Effectivity analysis of the application of TIA (total impervious area) and EIA (effective impervious area) in a micro scale watershed (case study on Sugutamu sub-watershed)

Nisrina Hanan¹, a, Dwita Sutjiningsih¹, b, and Evi Anggraheni¹, c
¹Civil Engineering Department, Faculty of Engineering, Universitas Indonesia, Depok 16424, Indonesia
²hananisrina97@gmail.com, b, dwita@eng.ui.ac.id, cevi.anggraheni@yahoo.com

Abstract. There are two methods that can be used to calculate the area of impervious cover on a watershed, Total Impervious Area (TIA) and Effective Impervious Area (EIA). Calculation of impervious cover generally uses the TIA method. Recently, based on several researches, EIA is the better indicator for identifying surface runoff discharge. This study aims to analyze the difference of surface runoff discharge using both TIA and EIA methods in different scales of an urban watershed area, specifically the Sugutamu sub-watershed and Sugutamu catchment area. Land cover identification with the TIA method uses the Rupa Bumi Indonesia map of 2017. While for the EIA method, the land cover identification uses the 2017 visual interpretation of high-resolution satellite imagery from the software GIS. FTUI and Cibinong stations have been selected as the daily rainfall data for the surface runoff simulation of the watershed and the catchment area using the software HEC-HMS. The result of the simulation shows that the EIA method in the urban catchment area has a more significant impact. In conclusion, the use of EIA should be considered more in micro-scaled modelling of an urban watershed’s surface runoff.

Keywords: Sugutamu sub-watershed; Catchment area 2; Effective Impervious Area; Total Impervious Area; Design flood hydrograph.

1. Introduction
The region of Jabodetabek is the largest megacity region in Indonesia which has a tremendous rate of urbanization. The current population of the region exceeds 30 million lives with a density of 4500 people per km² [1]. Urbanization that continues to increase will result in many changes in natural conditions, one of which is the hydrological system. The increasing rate of urbanization has led to an increase of population, and thus diverting the landscape of the region from a natural one into built environments.

In general, there are two types of land cover identified in a watershed, impervious cover and pervious cover. Impervious cover is defined as a surface that inhibits the rate of infiltration of water from the surface into the soil layer and increases surface runoff [2].

Impervious covers are used as an indicator of the impact of urbanization on a watershed’s hydrological cycle. Therefore, a substantial amount of research has been conducted to analyze the impact of urbanization on affected watersheds. So far, the calculation of impervious cover with Total Impervious Area (TIA) is the indicator most often used by researchers because it is considered simpler to use. However, recent research shows that a better indicator of predicting surface runoff is the
Effective Impervious Area (EIA), or part of Total Impervious Area (TIA) that is hydraulically connected to the drainage system [3]. While reference [4] shows no significant impact when either using the EIA nor the TIA method on a macro-scale watershed, this research aims to find the difference in effectiveness when applying the EIA and TIA method in a micro-scale urban watershed, specifically the Sugutamu sub-watershed and catchment area.

2. Material and Method

2.1. Study Area
The Sugutamu sub-watershed is located in Jabodetabek area, so it is categorized as an urban watershed. The Sugutamu Sub-watershed is part of the Central Ciliwung watershed where 60% of the area is in the administrative area of Depok City, and the remaining 40% is in the administrative area of Bogor Regency.

This research is conducted by performing an analysis on 2 different area scales namely the Sugutamu Sub-watershed scale and Sugutamu catchment area scale (Catchment area 2 is used as the study area). To facilitate design calculations, the Sugutamu Sub-watershed will be divided into 6 catchment areas and DTA 2 is divided into 4 Sub-catchment areas, which are presented in Figure 1 and Figure 2.

