run-off and erosion, and maintaining good quality of water. Several artificial recharge methods or techniques, according to Gale et al. (2002), consist of: spreading method, open well, boreholes, bank infiltration, sand storage dams, and roof-top rainwater harvesting[1].

3. Research methods

The areas that meet the research objectives include the entire slopes of Merapi volcano southern wing precisely between the Progo and the Opak River, from the peak of Merapi to the south coast. Those areas cover some parts of Sleman Regency. To know the impact of land change, river flow and rainfall data were analyzed. The data of river flow analyzed in this research include the Code river flow at Pogung station. In addition, land change data was gathered by analyzing the Landsat imagery of different year. The number of artificial recharge wells is calculated using the formula of DPU: $H = D.I.At - D.K.As / As + D.K.P$ [6]

4. Research Findings And Discussions

4.1. Land Use

Based on the interpretation of Landsat imagery data gathered in 2003, the area office field and garden was 1,488 hectares. This number decreased into 1,162 hectare in 2017. In this case, the area reduction is 326 hectares. Meanwhile, the area of settlement was increasing. The area of settlement in 2003 reached 574 hectares, while in 2017 it was 902 hectares. Therefore, the development of settlement reached 328 hectares (57.14%) within 14 years. The detail is presented in the following table.

| No. | Land Use          | Area 2003 (ha) | Area 2017 (ha) |
|-----|-------------------|----------------|----------------|
| 1   | Forests           | 793            | 791            |
| 2   | Settlements       | 574            | 902            |
| 3   | Rice fields and gardens | 1488          | 1162           |
|     | Total             | 2855           | 2855           |

Source: Results of interpretation
4.2. Rain

The rainfall data used in this research include the data gathered in 2002, 2003 and 2012 from Beran and Ngemplak rain station. These two stations are used because Ngemplak Station is located at the top at an altitude of 350 meters above sea level, while Beran Station is relatively below an altitude of 150 meters above sea level. Moreover, the selected-year-data are used because they provide complete data.

In Ngemplak Station, the amount of rainfall was 2259 mm in 2002, 2210 mm in 2003, and 2231 mm in 2012. The Kemput Station was 2020 mm, but there was no rainfall data in November, therefore the rainfall data from the nearest station namely Santan Station which reached 150 mm was used. With regard to this, the total rainfall reached 2170 mm. Furthermore, in Bronggang Station, the rainfall reached 2149 mm in 2003 and 2048 mm in 2012. The other stations include Beran Station which reached 2524 mm in 2002, 2239 mm in 2003, and 2294 mm in 2012. After calculating the average of algebra, the rainfall reached 2318 mm in 2002, 2199 mm in 2003 and 2191 mm in 2012.

Figure 1. Map of Land Use Code River Catchment Area 2017
Table 2. Rainfall in 2003 in Beran, Bronggang, and Ngemplak

|       | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-------|
| Beran |     |     |     |     |     |     |     |     |     |     |     |     | 2239  |
| Bronggang | 327 | 678 | 333 | 76 | 101 | 10 | 0 | 0 | 5 | 46 | 295 | 278 | 2149  |
| Ngemplak | 267 | 839 | 390 | 50 | 96 | 15 | 0 | 0 | 0 | 50 | 214 | 288 | 2210  |
| Total  | 340 | 650 | 357 | 81 | 14 | 0 | 0 | 7 | 60 | 262 | 330 |     | 2199  |

Source: Analysis results

Table 3. Rainfall in 2012 at Beran, Bronggang, Ngemplak Rain Station

| Station | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Tot |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Beran   | 542 | 509 | 299 | 150 | 76  | 4   | 1   | 0   | 0   | 123 | 390 | 202 | 2294 |
| Bronggang | 456 | 561 | 201 | 129 | 86  | 11  | 0   | 0   | 0   | 164 | 445 | 356 | 2049 |
| Ngemplak | 438 | 522 | 205 | 105 | 141 | 9   | 2   | 0   | 0   | 114 | 405 | 290 | 2231 |
| Total   | 479 | 531 | 235 | 128 | 101 | 8   | 1   | 0   | 0   | 134 | 413 | 283 | 2191 |

Source: Analysis results

The intensity of the rainfall plan or maximum rain for one hour duration within five-year return period is 48.90 mm while the 100-year return period is 68.64 mm. In reality, heavy rain often occurs in the duration of 30 minutes. With regard to this, 30 minutes rainfall duration is used to calculate rain plan. The intensity of 30 minutes rainfall duration within a five-year return period is 67.23 mm, while the intensity of 100-year return period reaches 109.1 mm / 30 minutes.

4.3. The Condition of Hydrology

The number of rivers that flow in the south wing of Merapi volcano slopes is pretty much. However, the rivers flowing from the upper slopes of Merapi eventually merge into two major rivers. The Krasak and Bedog River flows merge into the Progo River. In those areas, there are many rivers such as Boyong, Kuning, Winongo, Gajahwong, and Code rivers which all of their flows join into a single river named Opak rivers.

Those rivers become water sources for farming development. River water is utilized by the surrounding community. In those areas, there are no large pools such as lakes or ponds, but there are some small reservoirs along the great rivers as sandbars (sabo), as well as rainwater recharge. Along the Gendol river, there are 22 weirs. Opak river has 5 weirs, Kuning river has 16 weirs, Krasak river has 23 weirs, and Boyong river has 56 weirs.

Boyong River flows through Turgo and Plawangan hills and joins the Code River after reaching the urban areas of Yogyakarta. Code river of which the upstream is in Kaliurang
crosses the area of Sleman Regency, Yogyakarta City, and Bantul Regency. Code River runs on Opak River in Jetis area of Bantul regency. The length of the river channel is about 39 km. Code River is one of the rivers that divides the city of Yogyakarta. It’s only a few hundred meters from Malioboro and Yogyakarta palace. For people living in urban areas of Yogyakarta, the Code river is the main drainage system, beside the Gajahwong river which passes through the eastern city. Gajahwong river is 21 km long and runs on the Opak River located in Pleret Bantul regency.

