Green Cimahi watershed for balancing water supply and flood control

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Abstract. Lack and damage of clean water and also flooding occurred in Cimahi river basin. Water sources polluted by industry and human activities. The purpose of this study was to design the water balance model of the Cimahi watershed as a Green Watershed. The study locations were the Cimahi river, Cilember river, Cibeureum river and Cisangkan river, which flow through the city of Cimahi. The method used is the analysis of the rainfall runoff model with the hydrograph of convolution method in the four watersheds, land use analysis, runoff coefficient analysis, dilution model analysis, groundwater analysis and demographic analysis. The results of this study is Design Green Cimahi Watershed that re-functioning local drainage to maintain the hydrological storage capacity of all watersheds in the city of Cimahi, normalizing Cilember river to reach the width of the river by 5.6 m from the previous width of 1.5 m, and the river capacity which was 4.8 m$^3$/s to 42.37 m$^3$/s so that enough to accommodate Q$_{50}$ flood discharge, enforcing the rule that every industry must process its waste through a waste processing plant, building Pasirkaliki retention ponds that can function for groundwater conservation, flood control and clean water needs.

1. Introduction

Water as a natural resource is very important and vital for survival. In various countries, water is mostly used for domestic, industrial, recreational, agricultural and cultural purposes. Population growth, agriculture, urbanization and industrialization have caused a reduction in the amount of surface water [1]. Water is distributed in nature as surface and ground water in different forms and sources which are oceans, seas, rivers, streams, lakes, ponds, wells, boreholes and springs. Rivers are among the oldest water bodies in the world. Water is a resource that has many uses and also supports all forms of life and affects our health, lifestyle, and economic well-being [2]. Water resources on this earth consisting of surface water, rainwater and groundwater can be represented as a hydrological model in the form of watersheds [3]. Lakes that are a type of surface water are easily accessible water resources, and accommodate more than 95% liquid surface fresh water on the Earth's surface, for domestic, agricultural, and industrial water supply [4].
The drinking water problem is the pattern of distribution of rainfall and water quality as in Zhejiang Province, which is located on the east coast of China. Maintaining the quality of reservoir water is very important for water security and socio-economic development. The number of reservoirs have experienced increased pressure and degradation, increased waste disposal with sustainable economic development and urban construction, severely damaging the reservoir environment and affecting reservoir function [5]. Common problems with the distribution of clean water in urban areas are poor water quality, continuous service, inadequate disinfection and old infrastructure that is not repaired. To overcome this, in the city of Bandung a community-based program was conducted for the Cikapundung riverbank community that was representative of the community with socio-economic and geographical vulnerability [6].

Several provinces on the Mindanao Island of the Philippines have been flooded due to extreme rain during the Lingling and Jangmi storms which resulted in the overflowing of rivers and lakes. To reduce the impact of the disaster, a hydrological model of the Tago River basin was created and a runoff rainfall simulation was carried out using HEC HMS. The basin model, which is a physical representation of the watershed, was developed using the 10-m Synthetic Aperture Digital Elevation Model (SAR DEM) and river network in the delineation of the watershed, using information from the land cover map [7]. Mitigation of the Karnali flood disaster in the western part of Nepal was carried out by increasing the lag time from 2-3 hours to 7-8 hours which was informed through a community-based flood early warning system. The method used is a time series model that comes from a database that can be interpreted physically. The challenge is to communicate probability predictions to the farthest communities [8].

Cimahi River that flows along the City of Cimahi, West Bandung district and Bandung Regency is the largest river in the city of Cimahi besides other rivers, namely the Cibeureum river, Cisangkan river and Cilember river. This river network has contributed a lot to the water resources of Cimahi City, including the Sukawana Reservoir. The significant problem of water resources in the city of Cimahi is flooding and lack of clean water. Floods in the city of Cimahi often occur both in the northern areas such as Citeureup, Cipageran, and also Central Cigugur, Cibeureum and Melong. The depth of the flood can reach one meter so it is prone to accidents and turns off traffic flow for several hours. The cause of this overflow is that the local drainage is not functioning and the river border is narrowed so that the river is no longer able to accommodate the discharge that occurs [9-10].