![Figure 1. Catchment area of Sugutamu sub-watershed.](image1)

![Figure 2. Sub-catchment area of cathcment area 2.](image2)

Hydrological parameters of the study area such as the watershed, longest flow path, dan slope area identified using the software from ESRI namely ArcGIS 10.1. Time of concentration parameter is calculated using the Kirpich (1940) formula [5] as in (1).

\[
T_c = 0.0195 L^{0.77} S^{-0.385}
\]

where:
\[ L = \text{length of channel/ditch from headwater to outlet, meter} \]
\[ S = \text{average watershed slope, meter/meter} \]

Then the time lag parameter \( t_L \) is calculated using the formula (2) based on reference [5].

\[ t_L = 0.6 T_C \]  

(2)

Hydrological parameters of the Sugutamu sub-watershed and catchment area 2 are tabulated in Table 1.

| Study Area         | Area (km²) | Longest Flow Path (m) | Slope | Tc (min) | tl (min) |
|--------------------|------------|-----------------------|-------|----------|----------|
| Sugutamu Sub-Watershed |           |                       |       |          |          |
| C 1                | 3.04       | 5620.78               | 0.006 | 110.04   | 66.03    |
| C 2                | 2.42       | 5003.65               | 0.006 | 97.4     | 58.44    |
| C 3                | 3.25       | 3832.68               | 0.003 | 106.67   | 64       |
| C 4                | 2.39       | 4232.85               | 0.004 | 106.17   | 63.7     |
| C 5                | 1.91       | 4122.48               | 0.006 | 84.59    | 50.76    |
| C 6                | 1.72       | 3175.15               | 0.006 | 68.18    | 40.91    |
| Catchment Area 2   |            |                       |       |          |          |
| SC A               | 0.42       | 1281.67               | 0.011 | 27.43    | 16.46    |
| SC B               | 0.44       | 962.36                | 0.004 | 31.92    | 19.15    |
| SC C               | 0.72       | 959.9                 | 0.005 | 29.2     | 17.52    |
| SC D               | 0.84       | 1799.77               | 0.004 | 50.36    | 30.22    |

2.2. Impervious Cover Identification

The calculation of the area of impervious cover in this study is debated over two methods, the Total Impervious Area (TIA) and Effective Impervious Area (EIA). The calculation of the area of impervious cover using the Total Impervious Area (TIA) method in this study is based on the 2017 Ciliwung watershed land cover map issued by Badan Informasi Geospasial (BIG) Indonesia. Where the map of land cover with vector data format (.shp) is inputted into ArcGIS 10.1, then an impervious cover calculation is performed. Impervious cover on TIA is divided into residential areas and building areas.

Meanwhile for the EIA method, land cover identification uses the 2017 visual interpretation of high-resolution satellite imagery using ArcGis 10.1. Determination of the area of EIA is done by manually digitizing the impervious cover using basemap imagery in ArcGIS 10.1. In the EIA method, impervious cover is identified in more detail into several land cover classes, namely roofs, parking lots, and roads. Roads in the EIA method is divided into several classes based on their width, namely local roads, collector roads and arterial roads [6]. The roofs, parking lots and roads are manually digitized one by one to form a land cover map. Maps of land cover using the TIA method and the EIA method are presented in Figure 3 and Figure 4.
After an impervious cover analysis using the TIA and EIA methods in the Sugutamu Sub-watershed and catchment area 2, a significant difference in the value of the impervious cover was obtained. Where, the total area of impervious cover becomes smaller when identified using the TIA method. In Sugutamu Sub-watershed the percentage of impervious cover changed from 92% (using the TIA method) to 56% (with the EIA method). While in catchment area 2 the percentage of impervious cover changed from 98% (with the TIA method) to 48% (with the EIA method). Decreasing the percentage of impervious cover with the EIA method shows that there are still many pervious covers around settlements that are not identified by the TIA method. Percentage of impervious cover for each catchment area and sub-catchment area are tabulated together with the weighted CN and initial abstraction in Table 2.

