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Peak Runoff Model Base on Land use Existing and masterplan in Sentul City Area

A Suheri[1,2], C Kusmana[3], M Y J Purwanto[4], Y Setiawan[5]

[1]*Graduate School of Bogor Agricultural University, Bogor 16144 Indonesia*

[2]*School of Life Sciences and Technology, Bandung Institute of Technology, Bandung 40116, Indonesia*

[3]*Department of Silviculture, Faculty of Forestry, Bogor Agricultural University, Bogor 16144 Indonesia*

[4]*Department of Civil and Environmental Engineering, Faculty of Agricultural Engineering, Bogor Agricultural University, Bogor 16144 Indonesia*

[5]*Center for Environmental Studies, Bogor Agricultural University, Bogor 16144 Indonesia*

Abstract

This research aims to create a peak run-off mode based on land use existing and masterplan Sentul City, an urban area. To determine the peak run-off by rational method, the study uses the formulation as follows: Q = 0.2778.C.I.A, in which Q is the peak run-off, C is the run-off coefficient of area, I is the average rain rate intensity, and A is the area of study. For recognizing the existing of land use, the researcher used image analysis SPOT-6 (2017) by supervised classification. It estimated gamma distribution parameter through maximum likelihood method by using software QGIS 2.8, SAGA GIS, dan Arc-GIS 10.4.1. According to the analysis, the study result shows the land use existing peak run-off coefficient value and masterplan are 0.40 and 0.61, respectively, in which the difference is 0.21. The peak run-off increase is 25.32 m3/second due to changes in land use, so it must be anticipated so as not to negatively impact the environment, social, and economy such as: aggravating and expanding flooding areas, causing water shortages in the dry season, increasing erosion and sedimentation, etc.

Keywords: Peak runoff, Land use, Master plan

Corresponding author: A Suheri

Graduate School of Bogor Agricultural University, Bogor, School of Life Sciences and Technology, Bandung Institute of Technology, Bandung 40116, Indonesia.

E-mail: suheri.pslipb@gmail.com

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Introduction

Water supply potential in Sentul City (SC) area depends on biophysic condition including land use or land cover, topography, hydrology, climatology, living things, soil sorts, vegetations, animals, etc. 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 housing area, trade area, official area, industrial area, tourism area, and specific facility (commercials). Since geohydrology condition of SC, it becomes a water-lackness area. It is impossible to maintain water as the impact of loamy soil characteristic which dominates. As stated in the masterplan, the development concept of SC area divides SC area into two areas, including establishment area and coverage, and conservation area. The conservation area is arranged as park forest, playground (Masterplan, 2011). SC has a commitment to maintain the balance of built-up area and open area. According to the masterplan and land use existing, the aim of this research is to create a peak run-off model in the urban area SC.

Material and Method

Study sites

Geographically SC is located on coordinate 06°33´55´´- 06°37´45´´LS and 106°50´20´´- 106°57´10´´ BT. SC which area is 2,465 ha is located on the border area at value 3,001.4 ha (Masterplan, 2011). But, in this study the researcher conducted a spatial analysis at area 2,905.33 ha which was appropriate with area border line in vector form given by planner side. As governmental administration, SC is located on 8 Villages and 2 Subdistricts, 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.

Determine the sort of land use

For determining the sort of existing land use or land cover in the area of study, the researcher conducted two steps. First step, the georeferenced 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 UTM zone division, the SC area was located on UTM Zone 48S. Therefore, the map was projected to WGS84/UTM Zone 48S/EPSG:32748. Second step, the supervised classification was conducted to image map by maximum likelihood classification method to make a land closure map of study area. Then, the ground check was conducted to recognize directly the closure land of the urban area SC. The accuracy of land closure analysis result was evaluated by overall accuracy and kappa accuracy.

Determine the run-off coefficient

For determining the run-off coefficient (C), the calculation used the equation as follows (Gumbel EJ, 1954):

C=(dix86.400xQ)/(PxA)...……………….. (1)

where:

C = The running water (mm)/Rain intensity (mm)

di = The number of day in the month of -i

Q = The average monthly debit (m3/second) and 86,400 = the number of second in 24 hours (60 menit, 60 seconds, 24 hours).

P = The average yearly rain intensity (mm/year)

A = The area of Watershed (km2)

According to the land use map year 2017, the run-off coefficient value of SC (CSC) was calcultated by the equation as follows:

$$C\_SC = \frac{\sum_{i=1}^{n} C_i A_i}{\sum_{i=1}^{n} A_i} \qquad (2)$$

where::

C_{SC} = the run-off coefficient of study area

Ai = the area with soil coverage to-i (ha)

Ci = the run-off coefficient with soil coverage sort -i

n = the number of soil coverage sort

Rational Method

To determine the peak run-off in SC area (Qp_SC), this research used rational method, which formulation was presented as followed (Schwab et al. 1981):

Qp_SC=0.278xxIxA ……………………………………...............(3)

The rational method is generally used for area of study with small scope. Meanwhile, for large scope, it needs to use rational modification method (Theodore G, Cleveland, et al. 2011)

Result and Discussion

Land Use Existing

According to land cover classification in the image SPOT 2017 by land use map year 2015, the study results land use in SC as presented in Table 1.

