The peak runoff model based on Existing Land Use and Masterplan in Sentul City area, Bogor

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Abstract. This research aimed to create a peak runoff mode based on existing land use (LU) and masterplan in Sentul City area. To determine the peak runoff by rational method, the study uses the formulation as follows: \( Q = 0.2778 \cdot C \cdot I \cdot A \), in which \( Q \) is the peak runoff, \( C \) is the runoff coefficient of area, \( I \) is the average rain rate intensity, and \( A \) is the area of study. For recognizing the existing LU, the researcher used image analysis SPOT-6 (2017) by supervised classification. It estimated the gamma distribution parameter through the maximum likelihood method by using software QGIS 2.8, SAGA GIS, dan Arc-GIS 10.4.1. According to the analysis, the study result showed the existing LU peak runoff coefficient value and masterplan are 0.40 and 0.61, respectively, in which the difference is 0.21. The peak runoff increase is 25.32 m³/sec or 6,622,560 m³/year as the impact of land-use change.

Keywords: peak runoff, land use, masterplan

1. Introduction
Water supply potential in Sentul City (SC) area depends on biophysical conditions including land use (LU) or land cover (LC), topography, hydrology, climatology, living things, soil sorts, vegetation, animals, etc. The SC, an independent city in Bogor Regency, is developed by PT Sentul City Tbk. By applying the green development principle, SC is expanded through city parameter respond. The concept of ecocity is applied to both landscapes and establishments. This area is established as a housing area, trade area, official area, industrial area, tourism area, and specific facility (commercials). Since the geohydrology condition of SC, it becomes a water-lackness area. It is impossible to maintain water as the impact of loamy soil characteristics which dominates. As stated in the masterplan, the development concept of the SC area divides the SC area into two areas, including establishment area and coverage, and conservation area. The conservation area is arranged as a park forest, playground [1]. The SC commits to maintaining the balance of the

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built-up area and open area. According to the masterplan and existing LU, this research aimed to create a peak runoff model in the SC area.

2. Material and method

2.1. Study sites
Geographically SC is between latitudes 06°33’55” S, 06°37’45” S and longitudes 106°50’20” E, 106°57’10” E. SC which area is 2,465 ha is located on the border area at value 3,001.4 ha [1]. But, in this study, the researcher conducted a spatial analysis at area 2,905.33 ha which was appropriate with area borderline in vector form given by the planner side. As governmental administration, SC is located on 8 Villages and 2 Sub-districts, including Cipambuan Village, Babakan Madang Village, Citaringgul Village, Bojong Koneng Village, Sumur Batu Village, Cijayanti Village, Kadumanggu Village, and Cadas Ngampar Village. The subdistricts are Babakan Madang Subdistrict and Sukaraja Subdistrict, Bogor Regency. Settlement area SC has the nearest direct access, including Bogor outer ring road and Jagorawi road (Jakarta-Bogor). Other access toward the area is through Bogor Baru housing toward Cimahpar Village, then to Cijayanti Village by paved road.

2.2. Determine the sort of LU
For determining the sort of existing LU or LC in the area of study, the researcher conducted two steps. In the first step, the geo-reference process was applied to image SPOT-6 to reach the exact geographical position. The research used the coordinate reference system, which mentioned as Universal Transverse Mercator (UTM). Based on the UTM zone division, the SC area was located on UTM Zone 48S. Therefore, the map was projected to WGS84/UTM Zone 48S/EPSG:32748. In the second step, the supervised classification was conducted to image map by maximum likelihood classification method to make a land closure map of the study area. Then, the ground check was conducted to recognize directly the closure land of the urban area of SC. The accurate of the land closure analysis result was evaluated by overall accuracy and kappa accuracy.

2.3. Determine the runoff coefficient
For determining the runoff coefficient (C), the calculation used the equation as follows [2]:

\[ C = \frac{d_i \times 86,400 \times Q}{P \times A} \]  

(1)

where:

- \( C \) = The running water (mm)/Rain intensity (mm)
- \( d_i \) = The number of the day in the month of -i
- \( Q \) = The average monthly debit (m³/sec) and 86,400 = the number of sec in 24 hours (60 minutes, 60 secs, 24 hours).
- \( P \) = The average yearly rain intensity (mm/year)
- \( A \) = The area of Watershed (km²)

According to the LU map year 2017, the runoff coefficient value of SC (\( C_{SC} \)) was calculated by the equation as follows:

\[ C_{SC} = \frac{\sum\limits_{i=1}^{n} C_i A_i}{\sum\limits_{i=1}^{n} A_i} \]  

