Environmental Vulnerability Assessment and Stormwater Management to Enhance Watershed Performance

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Abstract. The declination of environmental quality triggers several harmful impacts on society, such as the increasing of water-borne diseases, low quality of health, and lousy habitat ecosystem. The research aims to conduct a vulnerability assessment method of a watershed and to perform stormwater management to increase the catchment performance due to dynamic changes. The observation focused on Sugutamu sub-catchment, Depok, West Java. The evaluation includes sub-watershed map compilation, impervious cover calculation, river assessment, and restoration capacity evaluation. The result indicates that the sub-catchment describes as restorable non-supporting sub-watershed. There are three main regions in the sub-catchment. These areas have a percentage of impervious cover 95.6%, 72.5%, and 38.5%, respectively. Also, according to the future impervious cover prediction, these areas will have 97.8%, 95.3%, and 97.5%, respectively. The paper used the National Stormwater Calculator and EPA SWMM 5.1 software to visualize and to predict the future condition of sub-watershed with the various scenario. The application of low impact development (LID) in the research area declines the level of runoff, enhances the level of infiltration, and reduces the peak discharge. The research concludes that watershed vulnerability assessment, along with stormwater management, could control flooding in urban areas.

Keywords: Low impact development in urban areas, storm water management model in urban areas, vulnerability assessment method in urban areas

1. Introduction

Today, the condition of a watershed is highly compulsory for the watershed health section. In fact, the sustainability of the economic level is also strongly influenced by the conditions of a watershed. That is the reason why management of a watershed is very necessary. In achieving this, some understandings of watershed in terms of characteristics, components, and their nature must be explored first. Some studies reveal that watersheds are formed from a variety of ecosystems that interact from upstream to downstream. The goal of watershed management generally is to harmonize ecosystems for service sustainability. Flooding and several other disasters in water bodies can be indicative of the poor management of watersheds. This is normally the result of forest ecosystem degradation. One of the problem solution of the declared problem is LID management. Low impact development (LID) is usually used to control flooding, especially in urban areas [1]. According to several research, LID could be a sustainable tool for urban flooding management [2 – 4].

Management of a watershed is a difficult thing to do. However, it can help to know the characteristics of the watershed to be managed. This is because each watershed and sub-watershed have different characteristics, such as peak discharge, impervious cover, and others. This is the same as understanding
the basic information of the application in an experiment. In other words, not all flooding is the result of poor watershed management. Also, not all landslides are caused by lack of forest vegetation. These can be triggered by watershed characteristics or abnormal rain events.

The research aims to investigate catchment vulnerability and proposes sustainable solution. In this research, the object of study is Sugutamu sub-watershed. Sugutamu catchment is located in Depok, West Java. Sugutamu watershed health audit is important because the area is the center of human activity. If the watershed management plan is not managed properly, it will have negative impacts on humans and nature in the watershed. Therefore, vulnerability analysis of Sugutamu watershed needs to be done.

2. Research Method
The research method is according to the vulnerability analysis method by Zielinski [5]. Firstly, the research is started by compiling mapping resources, delineating sub-watershed boundaries, verifying future development assumptions, and measuring impervious cover to obtain the initial classification of sub-watershed. Next, the research was carried out with stream assessment and sub-watershed assessment to get final classification of sub-watershed. In the following step, future impervious cover is estimated to rank the most vulnerable sub-watershed. Last, restoration capacity was evaluated to rank the priority of sub-watershed for implementation.

![Figure 1. Watershed vulnerability level analysis method [5].](image)

After watershed vulnerability level analysis method, the research simulates the storm water management model using EPA SWMM 5.1. This model is recommended by previous studies [6 – 12]. The analysis steps are provided by SWMM modules.
3. Result and Discussion

3.1. Vulnerability level analysis
The health of the Sugutamu watershed needs to be further investigated and analyzed because based on the latest research report of the Center for Watershed Protection [13] the Sugutamu Sub-watershed rating is restorable non-supporting. The range of year 2004 to 2017 is a long period while the City of Depok and the District of Cibinong (Bogor Regency) themselves have experienced a very rapid development period over 13 years. For this reason, it is necessary to analyze the dynamics of development that occurred in Depok City and Cibinong District (Bogor Regency) with their effects on the health of the Sugutamu Sub-watershed.

The first step of the watershed vulnerability analysis is compiling mapping resources, which could be seen in Figure 2. The figure below describes the location of Sugutamu sub-watershed. Next, the sub-watershed is delineated and verified for the current and future development assumption.