Land Use Masterplan

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

s.no	Description of land and surface character	coefficient c
1	Business • urban area • rural area	0.70 – 0.95 0.50 – 0.70
2	Housing • single housing • separate multiunit, separate • multiunit incorporated • village • apartment	0.30 – 0.50 0.40 – 0.60 0.60 – 0.75 0.25 – 0.40 0.50 – 0.70
3	Industry • light • weight	0.50 – 0.80 0.60 – 0.90
4	Pavement • asphalt and concrete • brick and paving	0.70 – 0.95 0.50 – 0.70
5	Roof	0.75 – 0.95
6	Home page, sandy land • flat • rather steep • steep	0.05 – 0.10 0.10 – 0.15 0.15 – 0.20
7	Home page and heavy land • flat • rather steep • steep	0.05 – 0.10 0.10 – 0.15 0.15 – 0.20
8	Train page	
9	Garden playground	
10	Parks, cemeteries	
11	Forest • flat • bumpy • hilly	0.10 – 0.40 0.25 – 0.50 0.30 – 0.60

Table 1: Runoff coefficient for rational methods

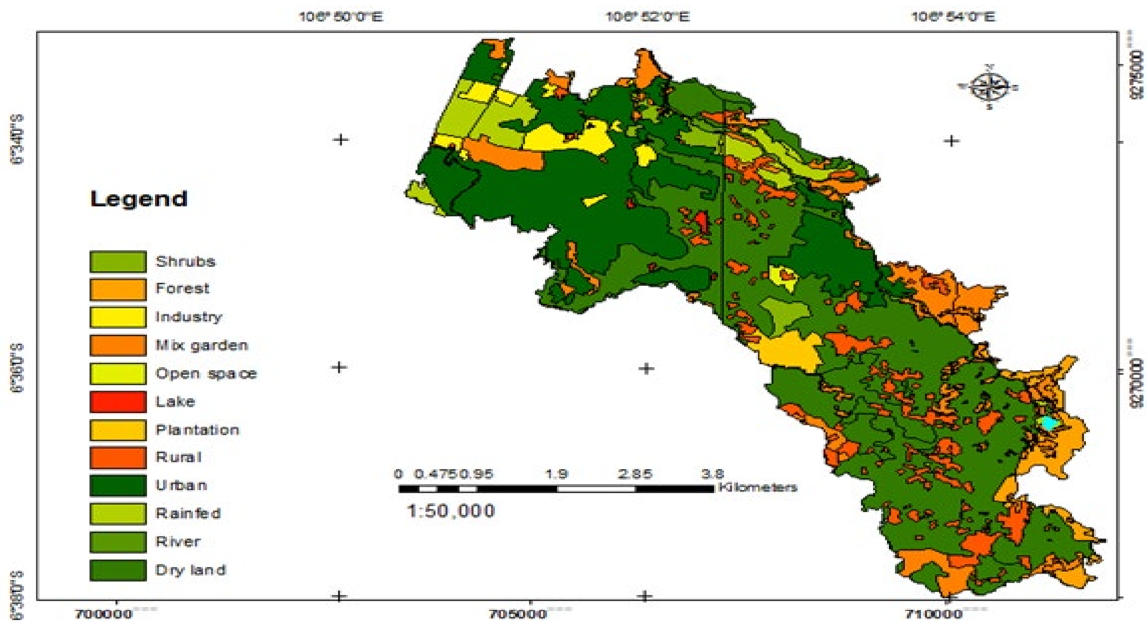

Figure 1: Existing land use in Secnul City(2017)

The data analysis result shows land use existing condition in the study consists of 12 classes of main land cover, 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% are the smallest area in the research area. The existing land use in SC area is showed by Figure 1.

