Water infrastructure development using water infrastructure and planning model

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Abstract. WEAP is one of the hydrological software in evaluating and planning the water balance of a region. The WEAP approach method operates with the basic principle of water balance and allows the creation of scenarios based on existing conditions to investigate the impact of policies or alternative assumptions in the use and availability of water in the future. The purpose of this study is to develop water infrastructure in the Ciliman watershed - the second largest watershed in Banten Province and a part of the Ciliman-Cibungur River Region with the main river length of 112.83 km, crossing the Lebak and Pandeglang Regencies. The types of data used in this study are secondary data including: (1) hydrological data at the year 1998 - 2015, (2) water use data (3) maps of the Ciliman watershed. The results of the analysis show that the scenario of dam development with 4 alternatives can reduce the number of water supply failures until the year 2036. In August and September, the water needs of Tanjung Lesung SEZ water requirements were only met (5.03% and 53.76%) and South Banten Airport (3.67% and 54.21%). The water needs of the Ciliman Irrigation can not be fulfilled in July to September. It only fulfilled 35.91%, 2.43% and 33.54%.

Keywords: water availability, water infrastructure, dam, Ciliman watershed.

1. Introduction
Water resources infrastructure is a facility needed for water distribution from its source to be used by users for any use. This infrastructure physically can be artificial facilities such as distribution channels, floodgate, dams, etc., or natural facilities such as lakes, rivers, waterfalls and springs. Depend on its function, water resources infrastructure can provide direct or indirect benefits. The raw water supply system can provide direct income for its managers and at the same time increase / provide opportunities to be further developed as a business sector. In Indonesia, the amount of available water potential is 3,221 billion m$^3$/year or can fulfill community water needs with a capacity of 16,000 m$^3$/capita/year (Ministry of Public Works, 2015). From this figure, the potential for water availability is actually sufficient according to average needs, but the problem is the availability is not evenly distributed in each region and time, Kalimantan and Papua have the highest water availability compared to other islands in Indonesia (30%), Sumatra Island (22%), Sulawesi Island (9%), while Java Island which covers only 7% of Indonesia's land area, have to provide water needs for 65% of the population, even though the water potential only 4.5% (Hatmoko et al. 2012). Based on the calculation of water requirements on the islands

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in Indonesia in 2010, Java has the largest water demand (2,079 m$^3$/s). The water needs include 12% of RKI's water needs (240 m$^3$/s) and 88% of irrigation water needs (1,838 m$^3$/s), but the problem is 46% of irrigation area is damaged, per capita water storage just reached 50 m$^3$/capita, the frequency of flood events in big cities are still high, raw water capacity until 2014 (51.44 m$^3$/s) has only reached ± 66.35% of the population. According to water balance in Java, generally, the river areas in Java included in critical zone (Hatlomoko et al, 2012). However, the amount of water availability from June to September in the river areas of Banten Province decreases close the amount of water demand. Assumed that the amount of water available is constant and the amount of projected water demand increases each year due to the growth of the population, then need the special efforts to overcome this condition.

The objectives of this study include; (1) Analyze the potential availability of raw water in each Ciliman Sub-watershed, (2) Analyze the water needs in Ciliman Watershed, (3). Analyze the water allocation for each water requirement in Ciliman Watershed to be fulfilled and (4). Analyze the potential for developing water infrastructure in Ciliman Watershed.

2. Methodology

2.1 Site and data sources
Location of this research is in Ciliman Watershed which is situated between 6°28'20.40" - 6°42'2.38" South Latitude dan 105°47'42.30" - 106°12'40.94" East Longitude. Ciliman Watershed is the second-largest watershed and is part of Ciliman-Cibungur River Region, has a very strategic potential of water resources, one of them is used to irrigate the Ciliman Irrigation Area of 5,423 Ha which is one of the largest technical irrigated rice fields in Pandeglang Regency and also contributes as national rice barns. This watershed is also utilized for the development of Tanjung Lesung Special Economic Zone, the Development of Panimbang Airport and the Serang-Panimbang Toll Road. Development along the Ciliman watershed is very rapid, making this river very vulnerable to flooding. Figure 1 shows the location of Ciliman Watershed.