2.3. Curve Number (CN) Identification

The catchment area with a very dense settlement where there is no open land around it has a percentage of impervious area differences that are not too significant. Because the area of TIA which is stated as a settlement will be identified as the area of the roof of houses and roads by the EIA method. Meanwhile, catchment areas with sparse settlements will give a very significant difference in the percentage of impervious cover. This is because the entire catchment area is declared as a settlement by the TIA method, while manually digitized results using the EIA method shows that in the sparsely residential area there are not only roofs and roads but there are still many pervious covers around it. The difference in the identification of the TIA method and the EIA method in both cases will have an impact on determining the value of the Curve Number (CN) used. Visualization of differences in the identification of the EIA method against TIA are presented in Figure 5 and Figure 6.
Determination of the curve number (CN) value for Sugutamu sub-watershed and catchment area 2 refers to the CN value by the USDA, 1986 [5]. Because no amount of rain data was obtained during the previous 5 days before the simulation was carried out, the condition of antecedent moisture content (AMC) in the study area was assumed to be in the average condition, AMC II. The initial abstraction parameter in the study area is calculated based on the weighted CN value for each catchment area [5]. Weighted CN, percentage of impervious cover, and initial abstraction for the sub-watershed and catchment area 2 are tabulated in Table 2.

**Table 2.** Weighted CN, percentage of impervious cover, and initial abstraction of the study area.

| Study Area                  | TIA Method | EIA Method |
|-----------------------------|------------|------------|
|                             | Impervious Cover (%) | Weighted CN | Ia (mm) | Impervious Cover (%) | Weighted CN | Ia (mm) |
| **Sugutamu Sub-Watershed**  |            |            |         |            |            |         |
| C 1                         | 92         | 85,62      | 8,53    | 56         | 85,94      | 8,31    |
| C 2                         | 97         | 85,34      | 8,73    | 55         | 83,19      | 10,26   |
| C 3                         | 98         | 84,41      | 9,39    | 48         | 82,56      | 10,73   |
| C 4                         | 78         | 84,79      | 9,11    | 38         | 89,51      | 5,96    |
| C 5                         | 99         | 84,81      | 9,1     | 71         | 90,45      | 5,36    |
| C 6                         | 98         | 82,92      | 10,46   | 74         | 88,35      | 6,7     |
| **Catchment Area 2**        |            |            |         |            |            |         |
| SC A                        | 98         | 85,18      | 8,84    | 48         | 86,4       | 7,99    |
| SC B                        | 100        | 86,61      | 7,85    | 61         | 82,88      | 10,49   |
| SC C                        | 88         | 85         | 8,96    | 38         | 82,98      | 10,42   |
| SC D                        | 100        | 85,03      | 8,94    | 49         | 81,94      | 11,19   |
2.4. Design Rainfall

There are 3 nearby rain gages that contributes to the Sugutamu Sub-watershed, namely FTUI station, Cibinong station, and Klimatologi Bogor station. The size of the regional distribution in Sugutamu Sub-watershed and catchment area 2 was calculated using the Thiessen Polygon method [7]. The result of the Thiessen Polygon method is that the regional rainfall distribution in the Sugutamu watershed are influenced by two rain gages, the FTUI station and the Cibinong station. FTUI Station gives an influence about 60% and Cibinong Station about 40%. Then the percentage of influence from each station is multiplied by the maximum daily rainfall data during 2003-2017 to get the amount of regional rainfall in the Sugutamu watershed. As for catchment area 2, it is only affected by the Cibinong station. Therefore, the amount of rain at the Cibinong station needs to be multiplied by a reduction factor ($\beta$) of 0.975 [8].

Furthermore, the calculation of design rainfall is done for a return period of 2, 5, 10, and 25 years. To obtain the design rainfall, it is necessary to analyze the frequency of rainfall, then to analyze the rainfall distribution plan using several methods, namely Normal distribution, Log Normal distribution, Gumbel Type I distribution, and Log Pearson Type III distribution [9]. Based on the calculation results, a fitness test of the distribution with the Chi-Square method and the Smirnov Kolmogorov method which refers to reference [10], it can then be concluded that the results of the Log Pearson Type III distribution method results are the results that closely resemble the true value of each return periods. The complete results are tabulated in Table 3.

