Effectiveness of stormwater facilities to reduce surface runoff and peak flow at JIExpo Kemayoran using Site Evaluation Tools (SET)

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Abstract. The high rate of urbanization is one of the problems that has occurred in Jakarta as capital of Indonesia. The implication is the change in land use from pervious cover to impervious cover which have an impact on increasing stormwater runoff. Jakarta International Expo (JIExpo) is one of commercial complex in Central Jakarta. The complex covered area around 43.59 hectares and highly impervious (approximately 84 percent). This study simulating two stormwater facilities green roofs and permeable pavements, with total area to be converted approximately 9.21 hectares (21 percent). The modelling run using Site Evaluation Tools (SET) Microsoft Excels spreadsheet to show the both of stormwater facilities effect on the surface runoff and peak flow. The results indicated that the techniques can be used to reduce runoff volume and peak flow. Per unit area, the green roofs better than permeable pavements at reducing the surface runoff evaporation and evapotranspiration. However, permeable pavements were better than green roofs at increasing infiltration. The simulation shows that by the combination of green roofs and porous pavement, the surface runoff can reduced by approximately 57%, the runoff volume can reduced by approximately 1.20% for 2-year daily rainfall, and the peak flow can reduced by approximately 50%. Overall, the SET is easy to use and useful for evaluating the effects of stormwater facilities.

1. Introduction
The high rate of urbanization is one of the problems that has occurred in Jakarta as capital of Indonesia. This causes high space requirements for human activities. BPS DKI Jakarta [1] stated that total population of Jakarta 2017 based on 2010 census data amounting to 10,374,235 people at a rate population growth per year by 0.94 percent with population density of 15,663 per km2. Urbanization decreases infiltration and increases surface runoff, peak flow and the magnitude of flooding [2]. Reduced infiltration may decrease groundwater recharge and stream base flow [3]. The implication is the change in land use from previous cover to impervious cover which has an impact on increasing stormwater runoff. Another problem is the difficulty of building conventional flood control infrastructure due to the high cost of development and the limited and high land prices in urban area such as Jakarta.

Stormwater is the component of runoff that is generated by human activities. Stormwater is created when land development alters the natural water balance. When vegetation and soils are replaced with roads and buildings, less rainfall infiltrates into the ground, less gets taken up by vegetation and more becomes surface runoff [4]. In natural landscapes, such as forests, soil...
Stormwater runoff is generally generated when precipitation from rain and snowmelt events flows over land or impervious surfaces and is unable to percolate into the ground [6]. The increased impervious cover which reduce the amount of infiltration will increase total runoff volumes and peak flow and consequently causing floods in urban area [7].

Stormwater management is the effort to reduce runoff of rainwater or melted snow into streets, lawns and other sites and the improvement of water quality, according to the United States Environmental Protection Agency (EPA) [8]. Stormwater management is as one solution to the problem of surface runoff in urban areas, also known as Low Impact Development (LID) or Best Management Practices (BMP). This system has been widely used in major cities in the world, but unfortunately it is still not a serious concern in cities in developing countries such as Jakarta. This might be due to the existing land use which makes it difficult to build this system. However, of course, it is still desirable to change the paradigm of the particular governance of cities in developing countries.

Recent research has demonstrated the successful use of low impact development (LID) strategies for managing the hydrology in urban areas [9]. The purpose is to reduce inundation due to surface runoff and improve runoff water quality. The approach taken is to implement stormwater management facilities in accordance with the availability of existing land and then integrated with the existing drainage system. There are several types of facilities such as bioretention, dry wells, filter strips, grass swales, infiltration trenches, permeable pavement, rain barrels, soil amendments, tree box filters, vegetated buffers and green roofs [10]. The concept has been implemented in most developed countries and began to be followed by developing countries.

This study was conducted to determine 2 type of stormwater facilities specifically permeable pavements and green roofs and show its effect on the surface runoff. The existing land cover and suitable location of the facilities determined by using google earth satellite imagery as base map. The model is run using site evaluation tools (SET) program which developed by Tetra Tech.