![Figure 1. Location Map of Research Area](image)

2.2 Data analysis method
WEAP is one of the hydrological software in evaluating and planning the water balance of a region. This program is very easy and flexible to use and provides easy information for stakeholders in the field of water resources. The attributes needed in this program are hydrological attributes and data forms in the shapefile. The output of this program is a water balance planning scheme, where the data collected will find out the shortcomings and excess water from an area and whether or not a reservoir/water reservoir is needed to design water requirements in an area. The WEAP approach operates with the basic
principle of water balance, WEAP can be applied to irrigation systems in agricultural and urban areas, a catchment area, or river conditions that pass through some complex boundaries. Moreover, WEAP can map broad problems, such as sectoral needs analysis, water conservation, water balance priorities, streamflow simulation and groundwater, operation of reservoirs, hydropower plants, pollution pathways, supposed ecosystem conditions, critical condition assessments, and designing financial analysis of work. The diagram WEAP methodology can be seen in figure 2.

![Figure 2. WEAP Flow Diagram](image)

3. Result and Discussion

3.1 Water Balance
The supply of water input in Ciliman River calculated from each main sub-watersheds, using dependable flow Q80, as shown in figure 3.
3.2 Water Supply dan Demand Schematization

DSS-WEAP is one of the Decision Support software systems in the river basin water resource planning process. DSS-WEAP itself is a package of generic models for simulating the behavior of one or more watersheds in various hydrological conditions, water requirements, and existing and planned structures. This model is a comprehensive, integrated and flexible simulation tool that connects hydrological input in water availability form in various locations for a variety of water usage. In the process of calculating water balance using DSS-WEAP, Ciliman watershed are divided into 24 sub-watersheds or water districts, which can be seen in figure 4.

3.3 Data Input in WEAP

3.3.1 The input of River Flow Data. Input for river flow is the result of debit analysis based on input rainfall data and potential monthly evapotranspiration at the year 1998-2015, soil moisture and groundwater storage using the Mock method.
3.3.2 **Input of Irrigation Water Needs Data.** Irrigation water needs in this simulation refer to the recommendations of the results analysis irrigation water requirements of each Irrigation Area. Selected with the most efficient use of water in planting pattern. This irrigation water returns to the river system but not entirely (return flow). The water returning to the river system maximum calculated of 20% of the supply (consumed by the irrigation area 80%); Especially for the Ciliman Irrigation Area, return flow calculated only 10%.
- The first priority in water allocation includes small irrigation such as Citiis and Cinangkaruka irrigation (each 70 ha with annual water needs reach 30,960 m³/ha), Cipanggelangan irrigation (335 ha and annual water requirements of 30,960 m³/ha), Cimanyangray irrigation (195 ha with annual water requirements of 28,451 m³/ha), Cibodas irrigation (100 ha and annual water requirements of 32,279 m³/ha), Cilimus irrigation (80 ha and annual water requirements of 29,842 m³/ha), Cibilakan irrigation (80 ha and annual water needs of 30,012 m³/ha)
- The 3rd priority in water allocation includes Kramat Jaya irrigation pump (108 ha and annual water requirements of 29,842 m³/ha) and Ciliman Irrigation (5,423 ha and annual water requirements of 39,084 m³/ha).

3.3.3 **Input of Population Water Needs Data.** The inputs for the population’s raw water needs in the Ciliman watershed, with a population in 2016 of 342,606 people consisting of 3 sub-districts in Lebak Regency (Banjarsari, Cirinten, and Gunung Kencana Districts), and 6 Districts in Pandeglang District (Angsana District, Munjul, Panimbang, Sindangresmi, Sobang, and Sukaresmi). Projection of population growth has also been included in the scenario for 2017-2036 with population growth rates in Lebak Regency is 0.83% and population growth rates in Pandeglang Regency are 1.30% and assumed water consumption per capita of 120 liters /day, or equal to 43.8 m³/year. The priority for Panimbang and Sukaresmi district set as the fourth while the rest are second.

3.3.4 **Input of Industrial Water Needs Data.** The average consumption of industry in Munjul reach 1,000 liters/unit/day or equal to 365.25 m³/year/unit of water needs. This water demand grows every year by 5%, and at the end of the projected year, (2036) industrial raw water needs in Munjul Sub-district are 0.000041 m³/s. The priority for the Munjul industry is the fourth.