### Table 3. Design rainfall for several number of return period in the study area.

| Return Period (year) | Design Rainfall (mm/day) |
|----------------------|---------------------------|
|                      | Sugutamu sub-watershed    | Catchment area 2 |
| 2                    | 112                       | 98              |
| 5                    | 130                       | 126             |
| 10                   | 142                       | 145             |
| 25                   | 158                       | 171             |

2.5. Design Flood

Estimation of the design flood hydrograph is then simulated using a HEC-HMS 4.0 model. Simulations will be conducted for the TIA method and the EIA method in the Sugutamu Sub-watershed and catchment area 2. After the schematic simulation model is made the parameters for each sub-basin component and reach component are then filled. The input data as parameters of each sub-basin components are sub-basin areas, weighted CN, initial abstraction, impervious cover percentage, and time lag [11]. The input data as parameters of the reach component are the longest flow path, slope, and channel properties [11]. The channel properties used in the simulation are based on survey data from several generalized locations for all reach in the Sugutamu Sub-watershed. The channel properties consist of trapezoidal shape with a bottom width of 0.65 meter, slide slope of 0.8, and manning coefficient of 0.02 [5].

After all data parameters for each component of the sub-basin and reach are filled, a meteorological model is identified using the frequency storm method for return periods of 2, 5, 10, and 25 years. the simulation model for the Total Impervious Area method and the Effective Impervious Area method is then ran. Simulation schematics for the Sugutamu Sub-watershed and catchment area 2 are shown in Figure 7 and Figure 8.
3. Result and Discussion

Flood design hydrograph simulation results of the HEC-HMS 4.0 model for the TIA method and the EIA method in the Sugutamu Sub-watershed and DTA 2 are shown in Figure 9 and Figure 10.

**Figure 7.** Schematic of Sugutamu sub-watershed.

**Figure 8.** Schematic of catchment area 2.

**Figure 9.** Design flood hydrograph of Sugutamu sub-watershed for (a) 2 years; (b) 5 years; (c) 10 years; (d) 25 years return period.
Figure 10. Design flood hydrograph of catchment 2 for (a) 2 years; (b) 5 years; (c) 10 years; (d) 25 years return period.

Based on the peak of the hydrograph generated for each flood plan made on the Sugutamu Sub-watershed and catchment area 2, the magnitude of the effectiveness of the EIA method for the TIA method can be calculated. Recapitulation of the results of the reading of the planned flood hydrograph in the Sugutamu sub-watershed and catchment area 2 are tabulated in table 4 and table 5.

| Table 4. Recapitulation of simulation result at Sugutamu sub-watershed. |
|-----------------------------|-----------------|----------------|-----------------|------------------|
| Information                | Peak Discharge Qp (m³/s) | Q2     | Q5     | Q10    | Q25    |
| EIA method                 | 85.6             | 112.5  | 128.8  | 146.9  |
| TIA method                 | 97               | 123.9  | 140.1  | 158    |
| ∆Q                         | 11.4             | 11.4   | 11.3   | 11.1   |
| Effectiveness (%)          | 11.75            | 9.20   | 8.07   | 7.03   |

| Table 5. Recapitulation of simulation result at catchment area 2. |
|-----------------------------|-----------------|----------------|----------------|------------------|
| Information                | Peak Discharge Qp (m³/s) | Q2     | Q5     | Q10    | Q25    |
| EIA method                 | 17.2             | 26.2   | 32.1   | 39.4   |
| TIA method                 | 21.7             | 30.6   | 36.5   | 43.7   |
| ∆Q                         | 4.5              | 4.4    | 4.4    | 4.3    |
| Effectiveness (%)          | 20.74            | 14.38  | 12.05  | 9.84   |