![Figure 2. Sugutamu sub-watershed.](image)

Current and future land use information is needed to accurately predict current and future impervious cover or waterproof zones in the sub-catchment. Information obtained includes development plans, urban infrastructure development plans such as schools, sports complexes, and parks, plans for conservation, plans for large tracts owned by individual landowners, transportation corridor planning, buffer zone or city planning, and open space planning. The plans can be directly estimated using photographic images and related planimetric data while GIS can be used to estimate the existing impervious cover and can accurately describe the existing land use. In some cases, a field survey needs to be carried out. The technique often used is zoning build-out analysis.
The next step of the analysis is estimating the current impervious cover in the subwatersheds. According to the GIS result, the percentage of land use management in the sub-watershed is provided in the Figure 3 and Table 1.

**Table 1. Land use management of Sugutamu sub-watershed.**

| Land use               | Previous Years Area (km²) | Current Area (km²) |
|-----------------------|---------------------------|--------------------|
| Settlement and housing| 3.17                      | 3.37               |
| Vegetated field       | 0.33                      | 0.15               |
| Grass                 | 0.03                      | 0.03               |
| Garden                | 0.14                      | 0.12               |
| Total area            | 3.67                      | 3.67               |

Based on the provided figure, Sugutamu subwatershed has 86.38% of impervious cover in the entire catchment. The subwatershed then is classified into "Non-Supporting" category. Impervious cover on each Sub-Catchment area (CA) is as follows: CA 1: 72.523%, Sub-CA 2: 95.597%, and Sub-CA 3: 38.444%. Percentage of impervious cover for all Sub Catchments in Sugutamu is included in the category of "Non-Supporting".

The next step of the analysis is stream corridor and land use assessment. The research conducted a field survey to the sub-watershed to identify the condition for vulnerability assessment. The following Table 2 and Table 3 are the result of land use and stream corridor assessment.
Figure 4. Impervious cover of sub-catchments of Sugutamu sub-watershed.

Table 2. Stream corridor assessment of sub-watershed.

| Research Criteria                                                                 | 1<sup>st</sup> catchment | 2<sup>nd</sup> catchment | 3<sup>rd</sup> catchment |
|-----------------------------------------------------------------------------------|---------------------------|---------------------------|---------------------------|
| The presence of rare, threatened, or endangered species in aquatic communities    | ✓                         | ✓                         | ✓                         |
| Confirm the presence of sensitive fish species.                                   | -                         | -                         | -                         |
| Rating of invertebrates                                                           | -                         | -                         | -                         |
| More than 65% of the Ephemeroptera, Plecoptera, and Trichoptera (EPT)             | -                         | -                         | -                         |
| There is no obstacle blocking the movement of fish                                | ✓                         | ✓                         | ✓                         |
| The lack of efforts to change the river                                           | -                         | -                         | -                         |
| Water quality                                                                      | -                         | -                         | -                         |
| Rivers and land remain connected and interact regularly.                          | ✓                         | ✓                         | ✓                         |
| The flow of water in the sub-watershed                                            | ✓                         | ✓                         | ✓                         |
| River flows are generally stable                                                  | -                         | -                         | -                         |

Table 3. Land use assessment of sub-watershed.

| Research Criteria                                                                 | 1<sup>st</sup> catchment | 2<sup>nd</sup> catchment | 3<sup>rd</sup> catchment |
|-----------------------------------------------------------------------------------|---------------------------|---------------------------|---------------------------|
| Plants or animals in the rare, threatened and endangered categories               | -                         | -                         | -                         |
| More than 10% area consists of wetlands                                          | ✓                         | ✓                         | ✓                         |
| More than 10% area is dedicated to conservation.                                 | ✓                         | ✓                         | ✓                         |
| More than 50% of the riparian corridors have forest cover, public.               | -                         | -                         | -                         |
| More than 40% of the watershed area is forest.                                   | -                         | -                         | -                         |
There is a section/ party responsible for watershed management.
The river border forms a continuous flow
The sub-watershed is connected to the watershed
Application of BMP in agriculture, animal husbandry and plantation activities.
The sub-watershed itself had managed rain runoff both in quality and quantity.

| Research Criteria                                                                 | 1stcatchment | 2nd catchment | 3rd catchment |
|-----------------------------------------------------------------------------------|--------------|---------------|---------------|
| There is a section / party responsible for watershed management.                  | -            | -             | -             |
| The river border forms a continuous flow                                          | -            | -             | -             |
| The sub-watershed is connected to the watershed                                   | -            | -             | -             |
| Application of BMP in agriculture, animal husbandry and plantation activities.    | -            | -             | -             |
| The sub-watershed itself had managed rain runoff both in quality and quantity.     | -            | -             | -             |

Based on the analysis results, catchment 1 is categorized as Restorable Non-Supporting Watershed, because it only qualified in 4 river corridor assessment criteria and 2 land use assessment criteria. The other 2 catchments are analyzed with the same step.