3.3.5 **Airport and Tanjung Lesung SEZ.** Airport and Tanjung Lesung SEZ water requirements are considered constant (not growing). Large water requirements for airports are 12.1 liters/sec or equal to 381,585.6 m³/year and Tanjung Lesung SEZs are 400 liters/sec or equal to 12,614.400 m³/year. The priority for the airports and Tanjung Lesung SEZ is the fifth.

### 3.4 Water Balance Calculation Results with DSS-WEAP
Based on the results of the water balance calculation using DSS WEAP, the process of taking water occurs in the sub-watershed as follows:
- Citiis Sub-watershed: Citiis Irrigation.
- Cipanggelangan Watershed : Cipanggelangan irrigation.
- Cimanyangray watershed: Cimanyangray irrigation.
- Cibodas Sub-watershed: Cibodas Irrigation.
- Ciliman Watershed : Cinangkaruka Irrigation, Cirinten District, Cibilakan Irrigation, Cilimus Irrigation, Kramatjaya Pump Irrigation, Gunung Kencana District, Banjarsari District, Ciliman Irrigation, Munjul District, Munjul Industry, Angsana District, Sindangresmi District, Sobang District, Sukaresmi District, Airport, Panimbang District, and Tanjung Lesung SEZ.

The highest water requirements in the Ciliman watershed used to irrigate ciliman irrigation up to 211.95 million cubic meters. Therefore, water requirements in each sector cannot be met especially in July, August, September, and November. The airport water demand and Tanjung Lesung SEZ experienced 100% adequacy except in August and September, only fulfilled at 5.03% and 53.76% (Tanjung Lesung SEZ) and 3.67% and 54.21% (Airports). The failure of the Ciliman watershed irrigation water supply...
occurred in May (0.01 m$^3$/s), July (1.92 m$^3$/s), August (7.67 m$^3$/s), September (2.52 m$^3$/s), and November (0.74 m$^3$/s). Generally, the amount of water supply shortages that occur in the Ciliman watershed is presented in figure 5.

![Figure 5](image)

**Figure 5.** The volume of Water Supply Failure in Ciliman Watershed at 2016

### 3.5 Infrastructure Development Analysis

Based on the results of the water balance calculation and water allocation using the WEAP application in the Ciliman watershed with the existing conditions in 2016 up to the year of 2036, it turns out that the Ciliman watershed is unable to supply water needs especially in the dry season in July, August and September. Then, it has to set the infrastructure development scenarios that are needed to accommodate the excess water in the rainy season to be used as needed. Based on the results of Feasibility of the Multipurpose DAM Development Study in the Ciliman Watershed, there were 3 (three) alternative dam developments in the Ciliman watershed (figure 6)

![Figure 6](image)

**Figure 6.** Alternative Dam in Ciliman Watershed

#### 3.5.1 Dam Alternative Operations in the Study Area

The operation of 3 (three) alternative dam calculation in this study refers to the results of Feasibility Study of Multipurpose DAM Development in the Ciliman watershed, with alternative dam storage capacity 1, alternative 2 and alternative 3 each at 15.08 million cubic, 16.32 million cubic and 44.67 million cubic and an initial storage capacity of 8.13
million cubic, 11.57 million cubic and 31.38 million cubic. Enter data for the Ciliman dam or reservoir is in the form of physical and operational data of the dam. From the three alternative dams above, the physical data of the dam required as input in WEAP can be seen in Table 1.

### Table 1. Physical and operational parameter of 4 alternative ciliman dam

| Physic Parameter | 1st Dam | 2nd Dam | 3rd Dam | 2nd + 3rd Dam |
|------------------|---------|---------|---------|---------------|
| Storage capacity | 15.08   | 16.32   | 44.67   | 44.67         |
| Initial storage  | 8.13    | 11.57   | 31.38   | 31.38         |
| Volume elevation curve | See fig. |         |         |               |

| Operation parameter | 1st Dam | 2nd Dam | 3rd Dam | 2nd + 3rd Dam |
|---------------------|---------|---------|---------|---------------|
| Top conservation    | 8.13    | 11.57   | 31.38   | 31.38         |
| Top buffer          | 1       | 1       | 3.5     | 3.5           |
| Top inactive        | 0.82    | 0.72    | 0.92    | 0.92          |

Source: Analysis Result, 2018

3.5.2 **Simulation Scenario.** The simulation is carried out with a simulation period of 20 years. As the initial year of simulation, according to the availability of data, it will be 2016. The following is a scenario from the simulation of water balance with WEAP in the Ciliman watershed:

- **Existing Condition**
  This WEAP simulation is a simulation of current conditions. The purpose of this simulation is to find out whether water is still available from the Ciliman River to meet raw water needs in all sub-districts in the Ciliman watershed and irrigation and to assess the potential for fulfilling the Tanjung Lesung SEZ and South Banten Airport from the Ciliman River.