Based on the results of the peak hydrograph in the Sugutamu sub-watershed as shown in table 4, the EIA effectiveness value of the highest TIA is 11.75%. While in table 5, it can be seen that the effective percentage of EIA against TIA in catchment area 2 is greater at 20.74%. Both results of the largest percentage of effectiveness occurred in the analysis with a 2-year return period. Based on table 4 and table 5, findings shows that the greater the return period used in the design, the percentage of effectiveness of the application of the EIA method to the TIA method increases.
4. Conclusions

HEC-HMS 4.0 simulation results show that the effectiveness of the EIA method on the TIA method in catchment area 2 is greater than in the Sugutamu sub-watershed. These results indicate that the application of the Effective Impervious Area method for flood discharge analysis in the urban catchment area has a more significant impact. So, the use of the Effective Impervious Area method as identification of land cover for flood design on micro-scale urban watershed needs to be considered. Conversely, the application of the Effective Impervious Area (EIA) method does not need to be done for macro-scale watershed analysis because it takes a lot of time and money to do the analysis of the EIA method.

Based on the visualization results of the application of the EIA method in Figure 5 shows that the use of the Effective Impervious Area method will not be effective in very dense residential areas. Because land cover is dominated by the roof, parking area, and pavement area where there is no pervious cover left around. So that the analysis by the EIA method and the TIA method did not provide a significant difference. Conversely, if the characteristics of land cover in urban watershed look like Figure 4, then the EIA method needs to be used to calculate the area of the impervious cover. Because there are still many pervious covers that are not identified if using the TIA method.

Simulation model of the analysis of the application of the EIA method and the TIA method was also carried out in several return periods, namely 2.5, 10, and 25 years. From the simulation results on Sugutamu Sub-watershed and DTA 2, it can be seen that the greater return period that used in the analysis, the effectiveness of the EIA method instead of TIA experiences no substantial change. So, the application of the EIA method is not too significant to be used in the analysis of extreme debits and long return periods.

Acknowledgement

The authors would like to thank Universitas Indonesia for the financial support through the research funding scheme “Hibah Penugasan Publikasi Internasional Terindeks 9 (PIT 9)” fiscal year 2019 number NKB-0053/UN2.R3.1/HKP.05.00/2019.

References

[1] Pravitasari, A. E. (2018, Januari). Dampak Urbanisasi dan Perkembangan Perkotaan di Jabodetabek dan Sekitarnya serta Pengaruhnya pada Peningkatan Degradasi Lingkungan. Bogor, Jawa Barat, Indonesia.
[2] Chithra S.V., D. H. (2015). Impacts of Impervious Surfaces on the Environment. *International Journal of Engineering Science Invention*, 27-31.
[3] Ebrahimian, A., Gulliver, J. S., & Wilson, B. N. (2015). *Determination of Effective Impervious Area in Urban Watersheds*. St. Paul: Local Road Research Board.
[4] Farika, N. (2017). Pengaruh Penerapan Metode Penentuan Tingkat Kekedapan Tutupan Lahan Terhadap Prediksi Debit Banjir untuk DAS Skala Makro . Depok : Universitas Indonesia.
[5] Chow, V. T., Maidment, D. R., & Mays, L. W. (1988). *Applied Hydrology*. Mc Graw Hill: New York.
[6] SNI. (2003). SNI 03-6967-2003 : Persyaratan umum sistem jaringan dan geometrik jalan perumahan. Jakarta: Badan Standarisasi Nasional.
[7] Sosrodarsono, I. S. (2003). *Hidrologi untuk Pengairan*. Jakarta: PT Prandnya Paramita.
[8] Maidment, R. (1989). *Handbook of Hydrology*. New York: McGraw-Hill.
[9] Soemarto, I. C. (1986). *Hidrologi Teknik*. Jakarta: Usaha Nasional.
[10] Soewarno. (1995). Hidrologi Aplikasi Metode Statistik untuk Analisis Data Jilid 1. Bandung: Nova.
[11] Scharffenberg, W. A. (2013). Hydrologic Modeling System HEC-HMS User's Manual Version 4.0. Washington, DC: USACE-HEC.