(2)

where:

- \( C_{SC} \) = the runoff coefficient of the study area
- \( A_i \) = the area with soil coverage to-i (ha)
- \( C_i \) = the runoff coefficient with soil coverage sort -i
- \( n \) = the number of soil coverage sort
2.4. Rational Method
To determine the peak runoff in the SC area ($Q_{p\_SC}$), this research used a rational method, which formulation was presented as followed [3] and [4]:

$$Q_{p\_SC} = 0.278 \times C_{SC} \times I \times A$$

where:
- $Q_{p\_SC}$ = The peak runoff of SC area (m$^3$/sec)
- $C_{SC}$ = The runoff coefficient for various LUs in the SC area
- $I$ = The rain intensity (mm/hour)
- $A$ = The area of study (km$^2$)

The rational method is generally used for the area of study with a small scope. Meanwhile, for large scope, it needs to use a rational modification method [5].

3. Result and discussion
3.1. Existing LU
According to LC classification in the image SPOT 2017 by LU map year 2015, the study results from LU in SC as presented in table 1.

| Land-use type      | Area (ha) | Percentage (%) | $C$ value | $C_{pl}$ value |
|--------------------|-----------|----------------|-----------|----------------|
| Shrubs             | 49.02     | 1.69           | 0.25      | 12.26          |
| Forest             | 101.69    | 3.50           | 0.05      | 5.08           |
| Industry           | 78.83     | 2.71           | 0.90      | 70.95          |
| Mix garden         | 297.16    | 10.23          | 0.25      | 74.29          |
| Open space         | 9.56      | 0.33           | 0.20      | 1.91           |
| Lake               | 6.36      | 0.22           | 0.03      | 0.19           |
| Plantation         | 42.68     | 1.47           | 0.25      | 10.67          |
| Rural              | 225.07    | 7.75           | 0.50      | 112.54         |
| Urban              | 705.47    | 24.28          | 0.75      | 529.10         |
| Rainfed            | 146.12    | 5.03           | 0.20      | 29.22          |
| River              | 29.85     | 1.03           | 0.05      | 1.49           |
| Dryland            | 1,213.52  | 41.77          | 0.25      | 303.38         |
| Sum                | 2,905.33  | 100.00         | -         | 1,151.08       |
| Runoff coefficient | -         | -              | -         | 0.40           |

*Source: Data analysis result, 2019*

Based on the runoff coefficient values given in table 2 and the area of LU can be found in the region runoff coefficient values as in table 1. Runoff coefficient ($C$) is a fixed value which is the ratio between effective rain and falling rain. The $C$ value is usually taken for saturated soil at the beginning of the rain with values ranging from 0-1 [6].

| Description of land and surface character | Coefficient $c$ |
|-----------------------------------------|-----------------|
| Business                                |                 |
| - urban area                            | 0.70 – 0.95     |
| - rural area                            | 0.50 – 0.70     |
| Housing                                 |                 |
- single housing 0.30 – 0.50
- separate multiunit, separate 0.40 – 0.60
- multiunit incorporated 0.60 – 0.75
- village 0.25 – 0.40
- apartment 0.50 – 0.70

**Industry**
- light 0.50 – 0.80
- weight 0.60 – 0.90

**Pavement**
- asphalt and concrete 0.70 – 0.95
- brick and paving 0.50 – 0.70

**Roof**
- 0.75 – 0.95

**Home page, sandy land**
- flat 0.05 – 0.10
- rather steep 0.10 – 0.15
- steep 0.15 – 0.20

**Home page and heavy land**
- flat 0.13 – 0.17
- rather steep 0.18 – 0.22
- steep 0.25 – 0.35

**Train page**
- 0.10 – 0.35

**Garden playground**
- 0.20 – 0.35

**Parks, cemeteries**
- 0.10 – 0.25

**Forest**
- flat 0.10 – 0.40
- bumpy 0.25 – 0.50
- hilly 0.30 – 0.60

*Source: Mc Guen 1989 in Suripin 2003 [7]*

Existing land use analysis results of SPOT-6 in 2017 with the supervised classification method identified by the 2015 land use map are shown in **figure 1**.

![Figure 1. Existing LU in SC (2017)](image_url)
3.2. Masterplan

The establishment of various means, infrastructures, and facilities in the settlement area SC intends to fulfill various sorts of inhabitant need. It characterizes to provide center area service and environmental center area. Effective LU is 2,465 ha. Effective land area is used for housing and facilities, non-effective land area has a slope situation more than 40%. All are shown in the effective LU plan and built-up LU plan in proportion to area 2,465 ha. The built-up area in proportion to area 2.465 ha is 29.95%.