2. Materials and methods

2.1. Study Area and Data

Jakarta International Expo (JIExpo) Kemayoran is one of commercial complex in Central Jakarta, see Figure 1. The complex covered area around 43.59 hectares and highly impervious (approximately 84 percent). Table 1 lists the existing land cover in the study area, obtained from 2019 Google Earth Satellite Imagery data [11]. The hydrologic soil group (HSG) data in the study area classified as group B. The SET using the soil conservation service - curve number (SCS-CN) method to simulated the runoff volume and peak flow. Table 2 shows the curve number (CN) values used in SET.

The SCS-CN is a very popular method used in runoff calculations. The method is an efficient and widely used method for determining the direct runoff (effective rainfall) from a storm event for flood disaster assessment (rainfall-runoff modelling). The CN can be estimated based on the area’s hydrologic soil group (HSG), land use/ cover, and hydrologic condition. The two former factors are of greater importance in determining the CN value [12]. Soil scientists rely on their interpretation of the published criteria to place soils into the appropriate hydrologic groups. The soil scientist’s interpretation of the published criteria has varied through time and across states and regions [13].

United States Department of Agriculture [14] generally divided soils to 4 HSG namely group A, B, C and D where each class is determined based on soil content, ability to drain runoff and infiltration. Generally group A has low runoff potential and high infiltration rates, group B has moderate infiltration rate, group C has low infiltration rates while group D has highest runoff potential and very low infiltration rates.
The CN has a range from 30 to 100; lower numbers indicate low runoff potential and the more permeable the soil is while larger numbers are for increasing runoff potential. As can be seen in the curve number equation, see Eq. (1), runoff cannot begin until the initial abstraction has been met. It is important to note that the curve number methodology is an event-based calculation, and should not be used for a single annual rainfall value, as this will incorrectly miss the effects of antecedent moisture and the necessity of an initial abstraction threshold.

\[
S = \frac{1000}{CN} - 10
\]  
\[S\] is the potential maximum soil moisture retention after runoff begins and \(CN\) is curve number.

2.2. Site Evaluation Tools

The SET is a Microsoft Excel spreadsheet-based tool designed to aid in the assessment of LID methods and available integrated management practices (IMPs) [15]. The program was developed by Upper Neuse River Basin Association and Tetra Tech, with funding from the NC Division of Water Quality, USA, and is obtainable on the SET website of UNRBA [16]. The SET can be used as a screening tool to evaluate various site designs to help achieve the water quality goal of a site in a cost-effective manner [15].

The hydrology/pollutant component and the cost component are two main component on SET. The hydrologic balance is given in the SET, see Eq. (2):

\[
P = R + E + I_{SW} + I_{BMP}
\]  

![Figure 1: Study area : (a) Complex boundary, (b) Existing land cover](image)
where $P$ is the annual precipitation, $R$ is the runoff, $E$ is the annual evaporation and transpiration, $I_{SW}$ is the annual groundwater recharge of stormwater and $I_{BMP}$ is the groundwater recharge via BMPs. The runoff is calculated using the “simple method” based on the fraction of the impervious to the total area, see Eq. (3).

$$R = 0.9 \times P \times \left( 0.05 + 0.9 \frac{A_{imp}}{A_{tot}} \right)$$

(3)

where $A_{imp}$ is the area of impervious cover and $A_{tot}$ is the total area. The SET estimate runoff using the soil conservation service curve number (SCS-CN) method, based on the average antecedent moisture condition (AMC II), see Eq. (4) and (5).

$$Q = \left( \frac{P - 0.2S}{P + 0.8S} \right)^2 \quad \text{for } P > 0.2S$$

(4)

$$Q = 0 \quad \text{for } P \geq 0.2S$$

(5)

where $Q$ is the runoff, $P$ is storm event precipitation and $S$ is the storage. The peak flow is calculated using the “rational method” and SCS-CN method, with pre and post development hydrographs estimated using the SCS-CN method.

Generally there are six sheets in the SET on Hydrology and Pollutant Components, see Figure 2. Almost all sheets are for inputting data, except for the last sheet that shows the results of the analysis.

The Storage-Release Model show the process how the runoff is passes through the BMP groups or the storm water facilities, see Figure 3. In this study the authors limit only conducting hydrological analysis on the SET, and not analyzing pollutants and costs components. There are several stages in operating the SET to show the results of the hydrological analysis. The first step is to fill in the “site data” sheet in the
Figure 3: The order of Storage-Release Model

form of general information consisting of two main parts namely "general site information" and "design storm selection". General site information includes project information, site information (area and slope) and percentage of the soil hydrologic group on the study area, while the design information includes the choice of peak flow, runoff volume (storm events and uniform depth).