The lack of clean water in the city of Cimahi occurs in a long dry season where there is very little or no rainfall for more than six months. Drought occurred in the Utama village, Cibeber village, Cipageran village, Cibabat village, Pasirkaliki village, Cimahi village and Leuwigajah village. In this condition, the availability of clean water cannot depend on rainfall, but the ground water supply in the city of Cimahi is not sufficient to meet the community's clean water needs. The industry in the city of Cimahi which has taken significant groundwater extraction at various depths has disrupted the balance of the water system in the city of Cimahi. Besides that, the uncontrolled disposal of industrial waste also made the water quality of Cimahi city highly polluted [11].

The purpose of this study was to design the water balance model of the Cimahi watershed as a Green Watershed. The study locations were the Cimahi river, Cilember river, Cibeureum river and Cisangkan river, which flow through the city of Cimahi.

2. Methods of the study
This research consists of four stages of activity, namely measuring field data in the form of river hydrology and hydraulics, analyzing situation maps intersecting regional areas and river areas, analyzing existing Cimahi river watershed systems consisting of water availability and water requirements and the design of Cimahi water systems in the form of Green Cimahi watershed.

2.1. Hydrology analysis method
The parameters needed in hydrology analysis in this study are the availability of water, namely the discharge plan for each river both for drinking water needs and design flood discharge. In addition,
groundwater availability will also be analyzed. Discharge per mm effective rainfall each river is calculated using the Nakayasu modification method that has been calibrated based on the characteristics of the watershed [12].

$$Q_p = \frac{0.99AR_o}{3.7(0.1T_p + T_{0.3})}$$

(1)

Peak discharge ($Q_p$) is the function of watershed area ($A$), watershed characteristic coefficient ($C = 0.99$), unit rainfall ($R_o$), time lag ($T_p$) and time required to discharge reduction up to 30% peak discharge ($T_{0.3}$). Design rainfall is calculated using Gumbel frequency analysis while effective rainfall is calculated using a runoff coefficient derived from the land use map.

The water needs analyzed are only clean water needs. The need for clean water is calculated based on the population of the city of Cimahi and the standard of urban clean water needs of each person, namely 144 liters/person/day. Clean water needs are analyzed spatially and temporally so that the water distribution in all villages can be known.

2.2. Hydraulic analysis method
The parameters of the river hydraulic data measured are river cross-section, river slope, flow velocity, flow depth and riverbed elevation [13]. This parameter is used to determine the maximum river hydraulic capacity calculated using the following Manning equation,

$$Q = \frac{1}{n} A R^{2/3} S^{1/2}$$

(2)

where $Q$ is discharge, $A$ is wet cross-sectional area, $R$ is hydraulic radius, $S$ is the slope of the energy line and $n$ is roughness coefficient from Manning.

2.3. Method of mapping intersections of river areas and regional areas
In analyzing water drainage both on land and in rivers, it is very necessary to make intersection maps of river areas and regional areas. River boundaries show patterns of drainage in accordance with topography and regional boundaries indicating administrative and regional management.

2.4. Method of analyzing existing Cimahi river watershed systems
To get the condition of existing city water system in Cimahi, the existing conditions of water availability and water requirements are calculated. In addition, disaster conditions were also reviewed, namely the problem of lack of clean water and flooding. The availability of surface water is viewed from discharge
of four major rivers in the city of Cimahi, namely the Cimahi River, Cibeureum River, Cisangkan River and Cilember River. Water availability is also viewed from groundwater discharge in the Cimahi area. If the groundwater discharge cannot serve water needs during the dry season, it will be planned for a dual function reservoir, namely flood control during the rainy season and water supplier during the dry season. The flood analysis of Cimahi city which was reviewed was the heaviest flood area, namely the Melong and Central Cigugur villages originating from the overflow of the Cilember river.

