Analysis of Water Carrying Capacity in Cibinong Urban Development

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Abstract. This study discusses the support of water related to the relationship between the region and availability, and its effects in the future, including the direction of spatial planning, and air requirements based on population development in the Cibinong catchment. In general, there are two main stages consist of several supporting aspects, carrying capacity of water-based on water availability and water needs. In the first stage consisting of: prediction analysis of land cover change; hydrological analysis to determine the planned rainfall for calculating the discharge of the plan; calculation of potential discharge seen from the ability of the land to collect water; and calculation of the ideal area and volume of reservoirs of water bodies. For the water needs stage are based on the calculation of demand discharge based on population projections, and land use; in accordance by applicable standards. The results show that Cibinong Urban area infiltration water experiences a downward trend from an increase in value of 0.16 m³/s/day to only 0.01 m³/s/day. As for the availability of surface water based on runoff water tends to rise statically. But the potential that can be used today as an urban water source is only 1.26 m³/s/day.

1. Introduction

Water is the main basic necessity in human activities. One of the water main sources that occurs naturally continuously is the source of atmospheric water (rainwater). Atmospheric water sources occur in the hydrological cycle. Hydrological cycle is important for sustaining life on Earth, because this is the process of replenishing the world’s freshwater resources and moderating extreme climate [1]. The hydrological cycle process only occurs in areas that have a river flow which are called as the River Basin (DAS). There are currently many changes in DTA ecosystems due to the developmental activities that are increasing or often referred to as the urban process. Some developing urban areas are close to rivers because water is the main source for providing clean water [2].

Physically, the urban process can be seen from the rampant changes in land use change, and an increase in urban area that characterizes non-agricultural activities, followed by an increase in the number and population density [3]. Urban process is determined by many factors that influence it, including internal and external factors. Internal factors are natural processes (birth), while external factors are migration, geographical position, urban sprawl, and establishment of a new center of activity.

Cibinong is a part of the "middle stream" in the Ciliwung River Basin and Cikeas River Basin which consists of the Central Ciliwung River Basin, and the Kali Cikeas River Basin. Based on the hydrological
system the Cibinong urban area is part of the water catchment area (DTA) of the two sub-watersheds. The sign is the east and west physical boundaries of the main river flow of Kali Cikeas and Ciliwung River. Cibinong is also bounded by Gunung Kapur (Ciliwung Tengah Sub-watershed) and Bukit Sentul. In terms of climate, Cibinong has a wet tropical climate and has a fairly high rainfall of 2705 mm/year with an annual temperature of 25%. Based on the Water Supply System Master Plan (RISPAM) in 2014, there are 7 areas, out of which 2 of them were slightly damaged.

Seeing the characteristics of the river basin, climate, and rainfall, Cibinong Urban should not have water problems. The fact is that the city of Cibinong is experiencing water problems, both the phenomenon of excess and lack of water. 17 sub-districts are experiencing a clean water crisis due to drought, one of which is in the Cibinong District [4]. Heavy rains in urban Cibinong caused flooding in some areas due to the inability of Cikaret to hold the flow of river currents from the affected areas, which were Ambar Residence and caused losses and floods on Tegar Beriman Street [5].

Water problems in Cibinong urban areas are certainly related to the high growth of land cover and will indirectly affect the hydrological cycle in Cibinong urban areas. The impact is the decrease of the land ability to absorb water which will potentially reduce water availability. By looking at the problems above, it is necessary to study the water carrying capacity in Cibinong urban areas for the intention of describing the balance between supply (availability) and demand (needs). The explanation above is that Cibinong Urban area is part of the Ciliwung and Cikeas River Basin water catchment area situated in the impact of the area’s urbanization. The urbanization reduces the ability of the water catchment resulting in an imbalancement between urban water supply and demand. Thus, the problem formulation in this study is how much is the impact of urbanization on the carrying capacity of urban water in Cibinong.

2. Methodology

This study uses a descriptive study design prediction study (prediction design). The point is that this study describes the cause and effect of a symptom that is happening now and its relation to the future with the state of symptoms that existed in the past. It is hoped that the results of this study can be used as a basis for determining urban development policy.