The data analysis result shows existing LU condition in the study consists of 12 classes of main LC, and most lands are moors at value 41.77% followed by urban settlement 24.48% and mixed garden 10.23%, inland freshwater 0.22% and open area 0.33% is the smallest area in the research area. Runoff coefficients are numbers that represent the ratio between the amount of surface runoff to the amount of rainfall. C = 0.65 means that 65% of rainfall will flow directly into a surface flow [7].

This coefficient also depends on the nature and condition of the soil. The infiltration rate falls on continuous rain and is also affected by previous water saturation conditions. Other factors that also affect the value of C are groundwater, the degree of soil density, soil porosity, and de{pressed} deposits. The following are the C values for various soil types and LUs [7].

The rational C or runoff coefficient, considered an empirical constant of proportionality between peak runoff Qp and products I and A [8], [9], [10], and [11].

The proportion of green open rooms in the city area is a minimum of 30% of the city area. Thereof, the settlement of SC has fulfilled the requirements of a green open room [12]. The LU in the cluster BGH is classified into settlement area, facility, open space area (RTH), and vacant plots. LU Masterplan is shown in figure 2.

![Figure 2. LU of Masterplan, 2011](image-url)
From that data, the average rain intensity value for 10 years, is calculated by the equation as follows:

\[ \text{Average monthly rain intensity} = \frac{\text{Total rainfall for 10 years}}{10 \times \text{Total area}} \]

The value of the runoff coefficient based on existing LU is 0.40 and the masterplan (development plan) is 0.61, there is a change in the runoff coefficient of 0.21. Data on monthly rainfall for a period of ten years (2009-2018) and the average monthly rain intensity (mm/month) are shown in Table 4.

| Year | Jan | Feb | Mar | Apr | May | June | July | Aug | Sep | Oct | Nov | Dec | Avg |
|------|-----|-----|-----|-----|-----|------|------|-----|-----|-----|-----|-----|-----|
| 2009 | 607 | 541 | 408 | 228 | 389 | 128 | 87   | 15  | 76  | 392 | 331 | 236 | 287 |
| 2010 | 417 | 526 | 485 | 84  | 291 | 257 | 139  | 306 | 375 | 445 | 287 | 300 | 326 |
| 2011 | 390 | 265 | 226 | 219 | 175 | 140 | 36   | 8   | 58  | 296 | 412 | 268 | 208 |
| 2012 | 384 | 348 | 240 | 321 | 152 | 64  | 41   | 12  | 122 | 260 | 366 | 423 | 228 |
| 2013 | 851 | 346 | 409 | 349 | 494 | 135 | 279  | 135 | 71  | 355 | 323 | 591 | 361 |
| 2014 | 1,138 | 624 | 290 | 407 | 244 | 199 | 344  | 250 | 34  | 94  | 549 | 459 | 386 |
| 2015 | 285 | 345 | 341 | 207 | 148 | 17  | 9    | 344 | 19  | 52  | 523 | 414 | 225 |
| 2016 | 310 | 587 | 574 | 467 | 291 | 213 | 266  | 101 | 431 | 398 | 329 | 181 | 346 |
| 2017 | 273 | 689 | 311 | 401 | 239 | 133 | 357  | 49  | 337 | 375 | 446 | 362 | 306 |
| 2018 | 340 | 798 | 444 | 291 | 150 | 152 | 9    | 21  | 162 | 135 | 412 | 232 | 262 |
| Total|     |     |     |     |     |     |      |     |     |     |     |     | 4,994 |
| Avg  | 499 | 507 | 373 | 297 | 257 | 144 | 157  | 124 | 138 | 280 | 398 | 347 | 293 |

Source: Meteorology Climatology and Geophysics Agency (BMKG) of Citeko, 2009 – 2018.

3.3. Rain intensity
The rain intensity is calculated by the mm (millimeter) unit, which is the height of water accommodated in area 1 m x 1 m or 1 squared meter (m²). Accordingly, rain intensity 1 mm is the amount of water falling from the sky as much 1 mm x 1m x 1m or 0.001 m³ or 1 dm³, identical with 1 liter. The effect of rainfall intensity on surface runoff depends on its infiltration capacity. If the intensity exceeds the infiltration capacity, then the amount of surface runoff will immediately increase in accordance with an increase in rainfall intensity [13]. Heavy rain in a short amount of time infiltration is limited and unbalanced time causes no time for water to enter the ground, so it will become direct surface runoff.

