Application of Watershed Carrying Capacity and Sustainability Index (Case Study: Cimahi Sub-Watershed)

R R Hikmat* and M Marselina

1 Faculty of Civil and Environmental Engineering, Institut Teknologi Bandung, Bandung, 40132, Indonesia, ORCID ID: 0000-0002-4704-5797

*rafidrisandri@gmail.com, mariana@tl.itb.ac.id

Abstract. Activities carried out in Cimahi City are quite diverse so that can affect the decline in environmental quality, one of which is the sub-watershed. This condition explains that a study on the application of watershed carrying capacity and sustainability index needs to be carried out to provide a comprehensive picture of the environmental conditions. The index is developed based on the study of carrying capacity and sustainability. The two studies are combined to complement the indicators that do not exist in each study. In general, the two studies consist of three main components, namely land, water resources, and social, economic, and institutional. The results of the study are then analyzed using the DPSIR framework. The analysis show that the sub-watershed is classified as poor performance. The final value obtained from the watershed sustainability study is 11,11. There are 13 out of 26 indicators that have poor performance. All indicators with these performances are priority actions. This research can be used by the government to create a management strategy for the Cimahi sub-watershed.

1. Introduction
Cimahi City is planned to be the core city of the Bandung Basin National Activity Center which is safe, comfortable, efficient, and sustainable [1]. This planning has the potential to cause various activities carried out in Cimahi City such as from the domestic, agriculture, livestock, and industrial sectors to increase. One of the impacts of increased activity from various sectors is the potential for more waste to be generated, resulting in environmental pollution, one of which is pollution in watersheds. That polluted ecosystems will disrupt the role of watersheds especially in terms of water regulation [2].

The Cimahi sub-watershed is one of the sub-watershed which locates in the Cimahi City area and part of the Citarum watershed. The sub-watershed is included in the plan to develop a water resource network system in the Cimahi City Regional Spatial Plan. The Cimahi sub-watershed because of its location in the Citarum watershed has contributed to the pollution of the watershed which is a national strategic river [3]. Other problem is the increase in population. It is one of the factors that causes land use changes in the Citarum watershed especially in the case of Cimahi sub-watershed [4].

The conditions previously described become the basis for the need of study on the application of watershed carrying capacity and sustainability index. The index is developed based on the study of carrying capacity and sustainability. The two studies are combined to complement the indicators that do not exist in each study. In general, the two studies consist of three main components, namely land, water resources, and social, economic, and institutional.
The basis of the carrying capacity study refers to the Regulation of the Minister of Forestry of the Republic of Indonesia Number: P.60/Menhut-II/2014 concerning Criteria for Determination of Watershed Classification. The final results of the study conclude whether the carrying capacity of a watershed is maintained or needs to be restored [5]. The sustainability study is conducted using the West Java Water Sustainability Index (WJWSI). The final results of the sustainability study are in the form of performance levels and priority actions for each indicator as well as overall [6]. The results of the watershed carrying capacity and sustainability index study are then analyzed using the DPSIR framework to determine environmental problems that are interrelated with social and economic conditions [7].

It is important to develop and apply a watershed carrying capacity and sustainability index to provide an overview of the environmental conditions of the watershed as an effort to protect and manage in a sustainable manner. The description given is in the form of environmental indicators that are in good or poor condition. These environmental indicators become the basis for determining priority actions in the protection and management of the Cimahi sub-watershed. Action priorities are selected based on environmental indicators that are in poor condition. The results of the study can then be used as a basis for making recommendations for the management strategy of the Cimahi sub-watershed.

2. Method
The development of watershed carrying capacity and sustainability index is carried out by combining carrying capacity and sustainability studies. The aim of those combinations is to provide a comprehensive picture of watershed condition. Indicators that do not exist in one study are complemented by indicators from other studies. There are 26 indicators used in this study.

The results of the study are then analyzed using the DPSIR framework. Within the framework there are causal relationships namely the driving forces (economic sector and human activities), pressures (emissions and waste), states (physics, chemistry, and biology), impacts on ecosystems, human health, and function, and response (priority, targeting, and indicators) [7].