2.5. Green Cimahi watersheds design method
The criteria for the design of Green Cimahi watershed water system are the achievement of a water balance management between surface water, land cover and ground water, without floods, drought and water pollution so as to be able to serve the water needs of the people of Cimahi. The design output in the form of the Green Cimahi watershed map is equipped with a design note for temporal and spatial water availability and water needs.

3. Results and discussion

3.1. Study area
The city of Cimahi is geographically located between 107°30'30" - 107°34'30" BT and 6°50'00" - 6°56'00" South Latitude. The total area of Cimahi City is 40.2 km² (4,020 Ha). The city of Cimahi is included in the West Java Province and includes 3 Subdistricts consisting of 15 villages, namely, North Cimahi Subdistrict consisting of 4 villages, Central Cimahi Subdistrict consisting of 6 villages and South Cimahi Subdistricts consisting of 5 villages.

![Figure 2. Cimahi City map](image-url)

The city of Cimahi is located in the upstream of Citarum River as a part of Bandung Basin and one of the Citarum River valleys. The river that passes through the City of Cimahi is the Cimahi River, Cibeureum river, Cibaligo (or Cilember) river, and Cisangkan River, meanwhile, the springs in Cimahi are Cikuda springs and Cisintok springs. Intersection map of those rivers and Cimahi Subdistricts is shown in Figure 3 below,
3.2. Water need and water availability existing
Clean water needs are calculated based on the population of Cimahi city in 2017 with the standard of clean water needs is 144 liters / second / person. Clean water needs are calculated monthly and distributed to each village as shown in Table 1 below,

**Table 1. Cimahi City water need existing**

| Subdistrict     | Villages     | Area (km²) | Population (people) | Clean Water Need (m³/s) |
|-----------------|--------------|------------|---------------------|------------------------|
| North Cimahi    | Cipageran    | 5.94       | 73,870.00           | 0.12                   |
|                 | Citeureup    | 1.27       | 15,794.00           | 0.03                   |
|                 | Cibabat      | 2.87       | 35,691.00           | 0.06                   |
|                 | Pasir Kaliki | 3.23       | 40,168.00           | 0.07                   |
| Central Cimahi  | Padasuka     | 0.84       | 14,596.00           | 0.02                   |
|                 | Setiamanah   | 1.98       | 34,404.00           | 0.06                   |
|                 | Cimahi       | 2.25       | 39,096.00           | 0.07                   |
|                 | Karang Mekar | 1.37       | 22,763.00           | 0.04                   |
|                 | Baros        | 2.25       | 39,096.00           | 0.07                   |
| South Cimahi    | Central Cigugur | 1.37   | 23,805.00           | 0.04                   |
|                 | Cibeber      | 3.33       | 51,612.00           | 0.09                   |
|                 | Cibeureum    | 3.93       | 60,911.00           | 0.10                   |
|                 | Leuwigajah   | 2.75       | 42,622.00           | 0.07                   |
|                 | Utama        | 3.13       | 48,512.00           | 0.08                   |
|                 | Melong       | 3.8        | 58,896.00           | 0.10                   |

Water availability is calculated from the monthly discharge of the Cimahi River, Cibeureum River, Cisangkan River, and Cilember River at the location as shown in the map in Figure 4. For the discharge
of clean water design, a 5-year return period is used, while the flood discharge design is used for a 50-year return period.

![Watershed Outlet as a River Cross Section for Spatial Water Availability](image)

**Figure 4** Watershed outlet for river water availability

The amount of water availability each month for the four rivers above at the outlet is shown in table 2