3.4. The average monthly rain intensity value
From that data, the average rain intensity value for 10 years, is calculated by the equation as follows:
\[
\bar{X} = \frac{\sum X_i}{\text{jumlah tahun} (n)}
\]  
(4)

where:
- \(\bar{X}_i\) = Average maximum rain intensity (mm)
- \(\sum X_i\) = Amount of rain intensity per year
- \(n\) = Number of year (data)

Average rain intensity for 10 years (\(\bar{X}\)) = 2.934/10 = 293. The average monthly rain intensity (mm/month) and standard deviation are shown in Table 5.

| Year  | Rain intensity, Xi (mm) | \((X_i - \bar{X})\) | \((X_i - \bar{X})^2\) |
|-------|-------------------------|----------------------|----------------------|
| 2009  | 286.53                  | -7                   | 47.13                |
| 2010  | 325.95                  | 33                   | 1,060.15             |
| 2011  | 207.69                  | -86                  | 7,344.20             |
| 2012  | 227.73                  | -66                  | 4,311.89             |
| 2013  | 361.37                  | 68                   | 4,620.83             |
| 2014  | 385.93                  | 93                   | 8,562.73             |
| 2015  | 225.28                  | -68                  | 4,638.52             |
| 2016  | 345.65                  | 52                   | 2,731.11             |
| 2017  | 305.70                  | 12                   | 151.54               |
| 2018  | 262.08                  | -31                  | 980.11               |

Sum 2,933.90 - 34,448.20

Average 293.39 - -

Standard deviation 61.87 - -

Source: Analysis result, 2019

3.5. Standard deviation

Standard deviation is calculated by using the following equation:

\[
S_x = \sqrt{\frac{\sum (X_i - \bar{X})^2}{n-1}}
\]  
(5)

where:
- \(S_x\) = Standard deviation
- \(X_i\) = Amount of rain intensity per year (year - i)
- \(\bar{X}\) = Average maximum rain intensity (mm)
- \(S_x = 61.87\)

3.6. Maximum daily rain intensity

Daily rain intensity maximum of 24 hours (mm/24 hours) is calculated by using the Gumbel probability distribution equation as follows:

\[
R_{24} = \bar{X} + S_x \left( y_t - y_n \right)
\]  
(6)

where:
- \(R_{24}\) = Amount of daily rain intensity maximum of 24 hours (mm/24 hours)
- \(\bar{X}\) = Average rain intensity (mm)
- \(S_x\) = Standard deviation
- \(y_n\) = Reduce mean (Table)
- \(y_t\) = Reduce variation as repeat period (Table)
- \(S_n\) = Reduce Standard deviation (Table)
\[ R_{24} = \bar{X} + \frac{S_x}{S_n} (y_t - y_n) = 293 + \frac{61.87}{0.9497} (1.4999 - 0.4952) \]

\[ R_{24} = 358.45 \]

### 3.7. Rain intensity

Average rain intensity for period 10 years (mm/hour) is calculated by Mononobe equation [14] below:

\[ I = \frac{R_{24}}{24 (\frac{t}{24})^{2/3}} \]  

where:

- \( I \) = Rain intensity (mm/hour)
- \( R_{24} \) = Maximum daily rain intensity for 24 hours (mm)
- \( t \) = Rain duration (24 hours)

\[ I = \frac{R_{24}}{24 (\frac{t}{24})^{2/3}} \]

\[ I = \frac{358.45}{24 (\frac{t}{24})^{2/3}} \]

\[ I = 14.93 \text{ mm/hour} \]

### 3.8. Peak run-of

The Rational method was developed since 1837 by Mulvaney [15]. This indirect peak runoff forecasting method uses supporting data related to surface runoff coefficient, rainfall intensity, and catchment area to determine peak runoff. In rational methods, calculations have included hydrological characteristics and flow processes, i.e. (1) rainfall intensity, (2) duration of rain, (3) watershed, (4) water loss due to evaporation, interception, infiltration and (5) concentration flow [16].

According to Regulation of the Director-General of Watershed Management and Social Forestry Number: P. 3 / V¬Set / 2013 [17] concerning guidelines for identifying watershed characteristics, the Rational method can be used in watersheds in Java with an area of less than 5000 ha. The study area covers 2,905.03 hectares, so this method can be applied.