- **Conditions with Dam 1 on the Ciliman River**
  This WEAP simulation is a simulation of conditions with the presence of dam 1 on the Ciliman River. Irrigation that extracts water from the Ciliman tributary is considered the first priority because it takes water for its needs first before the water flows to the Ciliman River (citiis irrigation, cipanggelangan irrigation, cibodas irrigation, cimanyangray irrigation and cinangkaruka irrigation), then the second priority is raw water, third priority are raw water sources, irrigation cilimus, cibulakan irrigation, kramatjaya pump irrigation, airport, and Tanjung Lesung SEZ. The fourth priority is industry and the fifth priority of Ciliman irrigation.

- **Conditions with Dam 2 on the Ciliman River**
  This WEAP simulation is a simulation of conditions with the presence of dam 2 on the Ciliman River. Priority sequences for priority 1 are citiis irrigation, cipanggelangan irrigation, cibodas irrigation, cimanyangray irrigation, irrigation cinangkaruka, irrigation cilimus, and cibulakan irrigation. The second priority is raw water. The third priority is raw water for sukaresmi, kramatjaya pump irrigation, airport, and Tanjung Lesung SEZ. The fourth priority is the munjul industry and the fifth priority is the development of 200 hectares of ciliman irrigation. The sixth priority is ciliman irrigation.

- **Conditions with Dam 3 on the Ciliman River**
  This WEAP simulation is a simulation of conditions with the presence of dam 3 on the Ciliman River. The priority sequence for priority 1 is citiis irrigation, cipanggelangan irrigation, cibodas irrigation, cimanyangray irrigation, irrigation cinangkaruka, irrigation cilimus, and cibulakan irrigation. The second priority is raw water. The third priority is raw water for sukaresmi, kramatjaya pump irrigation, airport, and Tanjung Lesung SEZ. The fourth priority is the munjul industry and the fifth priority is the development of 2,200 hectares of ciliman irrigation. The sixth priority is ciliman irrigation.

- **Conditions with Dam 2 and Dam 3 on the Ciliman River**
  This WEAP simulation is a simulation of conditions with the presence of dam 2 and dam 3 on the Ciliman River. Priority sequences for priority 1 are citiis irrigation, cipanggelangan irrigation, cibodas
irrigation, cimanyangray irrigation, irrigation cinangka,irrigation cilimus, and cibulakan irrigation. The second priority is raw water. The third priority is raw water for sukaresmi, kramatjaya pump irrigation, airport, and Tanjung Lesung SEZ. The fourth priority is that the industry starts and the fifth priority is the development of ciliman irrigation covering an area of 3,200 hectares. The sixth priority is ciliman irrigation.

a. From the results of the existing scenario simulation we can conclude several things, as follows:
   1. The average domestic water demand for the 2016-2036 period can be fully met (100%).
   2. The industrial water needs of Munjul in September to July are 100% fulfilled.
   3. Tanjung Lesung SEZ water needs from October to July, and November is 100% fulfilled. While in August only 5.03% was fulfilled and September was 53.76%.
   4. The water needs of South Banten Airport from October to July and November are 100% fulfilled, while August is fulfilled 3.67% and September is 54.21%.
   5. The water needs of the Ciliman Irrigation Area are 100% fulfilled in October to June except in November only 95.38% is fulfilled, while the July to September deficit is fulfilled 2.43% (August).

b. From the results of the scenario simulation with the existence of the Ciliman Dam (location 1) several things can be concluded, as follows:
   1. The average domestic water demand for the 2016-2036 period can be fully met (100%).
   2. The industrial water needs of Munjul in September to July are 100% fulfilled.
   3. The water needs of South Banten Airport from October to July and November are 100% fulfilled, while August is fulfilled 3.67% and September is 54.21%.
   4. The water needs of the Ciliman Irrigation Area are 100% fulfilled in October to June except in November only 99% are met, up 3.62% from existing conditions. In August to September the deficit was only fulfilled 17.24% (August).