| River Name | Notation | January | February | March | April | Mei | June | July | August | September | October | November | December |
|------------|----------|---------|----------|-------|-------|-----|------|------|--------|-----------|---------|----------|---------|
| Cimahi     | Qav (m$^3$/s) | 24.77   | 26.13   | 25.39 | 30.83 | 33.33 | 16.67 | 14.93 | 10.59 | 16.43 | 31.31    | 32.78   | 28.68    |
| Cibeureum  | Qav (m$^3$/s) | 30.55   | 32.23   | 31.32 | 38.03 | 41.11 | 13.06 | 20.27 | 38.62 | 40.43 | 35.34    |
| Cisangkan  | Qav (m$^3$/s) | 12.51   | 13.20   | 12.83 | 15.57 | 16.83 | 8.42  | 7.54  | 5.35  | 8.30  | 15.81    | 16.56   | 14.49    |
| Cilember   | Qav (m$^3$/s) | 17.30   | 18.25   | 17.74 | 21.54 | 23.28 | 11.65 | 10.43 | 7.40  | 11.48 | 21.87    | 22.90   | 20.04    |

In table 2 it can be seen that the smallest amount of water in one year is in August and the highest one is in November.

3.3. **Flood analysis of cilember watershed**

Floods due to the overflowing of the Cilember river caused a large amount of inundation in the villages of Melong and Central Cigugur. This level of flooding is a heavy category because it can occur in light rainfall even without rain. Flooding can occur if rainfall falls in the upstream area. The cause of the Cilember river flood is due to the narrowing of the very large river border so that the existing border is only 30% of the actual border. Due to the narrowing of this border, the capacity of the Cilember river starts in the Central Cigugur to the downstream decreases up to 70% as shown in table 3 below,
Table 3. Overflow of Cilember river downstream

| Discharge       | January | February | March | April | Mei   | June | July | August | September | October | November | December |
|-----------------|---------|----------|-------|-------|-------|------|------|--------|-----------|---------|----------|----------|
| Q_base (m³/s)   | 25.93   | 27.73    | 26.09 | 26.24 | 29.02 | 21.23| 20.80| 14.44  | 23.45     | 41.20   | 35.56    | 23.49    |
| Q_cap existing  (m³/s) | 4.80    | 4.80     | 4.80  | 4.80  | 4.80  | 4.80 | 4.80 | 4.80   | 4.80      | 4.80    | 4.80     | 4.80     |
| Q_surplus (m³/s) | 21.13   | 22.93    | 21.29 | 31.24 | 16.43 | 16.00| 9.64 | 18.65  | 36.40     | 30.76   | 36.69    | 26.69    |
| Q_surplus (%)   | 81.49   | 82.69    | 81.60 | 86.70 | 87.70 | 77.39| 76.76| 66.76  | 79.53     | 88.35   | 86.50    | 84.76    |

as shown in table 3, overflow discharge every month is average 80%, it means only 20% of runoff flows can be accommodated by Cilember river.

3.4. Groundwater and water quality analysis

The geographical position of Cimahi City is very strategic and has the potential as a center for service activities, especially industry, education, tourism and trade, causing an increase in the extraction of groundwater resources. Based on data on water potential in Cimahi City, it is known that potential water sources in Cimahi City consist of ground water (springs, shallow groundwater and deep groundwater) and surface water (lakes/ponds and Cimahi River). Cimahi City is in the Bandung-Soreang Groundwater Basin with unconfined aquifer potential of 795 million m³/year and confined aquifer potential of 117 million m³/year [14].

Groundwater extraction is generally carried out mostly by using boreholes for industrial businesses, other commercial businesses or communities, where some groundwater extraction has exceeded the allowable capacity. A number of areas in the Bandung basin that have been included in the red zone include industrial estates in Cimahi, namely Leuwigajah village, South Cimahi subdistrict.

An industrial plant in Cimahi city is 90% located in the Utama village and taking and removing water from the Cilember river. This is the dominant cause of the narrowing of the border of the Cilember river which has caused flooding. Waste from the factory waste without waste treatment is also a cause of...
pollution of river water and ground water in the city of Cimahi. In the monitoring period in September 2017, almost all of the rivers in the city of Cimahi had the status of the quality of heavy polluted water with the heaviest pollutant index of 100.96 in the Cilember river. The quality of ground water in Cimahi city is only 53% which still meets clean water quality standards [15].