![Research Analysis Framework](image)

**Figure 1. Research Analysis Framework**

The research method used in this study is quantitative method. The quantitative method is used to test a theory and see the relationship between variables. Variables used in research are measured by research instruments so that data in the form of numbers can be analyzed through statistical procedures.
In general, there are two main stages which consist of several supporting aspects and carrying capacity of water-based on water availability (supportive capacity) consisting of prediction analysis of land cover change, hydrological analysis to determine the planned rainfall for calculating the discharge of the plan, calculation of potential discharge seen from the ability of the land to collect water, and calculation of the ideal area and volume of reservoirs of water bodies. The next stage consist of water needs are based on the calculation of demand discharge based on population projections, and land use in accordance by applicable standards. The next stages consist of the carrying capacity of urban water that will compare the results of the availability and demand of urban water to support the results of research. If there is continuity, then this study shows that the carrying capacity of urban water in Cibinong is still in the sustainable category. if there is a shortage, then the carrying capacity category is overshoot (deficit) so it is necessary to study the application of infrastructures such as what can be used so that the carrying capacity becomes conditional sustain (conditional to support environmental carrying capacity).

Based on Figure 1, it can be understood that the first step taken is the analysis of land cover prediction using the CA Markov method in the Selva Idrisi application. Then proceed with hydrological analysis in the form of planned rainfall. From the results of hydrological analysis and land use prediction, the availability of discharge calculations is calculated based on the percentage of the hydrological cycle and the associated coefficients (runoff coefficient). The results of the availability, will be compared with the results of the analysis of clean water needs based on clean water needs. The balance chart will illustrate the situation and conditions of availability and needs in Cibinong urban areas. If these results are insufficient, it will be discussed by linking the concept of urban development that continues with the presence of excess water. The aim is to provide a form of recommendation in this study.

3. Results and Discussions

3.1. Validation of Land Cover Prediction

The first step to calculate the sustainability of water supply based on land cover is the calculation of land use prediction. Analysis of land cover change prediction is done using the Cellular Automata (CA) - Markov Chain method using the help of the Selva Idrisi application. The iteration used is a period of 5 years. The land cover data used are 2005, 2010, and 2015. Whereas the validation test uses the results of the 2015 projected calculation with the 2015 land cover. The following is a scheme for calculating the results of trends in land cover changes:

![Figure 2. Land Cover Trend Analysis Scheme and Spatial Match of 2015 Land Cover with Prediction](image-url)
Based on Figure 2 for spatial validation, the union tools are used in the Arc Map software. These tools are used to determine the suitability of land cover based on the land cover code. If the land cover code is the same, then the value is 0; whereas if there is a difference in the land cover code, then the value is outside 0. To homogenize the different values, the values should be changed to 1.

3.2. Land Cover Prediction
The value of the static’s up and downtrends are certainly based on the probability value generated from the CA Markov Chain analysis in the Selva Idrisi application with a proportional error of 0.15. The probability value that shows the tendency of land cover changes can be seen in each land cover. The following is a table of probability predictions for land cover in 2025:

| ID | 1     | 2     | 3     | 4     | 5     | 6     | 7     |
|----|-------|-------|-------|-------|-------|-------|-------|
| 2020 |       |       |       |       |       |       |       |
| 1   | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| 2   | 0     | 0.5178| 0.0804| 0.0179| 0.0075| 0.1269| 0.2496|
| 3   | 0     | 0     | 0.7966| 0.0022| 0     | 0     | 0.2496|
| 4   | 0.025 | 0.025 | 0.025 | 0.85  | 0.025 | 0.025 | 0.025 |
| 5   | 0     | 0.0189| 0.0636| 0.1687| 0.7488| 0     | 0.025 |
| 6   | 0     | 0     | 0.0578| 0     | 0.2311| 0.7112| 0     |
| 7   | 0     | 0     | 0     | 0     | 0.023 | 0.0496| 0     | 0.7204|

Note: Tendency of Change > 0.1

From the table above, we can read the probability value of 2025, which can be seen from the results of predictions for 2020. The results of the prediction of land cover in 2025 show that the coefficient of change tendency is most visible in 4 land covers, namely rice fields (0.2021), plantations (0.2596), shrubs, and dry fields (0.025). This means that between 20% and 25% of the tendency of rice field and plantation land cover can change to built-up land cover. The following are the results of the predictions made:

3.3. Calculation of Potential Water Sources Based on Rain Distribution Plans
The calculation of potential water sources in the Cibinong Urban area is only based on atmospheric water sources. The calculation of the rain distribution plan is used to identify the water received by the catchment area. The data to be used is the average rainfall data and the maximum rainfall obtained from the recording of the Cibinong Rain Station between 2008-2017. Furthermore, the data needs to be validated based on the plans and rainfall needs in Cibinong Area. The following are the terms and validations performed by each approach:
Table 2. Validation and Requirements of Maximux Daily Rainfall Plan Use

| Type of Distribution | Requirements | Calculation Results | Note  | Conclusion                      |
|----------------------|--------------|---------------------|-------|---------------------------------|
|                      |              |                     |       |                                 |
| Pearson III          | Cs ≠ 0       | ≠ 0                 | 1,340 | Fulfilled                       |
|                      | Cv ≈ 0.3     | ≈ 0.3               | 0.261 | 14,887                         |
|                      |              |                     |       |                                 |