Furthermore, in the second stage of the sheet "land use" data is inputted with the area of each existing and proposed land cover, where the total area of both land cover must be the same value in order to proceed to the next stage.

In the third stage, the sheet "drainage areas (DAs)" is carried out to fill the area of each land use. The maximum drainage area can be divided into ten areas, but in this study the area is only divided into one drainage area only. The total area of drainage area that is filled must be the same as the area of study area. Then in the fourth step, the sheet "BMPs" were filled in for the type of stormwater facilities to be used. There are fifteen type of stormwater facilities to selected and one additional facility which is custom, but specifically in this study only two types of stormwater facilities are selected, green roof and permeable pavement. On this sheet we can also input the peak flow and time of concentration on the site (if known). The additional facility can be filled in the next sheet, "user BMPs" sheet.

After all data has been filled in correctly, it can proceed to the next fifth or final step, the process to the output model. The "output model sheet" provides an overview of the results of the analysis carried out. There are five summaries produced in this sheet including land use summary, annual hydrology summary, annual pollutant load and target summary, storm event runoff volume and target summary, and peak flow and hydrograph summary.

The limited of return periods of rainfall is a weakness of this program. This program can only perform calculations for 1, 2 and 10 year daily rainfall. This might be because stormwater management is only focused on light and moderate rainfall, therefore this program cannot be used to calculate extreme rainfall. But in general this program is very easy to use and can help to analyze the effectiveness of stormwater facilities.

3. Modelling

3.1. Design rainfall

Daily precipitation data obtained from Meteorology Climatology and Geophysics Council at Kemayoran climatology station during 1998 – 2017 with the annual average precipitation approximately 1,951.68 mm [17]. The data with that period used to estimate design rainfall. The distribution of maximum daily rainfall follows distribution of Log Normal with the calculated coefficient of variety is equal to 0.357. The consistency test is done using Chi-Squared and Smirnov Kolmogorov. The calculated X2 (1.0) is less than critical Chi-Squared X2Cr (5.99), and the calculated Do (0.064) is less than critical D (0.29) for Smirnov Kolmogorov [18], mean that distribution of Log Normal can be accepted. Therefore, then the design rainfall is computed using Log Normal distribution. Design rainfall is calculated of 2-, 5-, 10-, 25-, 50, and 100-year return period. The design rainfall is multiplied by the area reduction factor (ARF) of
0.994 [19]. Priambodo [20] investigated that rainfall distribution using percentage of heavy rainfall distribution duration is 4 hours in Kemayoran station. The complete hydrology results are tabulated in Table 3.

### 3.2. Design simulation

Two stormwater facilities, green roofs and permeable pavement were simulating in this study, see Figure 4. Green roofs are an innovative solution that can simultaneously improve the energy performance of buildings, air quality and the urban ecology – all without taking up additional land [21]. Typically, a green roof consists of three layers: vegetation, substrate and drainage. The green roof can be classified depending on the depth of the substrate layer and can be named as extensive roofs and intensive [22]. Permeable pavements may reduce the peak flow and runoff volume by enhancing water storage and infiltration into the soil; this system is best applied to areas where vehicular traffic is minimal, such as parking lots and sidewalks [23].

Permeable pavements can provide some capture volume depending on its design, for instance, an inch or two of gravel can be placed below the underdrain, allowing a space for water to pond and infiltrate between storm events. Permeable pavements placed on the parking area with the assumption that this parking area can still be reconstructed and converted into a permeable pavements. The condition of the building roof is the main requirement in the placement of green roof. The curved or sloping roof of the building is not suitable as a base for placement of this facility. Therefore green roofs should be placed on a flat roof and can be reached for easy installation and for maintenance. Table 4 list the existing land cover compared with proposed land cover with two of stormwater facilities. There are 9.21 hectares (21% of total area) to be converted into both of the proposed stormwater facilities.

| Return Period (year) | Design Rainfall (mm) |
|----------------------|----------------------|
| 2                    | 139.94               |
| 5                    | 188.70               |
| 10                   | 220.61               |
| 25                   | 260.60               |
| 50                   | 290.22               |
| 100                  | 319.72               |