3.5. Green Cimahi watershed design with river flow spatial distribution

There are 3 Green Cimahi Watershed design criteria, first the balance of water quantity between availability and needs, the second watershed balance between the land cover and ground water, third quality of surface water and ground water that meets the quality standards of clean water quality.

The balance of the water quantity in this design will be used the concept of the spatial and temporal distribution of four rivers in Cimahi, namely the Cimahi River, Cibeureum River, Cisangkan River and Cilember River with the outlet as shown in Figure 4. Temporal distribution is the amount of water at each river outlet reviewed in the month distribution. The spatial distribution of water distribution means that water is distributed in space, that is the distribution of each river. The spatial water balance quantity distribution of each river is shown in the following table 4.

| River Name | Villages     | Area (km2) | Population (people) | Clean Water Need (m³/s) |
|------------|--------------|------------|---------------------|------------------------|
| Cimahi     | Citeureup    | 1.27       | 15,794.00           | 0.03                   |
|            | Cibabat      | 2.87       | 35,691.00           | 0.06                   |
|            | Central Cigugur | 1.37   | 23,805.00           | 0.04                   |
|            | Karang Mekar | 1.37       | 22,763.00           | 0.04                   |
|            | Baros        | 2.25       | 39,096.00           | 0.07                   |
|            | Utama        | 3.13       | 48,512.00           | 0.08                   |
|            | Total Load   |            |                     | **0.31**               |
| Cibeureum  | Melong       | 3.8        | 58,896.00           | 0.10                   |
|            | Cibeureum    | 3.93       | 60,911.00           | 0.10                   |
|            | Total Load   |            |                     | **0.20**               |
| Cisangkan  | Setiamanah   | 1.98       | 34,404.00           | 0.06                   |
|            | Padasuka     | 0.84       | 14,596.00           | 0.02                   |
|            | Cibeber      | 3.33       | 51,612.00           | 0.09                   |
|            | Leuwigajah   | 2.75       | 42,622.00           | 0.07                   |
|            | Cipageran    | 5.94       | 73,870.00           | 0.12                   |
|            | Cimahi       | 2.25       | 39,096.00           | 0.07                   |
|            | Total Load   |            |                     | **0.43**               |
| Cilember   | Pasirkaliki  | 3.23       | 40,168.00           | 0.07                   |
|            | Total Load   |            |                     | **0.07**               |

Based on the table above, the heaviest load of water needs is Cisangkan River. This is in accordance with the topographic position and for the efficiency of the clean water pipeline because the Cisangkan River is located in the western part of the city of Cimahi according to the location of the villages served. Although the Cibeureum River has a large discharge, its topography is at the lower elevation and its location at the easternmost border of the city of Cimahi borders the city of Bandung. The Cilember River is given the burden of one village taken from the upstream part of the outlet because in the lower part of
the Cilember river there has been damage, namely narrowing of the river border and heavy pollution of water quality due to industrial waste.

The discharge at each river outlet in this design is distributed temporally i.e every month. Discharge per month is calculated based on the distribution of effective rainfall each month. Table of distribution of monthly water availability and monthly water needs of each river outlet are shown in table 5.

| River Name | January | February | March | April | Mei | June | July | August | September | October | November | December |
|------------|---------|----------|-------|-------|-----|------|------|--------|-----------|---------|----------|----------|
| Cimahi     | 24.77   | 26.13    | 25.39 | 30.83 | 33.33| 16.67| 14.93| 10.59  | 16.43     | 31.31   | 32.78    | 28.68    |
| Qmax(m^3/s) | 0.31    | 0.31     | 0.31  | 0.31  | 0.31 | 0.31 | 0.31 | 0.31   | 0.31       | 0.31    | 0.31     | 0.31     |
| Qavg(m^3/s) | 0.65    | 0.62     | 0.64  | 0.53  | 0.49 | 0.97 | 1.08 | 0.99   | 0.94       | 0.94    | 0.94     | 0.94     |
| % of Water Used | 0.39    | 0.37     | 0.38  | 0.31  | 0.29 | 0.57 | 0.64 | 0.90   | 0.58       | 0.31    | 0.29     | 0.33     |

Based on table 5, the surface water of the four large Cimahi rivers if distributed spatially, the percentage of use is below 8%. Thus the available surface water is still very much, even though it is used for industrial, agricultural, public facilities such as offices, hospitals, school buildings etc. Calculation of water availability is analyzed based on very low wet year probabilities, namely a 5 year return period, so this it's safe enough for statistical calculations.