According to the analysis, it could be concluded that the final classification of sub-watershed of Sugutamu has the same category, which is provided in Table 4.

**Table 4. Final classification of Sugutamu sub-catchments.**

| Sub-watershed         | Final classification                  |
|-----------------------|---------------------------------------|
| First catchment       | Restorable non-supporting sub-watershed |
| Second catchment      | Restorable non-supporting sub-watershed |
| Third catchment       | Restorable non-supporting sub-watershed |

The next step analysis is predicting the impervious cover. To conduct an analysis in this step, a future land use map is needed as stipulated in the Depok City Regional Spatial Plan (RTRW) 2012-2032. This map is obtained from the City Public Works Department of Depok. Next, the location of the sub-catchment is overlaid with the RTRW Depok map. Based on the results of re-analysis using GIS, 97.37% impervious cover was obtained or increased by 5.55% from the current condition. Growth in occupation and infrastructure development have increased make the inclination of the percentage of impervious cover according to the land use of RTRW Depok. Total of impervious cover area is 3.7140 km$^2$ or 97.38%. The data is provided in Table 5.

**Table 5. Future land use of Sugutamu area.**

| Land Use                  | Area (km$^2$) |
|---------------------------|---------------|
| Area of trade and service | 0.2927        |
| Low density housing       | 0.0001        |
| Middle density housing    | 3.3514        |
| Industry                  | 0.0699        |
| Green space               | 0.1000        |
| Total                     | 3.8141        |

3.2. Mitigation Method
Rainwater management is needed to reduce the impact of urbanization on the hydrological cycle including increased runoff and decreasing rainfall infiltration. Without proper storm-water management, reducing base flow, decreasing water quality, and increasing flooding and erosion can lead to reduced diversity of aquatic life, fewer opportunities to utilize water resources, and floods that are detrimental to human life [14 – 15]. The LID (Low Impact Development) method is used for low rainfall (rainfall ≤ 50 mm) or with a return period of around 2 - 10 years (probability of 10 - 50%). Based on previous calculations, the types of LID that can be applied further in accordance with the condition and
topography of each catchment areas are infiltration wells, bio-retention, dry well, filter strip, porous pavement, and infiltration trenches.

3.3. Storm water management model

The analysis of storm water will use EPA SWMM 5.1 model. The preliminary user interface will be shown as the following Figure 5.

![Figure 5](image-url)

**Figure 5.** Preliminary analysis of low impact development using EPA SWMM 5.1.

![Figure 6](image-url)

**Figure 6.** LID Control Editor: Rain barrel.

![Figure 7](image-url)

**Figure 7.** LID Control Editor: Permeable pavement.

![Figure 8](image-url)

**Figure 8.** LID Control Editor: Rain garden.
The green infrastructure that would be applied in the sub-catchment are rain barrel, permeable pavement, and rain garden, which are provided in Figure 6, 7, and 8, respectively. According to the simulation result, the existence of the green infrastructure will make the surface runoff decreases approximately 1.07%, flow routing declines 0.05%, and the water quality routing drops 0.09%. The influence of low impact development in the sub-watershed according to the water quality is provided in the following Figure 9 and Figure 10.

![Figure 9. Water quality condition without LID application.](image)

![Figure 10. Water quality condition with LID application.](image)

4. Conclusions
Firstly, Sugutamu sub-watershed is classified into restorable non-supporting sub-watershed. Second, the application of LID and BMP in the study area with EPA Storm-water Calculator and EPA SWMM 5.1 software can reduce runoff and TSS. The storm-water management produces positive impacts for densely populated urban areas to gradually return to its original hydrological function by reducing peak runoff, increasing recharge, and enlarging evaporation. Last, long-term implementation of storm-water management is expected to be a leapfrogging step in the effort to reduce vulnerability from unwanted disasters such as floods and drought. For further research, detailed regional modeling should be conducted to obtain better result. Several green infrastructures need to be tried to get more satisfying result.
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Acknowledgments

The authors wish to thank Civil Engineering Department, Laboratory of Hydraulics and Water Infrastructure, Universitas Gadjah Mada and Civil Engineering Department, Universitas Indonesia. We would like to deliver our big appreciation to Prof. Dr. Ing. Dwita Sutjiningsih from Civil Engineering Department, Faculty of Engineering, Universitas Indonesia, for supervising the authors to study this research.