3.4. Effect of Land Cover on Urban Water Availability

The following are the results of the calculation of the availability of infiltration and runoff water in rainfall plans based on the ability of land cover:

![Figure 4. Prediction Result of Discharge Water and Surface Runoff Discharge Water](image)

The reservoir volume calculation also uses the river depth and width assumptions and the assumptions are assumed to be the same for each existing river type. The assumptions are obtained from measurements of the image that can be seen in the Google Earth software, while the depth is based on the desk study obtained from the BWS (Badan Wilayah Sungai) Ciliwung dan Citarum document and electronic media. The maximum volume of surface water in the Cibinong Urban area is 30.55 m³ / s / day. This value assumes 100% of the river and reservoir is full filled. Based on the 2014 RISPAM Kabupaten Bogor document, the mainstay discharge of the two rivers in the Cibinong Urban area that can be utilized as a source of raw water is 1.26 m³ / s. Thus, the availability of surface water value which will be carried out to calculate the carrying capacity of the water balance is 1.26 m³ / s adjusted to the existing mainstay discharge.

3.5. Calculation of Urban Water Needs

Calculation of clean water needs based on population projections is based on the theory, standards, and studies that apply. Clean water needs that will be calculated include domestic water needs for the community and non-domestic clean water for urban infrastructure facilities outside drinking water needs. The following is the calculation of clean water needs in Cibinong Urban:

![Figure 5. Raw Water Needs in the Cibinong Urban Area](image)
Raw water needs based on the RTRW are used to compare with raw water needs based on projections. In addition to knowing whether that carrying capacity of water based on the water balance is still safe according to the RTRW, the calculation of RTRW’s raw water needs is based on assumptions. The assumption used in the calculation of the size of the residential designation zone is divided by the average area of the house times the average density.

3.6. Cibinong Urban Water Carrying Capacity
The water carrying capacity of the Cibinong Urban area can be seen by the availability of average daily period of 2020-2025 the carrying capacity of water is still in safe status. Meanwhile, the period of 2025-2031 is safe but conditional. Above 2031 it can be said that the carrying capacity of water has been exceeded. Whereas for maximum daily availability, there will be no problems in the supply of water. But the results of the availability of water, based on daily average and maximum daily still cannot meet the drinking water needs of Bogor Regency RTRW. The following are the results of the carrying capacity of water based on the water balance per period:

Figure 6. Water Carrying Capacity Value of Urban Areas Based on Water Balance

The gap between the availability and demand for water will be a problem if it is not handled early. Because to maintain the sustainability of life, it is necessary to have a sustained water carrying capacity. The definition of sustainability is ongoing, continuous. Another cause of the carrying capacity of water that does not have a value for water sustainability is the change in the built-up land cover which reaches 78%. There is a need for control over the development of built-up land and a need to increase the extent of land cover in the form of water bodies or water catchments. It can be seen on regional spatial plan, which has a planned residential zone area of almost 96% of the Cibinong Urban area.

The relationship between influencing factors can be seen which show that changes in rainfall will continue to rise, but do not necessarily guarantee the availability of water, especially the availability of infiltrated water. Surface water will continue to rise. This is due to the continued increase in built-up land cover and the decrease in green land cover that may absorb more water. While the availability of surface water needs to be managed first as well as the position of the Cibinong Urban area, which is in the middle stream, the flow of the river will continue to flow downstream, except the surface water in a permanent reservoir. Thus, it can be said that the availability of water is very much influenced by the ability of land cover in the form of its water catchment area. Furthermore, it can also be seen that the water needs have increased along with population growth. Obviously, the population growth cannot be limited which causes the need for space to be increased as well (built-up land).

The high magnitude of the potential surface water that exists cannot be maximized as the main water source. To maximize this potential, an increase in surface water management infrastructure is needed. The available surface water that has the potential to be utilized is the surface water of reservoirs, because the function of the reservoir is to catch the flow of river water. As for the availability of river surface water, it will be more difficult to use because it depends on the flow velocity. From the explanations above, it is necessary to intervene in the form of a recommendation that is intended to increase or reduce
the gap between the availability of water and water needs that can increase the carrying capacity of water in the Cibinong Urban area in order to remain sustainable.