Analysis of the temporal distribution for the number of runoffs per month can answer the drought problems that have occurred in Cimahi over the past few years. The drought that occurs shows that runoff does not flow into the river. This is because the falling rainfall cannot reach the river, but flows as a flood on the land. As a result, excess rainfall is not in accordance with the calculation of river hydrology in a river network stream in the watershed. The inhibition of runoff flow into the river is due to the non-functioning of local drainage in almost all areas of the city of Cimahi which are experiencing drought. So the solution to the water drought in the city of Cimahi is the re-functioning of all the local drainage networks in the city of Cimahi.

The mitigation of the Cilember river flood due to the narrowing of the river border can be overcome by normalizing the downstream Cilember river to restore the Cilember river storage capacity. Calculation of river capacity for normalization is shown in the following table 6.

Table 5. Distribution of monthly water availability and monthly water needs

Table 6. The Dimension of river cilember cross section for normalization
The monthly design flood discharge for the Cilember river before, after normalization and after evaluation design is shown in table 7 below,

| Discharge          | January | February | March | April | Mei | June | July | August | September | October | November | December |
|-------------------|---------|----------|-------|-------|-----|------|------|--------|-----------|---------|----------|----------|
| Qflood (m³/s)     | 25.93   | 27.73    | 26.09 | 36.24 | 39.02 | 21.23 | 20.80 | 14.44  | 23.45     | 41.20   | 35.56    | 31.49    |
| Qcap existing (m³/s) | 4.80   | 4.80    | 4.80  | 4.80  | 4.80 | 4.80 | 4.80 | 4.80   | 4.80      | 4.80    | 4.80     | 4.80     |
| Qcap design by Government (m³/s) | 23.55 | 23.55   | 23.55 | 23.55 | 23.55 | 23.55 | 23.55 | 23.55  | 23.55     | 23.55   | 23.55    | 23.55    |
| Qcap Evaluation design (m³/s) | 42.37  | 42.37   | 42.37 | 42.37 | 42.37 | 42.37 | 42.37 | 42.37  | 42.37     | 42.37   | 42.37    | 42.37    |

River water pollution is overcome by enforcing the rule that every industry must process its waste through a waste processing plant so that liquid waste discharged into the river complies with waste water quality standards.

Cimahi municipal groundwater conservation can be done by building retention ponds that can function double, namely for groundwater conservation, flood control and clean water needs. Retention ponds can be built in areas with a relatively low elevation, namely in Pasirkaliki village at an elevation of 755 m MSL.

4. Conclusion
Green watershed can be designed by first identifying problems that occur in a watershed. The main criteria for green watershed are hydrological storage capacity, the balance between availability and water requirements, maintenance of land cover and groundwater conservation. Green Cimahi Watershed can be built by re-functioning local drainage to maintain the hydrological storage capacity of all watersheds in the city of Cimahi. The problem of narrowing the border of the Cilember river which caused flooding in Melong and Central Cigugur villages can be improved by normalizing the river to reach the width of the river by 5.6 m from the previous width of 1.5 m, and the river capacity which was 4.8 m³ / s to 42.37 m³ / s so that enough to accommodate Q₉₀ flood discharge with a maximum value of 41.2 m³ / s and occurs in November. River water pollution is overcome by enforcing the rule that every industry must process its waste through a waste processing plant so that liquid waste discharged into the river complies with waste water quality standards. Cimahi municipal groundwater conservation can be done by building retention ponds that can function double, namely for groundwater conservation, flood control and clean water needs. Retention ponds can be built in areas with a relatively low elevation, namely in the Pasirkaliki village at an elevation of 755 m msl.

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