4.4. Flow Coefficient
The flow coefficient is calculated based on rainfall and river discharge data of Code in different year. The data used in this study are the average rainfall in 2003 and 2012 for Code River, while the Gajahwong river is in 2002 and 2012. The selection of Code river sub-watershed (locally abbreviated as sub-DAS) considers that they are located on the southern slope of Merapi which have undergone many changes of land use. In addition, the years are selected because they perform complete rainfall and discharge data.

The flow coefficient of Code river in 2003 was 0.239, while its flow coefficient in 2012 was 0.674. Referring to these facts, the river discharge in 2003 is much smaller than that of 2012. This indicates that most of the rainfall occurring in 2012 becomes the surface water flow. This is very likely to occur due to land change. The main land change is the change of land into a settlement. For example the area of settlement in 2006 reached 767.2 hectares of the 29.05 km² sub-watershed Code area. By the year of 2017, the area of settlement has grown to 902.0 hectares. The following is the flow coefficient of Code sub-watershed in different years.

Table 4. Coefficient of Flow of Code sub-watershed

| No. | Year | Area (km²) | Rain (mm) | Annual Volume (m³) | Coefficient of flow |
|-----|------|------------|-----------|-------------------|--------------------|
| 1.  | 2003 | 29.05      | 2315      | 15,30             | 0.239              |
| 2.  | 2012 | 29.05      | 2032      | 41,76             | 0.674              |

Source: Analysis results

4.5. Recharge
Based on the data of the two river flow coefficients from different years, it can be concluded that there has been a significant change regarding the flow coefficient. The more rainwater that falls on the soil surface, the less water which seeps into the soil will be. In the watershed of a Code river, the flow coefficient in 2003 was only 0.239. This is much smaller than that of
2012 flow coefficient which reached 0.674. In other words, the amount of rainfall in 2003 that became ground water was higher than that of 2012.

When referring to the land use data in 2017, the area of settlement in the Code rivers watershed which is 29.05 km² wide was 902 hectares (30.98%). This is for sure the cause of the high flow coefficient or low recharge coefficient. To reduce the water which highly flows into the river and finally to the sea, artificial recharge can be built. They can be puddles, pools, recharge wells, and weirs.

4.6. Recharge wells

The calculation of the depth of the recharge wells using the formula of DPU: \( H = D \cdot I \cdot A_{t} - D \cdot K \cdot A_{s} / A_{s} + D \cdot K \cdot P \) [6] is based on local conditions data as follows.

The rainfall duration that occurs in the majority of research area is 30 minutes. The maximum rainfall of the five-year return period is 67.23 mm. For estimating the depth of the well, the rainfall intensity of 70 mm is employed. The area of roof for simulated calculation is 50 m² on the condition that the well is not too deep, because the depth of wells in settlement regions is not too deep. In addition, the recharge well diameter is 80 cm, because based on observation, most people make recharge wells having a diameter of 80 cm. The permeability (K) is very diverse. But, the soil permeability in Sleman regency and watershed areas of Code is quite porous. Based on the results of laboratory test, three spots show the score of K ranging between 11 to 12 cm/hour.

\[
H = \frac{0.5028 m^2 \cdot (0.5 \text{ hour} \times 0.1156 m/\text{hour} \times 50 m^2) - (0.5 \text{ hour} \times 0.1156 m/\text{hour} \times 0.5028 m^2)}{1.75 m^3 - 0.02906 m^3} \\
H = \frac{0.5028 m^2 + 0.1454 m^2}{1.72094 m^3/0.6482 m^2} \\
H = 2.655 \text{ meters}
\]

The area of settlement in Code watershed reaches 902 hectare. With regard to this, referring to depth of the shallow recharge wells which is 2.65 meters every 50 m² of roof area, the maximum recharge wells needed are \( 9,020,000 \text{ m}^2 / 50 \text{ m}^2 = 180,400 \text{ recharge wells} \).

The word “maximum” is used because there are some areas which have very deep groundwater so that there is a possibility that the community in those areas build relatively deep wells. Thus, the unit of roof area is not only 50 m², but it is wider. Also, the number of recharge wells which are required is more than 180,400 wells. Besides, people may not only build artificial recharge in the form of wells, but also they can build it in other models such as basin, pools, weirs or sandbars (sabo). The number of sabos in Boyong River, which is a tributary of a Code river reaches 43 sabos.
Another way is building a pool which serves as water storage for irrigation purposes or water reserving in the dry season. The government has planned to build 30,000 pools starting from 2017, therefore one pool is built in every two villages. Some best spots on which the pools are built in the watershed of Code have been identified. According to Gatot Irianto (2007), the pool is feasible to be built in an area of dry land farming/plantation/livestock that needs water from the pool as an irrigation water supplier. Moreover, the area should have very deep soil water; it is not sandy land; there is a source of water that can be accommodated either rainwater, surface runoff and springs or ditches or streams; and the upper region has a water catchment area or areas with a water source such as springs, streams or trenches.

5. Conclusions
The conclusions of this paper are as follows:
1. Land which changes into settlement is quite high. Within ten years, it has increased to 130 hectares or 4.65% of the watershed.
2. Runoff is getting higher. This is indicated by the river flow coefficient in 2003 which reached 0.239, whereas it increased into 0.674 in 2012. It means that the amount of rainwater which seeps into the soil is decreasing.
3. Many recharge wells are needed to reduce the amount of surface flow and increase the volume of recharge water.

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