The use of the formula for each indicator is seen from the maximum and minimum values. If the maximum value is preferred then use equation 1 and vice versa. The calculation of the final index value is done by aggregating the values of each indicator using the geometric method which can be seen in equation 3. The weight of each indicator is adjusted to the weights that have been determined in the regulations and journals. The interpretation of the final index value can be seen in table 1. Meanwhile the indicators for the watershed carrying capacity and sustainability index can be seen in table 2. The following three formulas are used.

\[
S_i = \frac{x_i - x_{\text{min}}}{x_{\text{max}} - x_{\text{min}}} \times 100 \quad (1) \\
S_i = 0 \text{ if } x_i < x_{\text{min}} \\
S_i = 100 \text{ if } x_i > x_{\text{max}} \\
S_i = 100 - \left(\frac{x_i - x_{\text{min}}}{x_{\text{max}} - x_{\text{min}}} \times 100\right) \left(2\right) \\
S_i = 0 \text{ if } x_i < x_{\text{min}} \\
S_i = 100 \text{ if } x_i > x_{\text{max}} \\
I = \prod_{i=1}^{N} S_i^{w_i} \quad (3)
\]

with:
- \( S_i \) = index or sub index value of indicator \( i \)
- \( x_i \) = actual value of indicator \( i \)
- \( x_{\text{min}} \) = maximum/minimum threshold value of the indicator
- \( I \) = final index value
- \( N \) = number of aggregated indicators
- \( w_i \) = weight of indicator \( i \)

| Index/Sub Index Value | Performance | Condition |
|-----------------------|-------------|-----------|
| 0 - <25               | Poor        | Restored  |
| 25 - <50              | Poor-Medium |           |
| 50 - <75              | Medium-Good | Maintain  |
| 75 - 100              | Good        |           |

Table 1. Interpretation of the sub index and final index value.
3. Results and discussion
The final value obtained from the Cimahi sub-watershed carrying capacity and sustainability study is 11.11. Thus, the Cimahi sub-watershed is classified as a watershed with poor performance so that its condition needs to be restored. There are 13 out of 26 indicators that have poor to poor-medium performance. All indicators with these performances are priority actions in making recommendations for strategic management for the Cimahi sub-watershed by referring to the results of the DPSIR analysis. The analysis results of the watershed carrying capacity and sustainability index of the Cimahi sub-watershed can be seen in table 2. The indicators analyzed in the DPSIR framework for the driving force, pressure, state, and impact components are only those with poor performance. The results of the DPSIR analysis can be seen in figure 1.

| Table 2. The results of the watershed carrying capacity and sustainability index. |
|-----------------|------------|------------|--------------|--------------|-----------------|-----------|
| Indicator       | Unit       | Max        | Min         | Weight (%)   | Actual Value   | Sub Index |
| Percentage of critical land | %          | 20b        | 5a          | 10.19        | 23.73          | 0         |
| Percentage of vegetation cover | %           | 80b        | 20b         | 5.19         | 19.69          | 0         |
| Erosion index   | -          | 2b         | 0.5a        | 5.19         | 0.5            | 100       |
| Conservation areas | %           | 70b        | 15b         | 2.69         | 48.27          | 60.50     |
| Cultivation areas | %          | 70b        | 15b         | 2.69         | 99.82          | 100       |
| Land use changes | %         | 100b       | 0a          | 4.70         | 40.79          | 40.79     |
| Flow regime coefficient | -         | 20b        | 5a          | 2.69         | 8.48           | 76.78     |
| Annual flow coefficient | -         | 0.5b       | 0.2a        | 2.69         | 0.70           | 0         |
| Sediment load   | ton/ha/year | 20b        | 5a          | 2.19         | 4.05           | 100       |
| Flood           | time/year  | 1b         | 0a          | 1.19         | 7              | 0         |
| Water use index | -          | 1b         | 0.25a       | 2.19         | 1.42           | 0         |
| Water quality   | -          | 0a         | -31b        | 5.05         | -74.67         | 0         |
| Water availability | m³/capital/year | 1.700b | 500b       | 5.07         | 44.48          | 0         |
| Water demand    | %          | 40b        | 10a         | 4.31         | 229.08         | 0         |
| Water service provision coverage | % | 80b | 0b | 4.21 | 21.96 | 27.45 | Poor-Medium |
| Water loss      | %          | 30b        | 15a         | 4.10         | 21             | 60        |
| Population pressure on land | ha/family | 4a | 0.5b | 5.19 | 0.03 | 0 | Poor |
| City classification | - | 1.5b | 0.5a | 2.69 | 1.25 | 25 | Poor-Medium |
| Water infrastructures value classification | Rp billion | 60b | 15a | 2.69 | 20 | 88.89 | Good |
| Information disclosure | - | 100b | 0b | 2.76 | - | 93 | Good |
| Governance structure | - | 100b | 0b | 3.46 | - | 100 | Good |
| Education       | %          | 100b       | 0b          | 3.73         | 76.14          | 76.14     |
| Poverty         | %          | 20b        | 0b          | 3.41         | 4.38           | 78.10     |
| Health impact   | cases/1.000 pop | 2b | 0a | 3.93 | 1.66 | 16.98 | Poor |
| Sanitation      | %          | 100b       | 0b          | 3.67         | 79.90          | 79.90     |
| Law enforcement | -          | 100b       | 0b          | 4.10         | -              | 50        |

a preferred value
b least preferred value
Figure 1. The results of the DPSIR analysis of the Cimahi sub-watershed.