		Area			
No	Land use type	ha	Percentage (%)	C value	Cpl value
1	Shrubs	49.02	1.69	0.25	12.26
2	Forest	101.69	3.50	0.05	5.08
3	Industry	78.83	2.71	0.90	70.95
4	Mix garden	297.16	10.23	0.25	74.29
5	Open space	9.56	0.33	0.20	1.91
6	Lake	6.36	0.22	0.03	0.19
7	Plantation	42.68	1.47	0.25	10.67
8	Rural	225.07	7.75	0.50	112.54
9	Urban	705.47	24.28	0.75	529.10
10	Rainfed	146.12	5.03	0.20	29.22
11	River	29.85	1.03	0.05	1.49
12	Dry land	1,213.52	41.77	0.25	303.38
	Sum	**2,905.33**	100.00	-	1,151.08
	Run-off coefficient	-	-	-	**0.40**
Source: Data analysis result, 2019					

Table 2: Land Use Existing and Run-off Coefficient in SC

Based on the runoff coefficient values given in Table 1 (Appendix-1) and the area of land use can be found the region runoff coefficient values as in Table 2

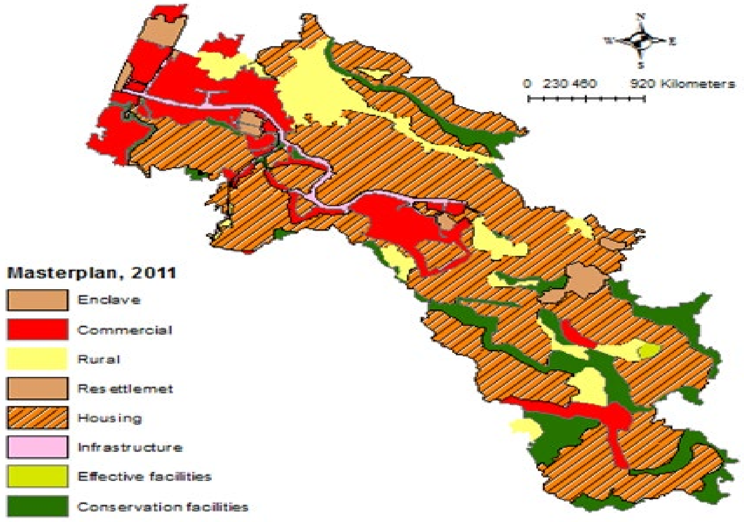

Figure 2: Land Use of Master plan, 2011

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 depressed deposits. The following are the C values for various soil types and land uses (McGueen 1989 in Suripin 2003):

The proportion of green open room in city area is minimum 30% of city area. Thereof, the settlement of SC has fulfiled the requirements of green open room (Barus B., and Wiradisastra U.S. 2000). The land use in the cluster BGH is classified into settlement area, facility, RTH, and vacant plots. Land Use Masterplan is showed in Figure 2.

		Area			
No	Sorts of land use	ha	Percentage (%)	C value	Cpl value
1	Enclave	63.20	2.18	0.75	47.40
2	Commercial	459.35	15.81	0.85	390.45
3	Rural	277.37	9.55	0.60	166.42
4	Resettlement	23.18	0.80	0.75	17.39
5	Housing	1.638.19	56.38	0.60	982.91
6	Infrastructure	61.40	2.12	0.90	55.26
7	Effective facilities	6.56	0.23	0.95	6.23
8	Conservation facilities	376.08	12.94	0.25	94.02
	Total	2,905.33	100.00		1,760.08
Run-off coefficient					0.61
Source: Data analysis result, 2019					

Tabel 3: Land Use Masterplan (Masterplan, 2011)

The value of runoff coefficient based on existing land use is 0.40 and the master plan (development plan) is 0.61, there is a change in runoff coefficient of 0.21.

Year	Month												Average
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	
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	33.7	375	446	362	306
2018	340	798	444	291	150	152	9	21	162	135	412	232	262
Total	4,994	5,067	3,727	2,973	2,573	1,438	1,566	1,241	1,381	2,803	3,978	3,466	-
Average	499	507	373	297	257	144	157	124	138	280	398	347	293
Source: Meteorology and Geophysics Agency (BMKG) of Citeko, 2009 – 2018													

Table 4: Average monthly rain intensity (mm/month) in SC

Rain Intensity

The rain intensity is calculated by mm (millimetre) unite, which is the height of water accomodated in area 1 m x 1 m or 1 squared metre (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, identic with 1 liter.

Average monthly rain intensity value

From that data, the average rain intensity value for 10 years, is calculated by equation as follows:

$$\bar{X} = \frac{\sum xi}{Junlah\ tahun\ (n)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where::

$\overline{Xi}$ = Average maximum rain intensity (mm)

$\sum Xi$ = Amount of rain intensity per year

n = Number of year (data)

Average rain intensity for 10 years ( ) = 2.934/10 = 293. Average monthly rain intensity (mm/month) showed are showed in Tabel 4 and standard deviation are showed in Table 5.