The equation in calculating peak discharge with a rational model (United State Soil Conservation Service 1987) is as follows [3] and [4]:

\[ Q_p = 0.0028 C I A \]

which states that \( Q_p \) is the peak discharge for a rain with a certain interval in m\(^3\)/sec, \( C \) is the coefficient of surface runoff, \( I \) is the intensity of the rain i.e the amount of rainfall per unit time of the maximum rainfall expected duration of rainfall that occurs equal to the time of concentration of a watershed in mm hour\(^{-1}\) and \( A \) area of a watershed in hectares.

The constant 0.278 is a conversion factor for peak runoff to units (m\(^3\)/sec) [14]. Some basic assumptions for using rational formulas are as follows [18]:

a. Rainfall occurs with a fixed intensity in a certain period, at least the same as the time of concentration.

b. Direct runoff reaches a maximum when the duration of rain with fixed intensity, equal to the time of concentration.

c. The runoff coefficient is considered constant for the duration of the rain.

d. The extent of the watershed does not change during the duration of the rain.

The rational model assumes that the watershed concentration time is the same as rain that occurs with uniform intensity throughout the watershed [3] and [19].

The runoff coefficient (C) is defined as the ratio between the peak surface runoff rate and the rainfall intensity. The main factors influencing the C value are the infiltration rate of the soil, cover crops, and rainfall intensity [3]. C values are generally classified based on existing studies.

Peak runoff in the SC area (Qp_SC) is calculated as the following equation (Rational Method):

\[ Qp_S C = 0.278 \times C_{SC} \times I \times A \]  

where:

- \( Qp_{SC} \) = Peak runoff of SC area (m\(^3\)/sec)
- \( C_{SC} \) = Runoff coefficient for various LU in the SC area
- \( I \) = Rain intensity (mm/hour)
- \( A \) = Study area (km\(^2\))
Constant 0.278 is a peak runoff conversion factor to unite in m³/sec. SC existing area is 29.05 km², by peak runoff coefficient (C_{pC}) at value 0.40 with peak runoff value (Q_{p SC}) at value 48.29 m³/sec. Based on the rational method as in equation (7), the calculation is showed as follows:

\[ Q_{p SC} = 0.278 \times C \times I \times A = 0.278 \times 0.40 \times 14.93 \times 29.05 = 48.29 \\text{m}^3/\text{sec} \] or 1,522,873,440 m³/year

According to Masterplan (2011) the peak runoff coefficient is 0.61 with peak runoff value (Q_{p SC}) is 73.55 m³/sec. The calculation is showed as following equation:

\[ Q_{p SC} = 0.278 \times C \times I \times A = 0.278 \times 0.61 \times 14.93 \times 29.05 = 73.55 \text{m}^3/\text{sec} \] or 2,319,472,800 m³/year.

Existing LU data for 2017 and the masterplan can also be used to determine changes in runoff coefficients that occur due to changes in LU. Each LU has its coefficient value so that if the area of each LU is known, the study area runoff coefficient can be found.

Changes in LU will have a significant impact on the quality and quantity of water such as surface runoff, groundwater, and pollution on a temporal and spatial scale [20], [21], [22], and [23].

In general, the value of the existing runoff coefficient for LU 2017 is 0.40 and the masterplan changes to 0.61. As a result of changes in LU based on existing LU on the masterplan (2011-2050), there is a change in the runoff coefficient of 0.21. Changes in runoff coefficient of 0.21 will affect the amount of runoff peak, with peak runoff value is 25.32 m³/sec or 6,622,560 m³/year.

4. Conclusions

There is a change of peak runoff coefficient value as the impact of existing land-use change to land-use masterplan [1] at value 0.21 or peak runoff 25.32 m³/sec or 6,622,560 m³/year. According to classification result in the image SPOT-6 year 2017 shows 12 sorts of existing LU, most lands are moor by 41.77%, urban settlement by 24.48%, mixed garden by 10.23%, terrain freshwater by 0.22% and open area by 0.33%. Peak runoff coefficient based on existing LU is at value 0.40 or peak runoff at value 48.29 m³/sec or 1,522,873,440 m³/year, and based on Masterplan (2011) at value 0.61 with peak runoff (Q_{p SC}) at value 73.55 m³/sec or 2,319,472,800 m³/year. Maximum peak runoff happens if C=1 or value 120.73 m³/sec or 3,807,341,280 m³/year, is a supply rain potential which is useful for fulfilling water needs in the SC area.

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