Details of the carrying capacity of water in each part of the Cibinong Urban area can be seen from every part of the existing kelurahan (village). The following is the status of the carrying capacity of water in each of the existing villages:

**Table 3. Water Carrying Capacity Status Per Village 2035**

| Name of Village         | Total of Water Availability | Water Needs | Gap | Carrying Capacity Status |
|-------------------------|-----------------------------|-------------|-----|--------------------------|
| Kelurahan Cibinong      | 0.28                        | 0.27        | 0.01| With Condition           |
| Kelurahan Cirimekar     | 0.18                        | 0.15        | 0.03| With Condition           |
| Kelurahan Ciriung       | 0.29                        | 0.34        | -0.05| Overshoot                |
| Kelurahan Harapan Jaya  | 0.22                        | 0.27        | -0.05| Overshoot                |
| Kelurahan Karadenan     | 0.29                        | 0.30        | -0.01| Overshoot                |
| Kelurahan Nangewer      | 0.27                        | 0.31        | -0.04| Overshoot                |
| Kelurahan Nangewer Mekar| 0.24                        | 0.17        | 0.08| With Condition           |
| Kelurahan Pabuaran      | 0.29                        | 0.86        | -0.57| Overshoot                |
| Kelurahan Pakansari     | 0.31                        | 0.37        | -0.06| Overshoot                |
| Kelurahan Pondok Rajeg  | 0.20                        | 0.17        | 0.02| Overshoot                |
| Kelurahan Sukahati      | 0.27                        | 0.29        | -0.02| Overshoot                |
| Kelurahan Tengah        | 0.24                        | 0.13        | 0.10| With Condition           |
| **Total**               | **3.07**                    | **3.63**    |     |                          |

From the table above, 7 of 12 villages in Cibinong Urban experience overshoot status. The remaining 5 villages are still in with condition status. The highest gap value is in Kelurahan Pabuaran, which is a shortage of almost 0.57 m³/s/day. From the existing condition, Kelurahan Pabuaran is a part of Cibinong urban area which has a high building density, it means the overshoot status has a strong correlation with the density.

![Figure 7. Distribution of Water Carrying Capacity and Quadrant Diagram](image)

It can be seen that distribution of 7 villages are experiencing overshoot conditions, such as of Ciriung, Harapan Jaya, Karadenan, Nangewer, Pabuaran, Pakansari, and Sukahati. With this distribution, a form
of intervention with development restrictions can be proposed. From the quadrant diagram above, it can be seen that almost everything in the Cibinong Urban area is on the + side, which means that Cibinong Urban is a developing city except the Kelurahan Pabuaran which almost touches the maximum limit. With this description, of course, it can be anticipated that the development of Urban Cibinong will be sustainable in terms of water carrying capacity.

4. Conclusions
The Cibinong Urban Area is a Catchment Area (DTA) in the Ciliwung watershed and the Cikeas watershed that has experienced a massive growth of built land cover. Based on the predicted results, the land cover has been built up to 78% from 73%. Surely these changes will reduce the function of the Ciliwung and Cikeas watersheds to absorb water and will affect water availability in the Cibinong Urban area. The biggest increase in land cover was in Sukahari, Pondokrajeg, Tengah, and Nanggewer Mekar villages. Whereas the highest gap between availability and demand is in Kelurahan Pabuaran and Kelurahan Pakansari. Cibinong Urban area infiltration water experiences a downward trend from an increase in value of 0.16 m³/s/day to only 0.01 m³/s/day. As for the availability of surface water based on runoff water tends to rise statically. But the potential that can be used today as an urban water source is only 1.26 m³/s/day.

The projected population of the Cibinong Urban area is 1,019,326 people in 2035. Then the water demand outside drinking water is 3.46 m³/s/day with a maximum requirement of 3.63 m³/s/day. Whereas the water demand based on the Bogor Regency spatial plan (RTRW) is 7.33 m³/s/day. The high water demand value based on the RTRW is according to the percentage of allotment of urban settlements reaching 96% of the total area, or it can be assumed that there will be 2,149,000 inhabitants by 2036. The population is twice the population projection calculation done. The carrying capacity of the water environment is based on the general and maximum water needs in the Cibinong urban area, which are in 3 statuses with different periods, in the period of 2020-2025 with a sustained status and during 2025-2030 with a status with condition, and in the period of 2030-2035 in a state of overshoot status. When compared to water needs based on the RTRW, the status will be overshot in every span of the year. So, it can be said that the existing RTRW zone plan in the Cibinong urban area does not consider the water carrying capacity of the urban area. This can be proven from the influence of land cover on the availability of water whose upward trend tends to decrease. Besides that, there is a condition of the carrying capacity of water experiencing an overshoot condition in 2030-2035.

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