Year	Rain intensity, Xi (mm)	$(Xi - \overline{X})$	(Xi - ^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	-	

Table 5: Average monthly rain intensity (mm/month) and standard deviation
Source: Analysis result, 2019

Standard Deviation
Standard deviation is calculated by using following equation:

$$Sx = \sqrt{\sum \frac{(xi-\bar{x})^2}{n-1}} \quad \text{...} (4)$$

where:
Sx = Standard deviation
xi = Amount of rain intensity per year (year − i)
$\bar{x}$ = Average maximum rain intensity (mm)

$$S_x = 61.87$$

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

$$R_{24} = \bar{X} + \frac{S_x}{S_y}\ (y_t - y_n)$$

where:
R_{24} = Amount of daily rain intensity maximum 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)

$$R_{24} = \bar{X} + \frac{S_x}{S_n}(y_t - y_n) = 293 + \frac{61.87}{0.9497}(1.4999 - 0.4952)$$

$$R_{24} = 358.45$$

Rain intensity

Average rain intensity for period 10 years (mm/hour) is calculated by Mononobe equation (Seyhan, E., 1990) below:

$$I = \frac{R_{24}}{24}\left(\frac{24}{t}\right)^{2/3}$$

where:

I = Rain intensity (mm/hour)

R_{24} = Maximum daily rain intensity for 24 hours (mm)

t = Rain duration (24 hours)

$$I = \frac{R_{24}}{24}\left(\frac{24}{t}\right)^{2/3}$$

$$I = \frac{358.45}{24}\left(\frac{24}{24}\right)^{2/3}$$

$$I = 14.93\ mm/hour$$

Peak Run-of ……………………………………………..……………………..…….. (6)

Peak run-off in SC area (Qp_SC) is calculated as following equation (Rational Method):

Qp_SC = 0.278 x x I x A ……………………………………..……..………………………….. (7)

where:

Qp_SC = Peak run-off of SC area (m^3/second)

C_{SC} = Run-off coefficient for various land use in SC area

I = Rain intensity (mm/hour)

A = Study area (km^2)

Constant 0.278 is a peak run-off convertion factor to unite in m3/second. SC existing area is 29.05 km2, by peak run-off coefficient (CSC) at value 0.40 with peak run-off value (Qp_SC) at value 48.29 m3/second. Based on the rational method as in equation (7), the calculation is showed as follows:

Qp_SC = 0.278 x C x I x A = 0.278 x 0.40 x 14.93 x 29.05 = 48.29 m3/second or 1,522,873,440 m3/year

According to Masterplan (2011) the peak run-off coefficient is 0.61 with peak run-off value (Qp_SC) is 73.55 m3/second. The calculation is showed as following equation:

Qp_SC = 0.278 x C x I x A = 0.278 x 0.61 x 14.93 x 29.05 = 73.55 m3/second or 2,319,472,800 m3/year.

Existing land use data for 2017 and the master plan (development plan) can also be used to determine changes in runoff coefficients that occur due to changes in land use use. Each land use has its own coefficient value so that if the area of each land use is known, the study area runoff coefficient can be found.

In general, the value of the existing runoff coefficient for land use 2017 is 0.40 and the master plan is 0.61. As a result of changes in land use based on existing land use on the master plan (2017 - 2050) there is a change in runoff coefficient of 0.21. Changes in runoff coefficient of 0.21 will affect the amount of runoff peak, with peak run-off value is 25.32 m3/second due to changes in land use, so it must be anticipated so as not to negatively impact the environment, social, and economy such as: aggravating and expanding flooding areas, causing water shortages in the dry season, increasing erosion and sedimentation, etc.

Conclusions

There is a change of peak run-off coefficient value as the impact of existing land-use change to land use masterplan (Masterplan, 2011) at value 0.21 or peak run-off 25.32 m3/second.

According to classification result in the image SPOT-6 year 2017 shows 12 sorts of existing land use, 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 run-off coefficient based on existing land use is at value 0.40 or peak run-off at value 48.29 m3/second, and based on Masterplan (2011) at value 0.61 with peak run-off (Qp_SC) at value 73.55 m3/second.

An increase in peak runoff of 25.26 m3/second due to changes in land use, so it must be anticipated so as not to negatively impact the environment, social, and economy such as: aggravating and expanding the area of flooding, water shortages in the dry season, increasing erosion and sedimentation, and etc. Recommendation Changes in land use result in changes in the value of peak runoff. Peak runoff will increase with decreasing green open space and or increasing open land (no vegetation).

Efforts to reduce runoff in SC can be done including planting vegetation (adding green open space) to increase water infiltration into the soil. Besides this, the low availability of green open space can also reduce the carrying capacity of the biotic environment in overcoming the effects of human (anthropogenic) activities in urban areas (Sari, Wiryanto, and Setyono. 2019) as in SC. Other efforts to reduce runoff can be carried out by collecting water by the construction of artificial lakes, infiltration wells, absorption biopori holes, smart tanks and utilization of river water

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