c. From the simulation results of the scenario with the existence of the Ciliman Dam (location 2) several things can be concluded, as follows:
   1. The average domestic water demand for the 2016-2036 period can be fully met (100%).
   2. The industrial water needs of Munjul in September to July are 100% fulfilled.
   3. Tanjung Lesung SEZ water needs from October to July, and November is 100% fulfilled. While in August only 48.94% was fulfilled and September was 53.67%.
   4. The water needs of South Banten Airport from October to July and November are 100% fulfilled, while August is fulfilled 49.34% and September is 53.67%.
   5. The water needs of the Ciliman Irrigation Area are 100% fulfilled in October to June except in November only 99% are met, up 3.62% from existing conditions. In August until September, the deficit was only fulfilled at 16.92%. and the development of the new Ciliman irrigation area of 2200 ha in MT.III (July-September) failed to be fulfilled, while in MT II 100% could be fulfilled.

d. From the results of the scenario simulation with the presence of the Ciliman Dam (location 3) several things can be concluded, as follows:
   1. The average domestic water demand for the 2016-2036 period can be fully met (100%).
   2. The industrial water needs of Munjul in September to July are 100% fulfilled.
   3. Tanjung Lesung SEZ water needs from October to July, and November is 100% fulfilled. While September is 40.89%.
   4. The water needs of South Banten Airport are October to July, and November is 100% fulfilled, while September is 41.29%.
   5. The water needs of the Ciliman Irrigation Area are 100% fulfilled in October to June except in November only 99% are met, up 3.62% from existing conditions. In August until September, the deficit was only fulfilled at 16.92%. and the development of the new Ciliman irrigation area of 2200 ha in MT.III namely July-September failed to be fulfilled, while in MT I and II could be fulfilled 100%.
6. The potential for electricity generation is an average of 0.97 MW in a year. However, this electricity generation cannot be distributed every month. January to May generation potential is 1 MW. September to December the generation potential is very low, even in September, there is no generation. If the dam is to be developed to be able to generate electrical energy, the volume of the reservoir needs to be increased, so that it needs to increase the dam height.

e. From the results of the scenario simulation with the existence of the Ciliman Dam (location 2 + 3) several things can be concluded, as follows:
   1. The average domestic water demand for the 2016-2036 period can be fully met (100%).
   2. The industrial water needs of Munjul in September to July are 100% fulfilled.
   3. The demand for water from Tanjung Lesung SEZ and South Banten Airport is met 100.
   4. The water needs of the Ciliman Irrigation Area are 100% fulfilled in October to June except in November only 99% are met, up 3.62% from existing conditions. The August to September deficit was only fulfilled 99%. and the development of the new Ciliman irrigation area covering 3200 ha in MT.III (July-September) failed to be fulfilled, while in MT I and II 100% could be fulfilled.
   5. The potential for electricity generation is an average of 0.97 MW in a year. However, this electricity generation cannot be distributed every month. January to May generation potential is 1 MW. September to December the generation potential is very low, even in September, there is no generation. If the dam is to be developed to be able to generate electrical energy, the volume of the reservoir needs to be increased, so that it needs to increase the dam height.

4. Conclusion
   a. The total water availability of the Ciliman Watershed is 210.73 m$^3$/s, while the total water demand is 111.724 m$^3$/s. Therefore, there was still a surplus of 99,006 m$^3$/s. However, the water balance per month in the Ciliman Watershed there is still a water deficit for 3 (three) months from July to September.
   b. The best alternative scenario of meeting the needs of raw water in the Ciliman Watershed, is the fifth scenario with the potential for the construction of 2 (two) dam units with large dam storage capacity of 16.32 million m$^3$ and 44.67 million m$^3$, the development of new agricultural land is 3,200 hectares and the potential for power plants is an average of 0.97 MW per year.
   c. The total volume of raw water finally produced with 2 dam units is approximately 6,847.5 million m$^3$, while from the 1st dam, total water production is approximately 2,778 million m$^3$, total water produce from 2nd dam is approximately 2,471.2 billion m$^3$, total water produces 3rd dam is approximately 4,376.3 billion m$^3$.

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