Table 3: Design rainfall

| Land cover | Existing | Proposed |
|------------|----------|----------|
| Pervious area | Row crop | 5.42 | 5.42 |
|             | Lawn | 1.18 | 1.18 |
| Impervious area* | Roof tops | 12.32 | 11.30 |
|             | Parking lots | 8.18 | 0 |
|             | Other impervious | 12.54 | 12.54 |
|             | Road | 3.61 | 3.61 |
| Pond | 0.35 | 0.35 |
| Stormwater facilities | Permeable pavement | 0 | 8.18 |
|             | Green roofs | 0 | 1.03 |
| Total | 43.59 | 43.59 |

*Total proposed impervious area = 27.74 hectares (62.95%)

Table 4: Comparison between existing and proposed land cover (hectares)
4. Result and discussion

In terms of the annual hydrology component, see Table 5, the result shows that green roofs can reduce surface runoff by approximately 49%, increase evaporation and evapotranspiration by approximately 149% but do not contribute to infiltration. Permeable pavements alone contributed to a decrease in surface runoff by only 15%, increased infiltration by approximately 161% and increased evaporation and evapotranspiration by approximately 30%. Using the combination of the two stormwater facilities, the current surface runoff could be reduced by approximately 57%, the current infiltration increased by about 161%, while evaporation and evapotranspiration increased by approximately 156%.

It can be concluded that both of stormwater facilities are very effective at reducing surface runoff and increasing evaporation, evapotranspiration and infiltration. Whereas green roofs are more effective against decreasing surface runoff and increasing evaporation and evapotranspiration, while the permeable pavements are more effective than green roofs at increasing infiltration into the soil. The effectiveness of both stormwater facilities per unit area summarized in Table 6.

Table 7 summarize the simulated runoff and storage volumes for 2-year daily rainfall under the stormwater facilities. The simulated storage volumes for green roofs, permeable pavements and the combination of both facilities were 130, 519 and 519 m3, respectively. Table 8 shows the peak flows under the both of stormwater facilities. The peak flows for the existing land cover for 2-year and 10-year daily rainfall were estimated to be 21.50 and 33.48 m3/s, respectively. By the combination of green roofs and porous pavements in the SET simulation, the peak flow...
Table 6: Reduction or increase of the hydrologic components (mm/yr/m²)

| Proposed facilities | Green roofs | Permeable pavement | Both |
|---------------------|-------------|--------------------|------|
| Surface runoff      | -6.9        | -2.1               | -7.9 |
| Infiltration        | 0.0         | 0.7                | 0.7  |
| Evaporation and evapotranspiration | 6.9 | 1.4 | 7.2 |

Negative symbol indicate a reduction and and positive symbol indicate an increase, respectively.

Table 7: Summary of the runoff volumes for 2-year daily rainfall (m³)

|                   | Existing land cover | Proposed facilities | Both |
|-------------------|---------------------|---------------------|------|
| Runoff volume     | 54,381              | 54,251              | 53,682| 53,731| |
| Storage volume    | 0                   | 130                 | 519  | 650  | |

Table 8: Peak flow during simulated storm events (m³/s)

|                   | Existing land cover | Both of proposed facilities |
|-------------------|---------------------|-----------------------------|
| 2-yr daily rainfall| 21.50               | 10.75                       |
| 10-yr daily rainfall| 33.48               | 16.74                       |

Figure 5: Hydrographs for 2-year and 10-year daily rainfall for the existing and with both of stormwater facilities.

was reduced by approximately 50%. Figure 5 presents hydrographs for the existing land cover and with both of stormwater facilities.

5. Conclusion

SET is one of the tools to evaluate stormwater facilities. This tool is based on Microsoft Excel spreadsheets. This study aims to evaluate the effectiveness of green roof and permeable pavements on surface runoff and peak flow at JIExpo Kemayoran, Central Jakarta. The results of the analysis shows that the two stormwater facilities have a fairly good effect on decreasing
runoff and peak flow, while also increasing infiltration, evaporation and evapotranspiration. In particular the green roof is very good in terms of increasing evaporation and evapotranspiration while permeable pavements are more effective on increasing infiltration into the soil. The weakness of SET is that it is only designed to calculate daily rainfall for 1, 2 and 10 year return periods, but overall the SET is easy to use and useful for evaluating the effects of stormwater facilities.

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