Based on the results of the analysis, the driving forces for environmental problems and conservation of the Cimahi sub-watershed are population growth, the Cimahi City Spatial Plan 2012-2032, and the Presidential Regulation 15/2018. The population of Cimahi City for the last 10 years has increased. This condition causes population pressure on land in Cimahi City in this case in the Cimahi sub-watershed to increase. Population growth that is directly proportional to the increase in population pressure on land is a challenge because as stated in the Cimahi City Spatial Plan 2012-2032 that Cimahi City is planned to be the core city of the Bandung Basin National Activity Center. In addition, the Cimahi sub-watershed located in the upstream Citarum watershed makes its management important because the watershed is a national strategic river.

Population growth in Cimahi City causes land use changes. Land that was originally green or unused is then used for the purposes of the domestic, agricultural, and industrial sectors [4]. These three sectors are the main activities carried out in the Cimahi sub-watershed which have the potential to be the main source of river pollution. The two things described earlier are the pressures which then affect the state of the Cimahi sub-watershed.

Land use changes due to population growth have caused the condition of water availability in the Cimahi sub-watershed to be low or even shortage, especially from surface water. This condition is exacerbated by the occurrence of a dry season with little or no rainfall for approximately six months [8]. In addition, pollution from the domestic, agricultural, and industrial sectors causes the water quality of the Cimahi river to be in a heavily polluted condition. The water pollution load capacity of the Cimahi river for the parameters of TSS, BOD, COD, NO₂, NH₃, and Total-P has been exceeded at several points so that it is no longer able to accept the pollution load.

The poor condition of the Cimahi sub-watershed, especially in terms of water availability and water quality, has an impact on unfulfilled water demand, flood, and water-borne diseases. The unfulfilled
water demand by the water service provision causes people to use other sources such as ground water. This has the potential to cause uncontrolled use of groundwater so that the soil surface has the potential to be degraded. Then the land use changes is one of the causes of the flood disaster. This is because the land that was previously able to seep water turns into pavement so that the runoff water flow increases. While water-borne diseases appear in an area which caused by poor water quality and the unavailability of proper sanitation facilities.

There are three main indicators related to the response to DPSI conditions, namely improvement and supervision of regulation implementation, provision of proper sanitation facilities, and water infrastructure investment. These three indicators have good performance but it is not optimal yet so those can still be improved.

Improvement and supervision of regulation implementation is carried out through improving the performance of the government, especially the agencies or sectors which are responsible for watershed management and stricter enforcement of regulations/laws. Then the provision of proper sanitation facilities aims to reduce the impact of water-borne diseases. In addition, the availability of these facilities can prevent domestic wastewater from being discharged directly into rivers so that it’s quality is maintained or even increased. Water infrastructure investment is needed to deal with problems related to water demand and flood. It is necessary to increase the water service area from the Cimahi City water service provision and the development of a drinking water supply system for other raw water sources so that the community’s water demand are met so that do not rely on ground water. Then to prevent or at least reduce the risk of flood, it is carried out through maintenance and construction of embankments, drainage channels, and reservoirs as part of water infrastructure investment.

4. Conclusion
The results of the watershed carrying capacity and sustainability index analysis show that the Cimahi sub-watershed is classified as a watershed with poor performance so that its condition needs to be restored. The main challenges and problems in the management of the Cimahi sub-watershed based on the results of the DPSIR analysis are driven by population growth, the Cimahi City Spatial Plan 2012-2032, and the Presidential Regulation 15/2018, causing pressure in the form of land use changes and increased activities from the domestic, agricultural, and industrial sectors. This causes the state of water availability and water quality are in poor condition. All of these problems have an impact on unfulfilled water demand, flood, and water-borne diseases. These main problems need to be addressed by improvement and supervision of regulation implementation, provision of proper sanitation facilities, and water infrastructure investment.

The development of an index related to environmental management have to consider the environmental, social, and economic conditions of the research area as well as the availability of data. The watershed carrying capacity and sustainability index is more suitable to be used as a basis for making long-term watershed management strategies due to its detailed character so that the interrelationships between indicators are described clearly. This study needs to be carried out periodically so that changes in environmental conditions can be seen after a strategy is implemented. The maximum and minimum values of each indicator must be updated regularly so that their values are in accordance with the latest conditions. Community participation indicator can be added to describe the influence of the community on environmental management, especially watershed management. The DPSIR framework can be used as a tool to analyze the carrying capacity and sustainability index of a watershed so that the interrelationships of problems between indicators can be described thoroughly and the recommendations for the watershed management strategy are more precise.

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