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DEVELOPMENT OF GREEN INFRASTRUCTURE IN URBAN CATCHMENT AREA (CASE STUDY: TANJUNG BARAT SUB-DISTRICT, SOUTH JAKARTA)

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ABSTRACT: The rapid urbanization of the city of Jakarta has resulted in the decreasing of the hydrological function of the city due to the increase of impervious land cover and the reduced water catchment area. Water conservation efforts are needed by increasing water infiltration and reducing surface water runoff with the Low Impact Development approach with green infrastructure (GI) implementation in the urban catchment area. This research takes a case study in Tanjung Barat Sub-district, South Jakarta, which acts as one of the water catchment area of Jakarta. The aims of this study are to determine the placement of GI in accordance with the criteria of land suitability and analyze the effectiveness of its application. The method used in this research is the modeling of GI placement by using BMP Siting Tools module on the SUSTAIN program and ArcGIS. And its effectiveness analysis with the calculation of flow coefficient and flow of runoff. The study result showed some of GI types that suitable to be implemented are bioretention and rain barrel. Based on the calculation of flow coefficient and runoff flow, it is known that GI application is effective in lowering the flow coefficient and reducing runoff discharge by 26.25%.

Keywords: Urbanization, Low Impact Development, Water Conservation, Land Suitability, Effectiveness Analysis

1. INTRODUCTION

The rapid development of urban areas characterized by increasing population and settlement expansion led to the increased impervious area and urban activity. This has an impact on the disruption of the hydrological cycle balance in urban areas, due to increased water runoff during rainfall and decreasing water absorption [1].

The city of Jakarta as one of the most rapidly growing urban areas in Indonesia [2] experienced problems related to the decreasing of the city's hydrological function due to the higher percentage of built-up areas and the reduced water catchment area [3]. This is exacerbated by conventional urban drainage systems, climate change and inadequate provision of water infrastructure so that there are still many people who use groundwater [4]. As a result, Jakarta is difficult to get rid of problems related to the decline of hydrological functions, such as floods, water crisis, land subsidence, and seawater intrusion [3].

Water conservation efforts are needed to restore hydrological functions in urban areas, particularly those in catchment areas. This can be done by increasing the capacity of water infiltration, thereby increasing groundwater levels [5]

One of the water conservation methods is the Low Impact Development (LID) approach, with the application of green infrastructure (GI) [6]. GI is the best practice implementation based on LID approach in the stormwater management by holding for as long as possible stormwater in an area to enlarge the infiltration flow into groundwater [5]. GI serves to increase water absorption capacity by reducing the impact of surface water flow by retaining and absorbing water runoff on the soil, thus protecting the city from floods and droughts [6, 7]. The form of GI can be a natural, semi-natural, and artificial network of multifunctional ecological systems located within or within urban areas on all spatial scales [8]. Examples of GI include bioretention or rain garden, green roof, rain barrels or cisterns, infiltration trench, vegetated swales, wetland, retention pond, porous pavement, etc [9].

The application of GI has been successful in providing both direct and indirect benefits such as drainage system cost efficiency, decreasing rainfall runoff, reducing pollution, increasing green open space, improving climate comfort as well as the quality of life in an environment [4, 10]. However, in order to apply the GI more optimally and effectively in accordance with its function, it is necessary to further study in determining the suitability of the site or location of the placement of GI in accordance with the character and function of each GI [1].

This study aims to obtain modeling related to the type and location of GI implementation based

on suitability analysis and its effectiveness. The research took place in the Tanjung Barat subdistrict, South Jakarta, which is one of the areas that became a water catchment area for the city of Jakarta.

The result of modeling of suitability analysis is a map of GI placement according to land suitability criteria based on a physical criteria, such as soil type, groundwater level, drainage area, land slope, head, land cover, road network, water body, and the percentage of impervious [12]. Then to know the effectiveness of the placement of GI that has been modeled, can be analyzed with the calculation of flow coefficient and runoff discharge.

2. METHOD

There are two stages in this research: (1) map of GI placement modeling; and (2) hydrological analysis to determine the effectiveness of GI placement.

2.1 Map of GI Placement Modeling

At this stage, it is done using a suitability analysis method, assisted by BMP Sitting Tools (BST) module on the SUSTAIN Model, that is embedded in ArcGIS 10.1 software. BST is software that can assist in choosing the appropriate location for each GI that refers to the method of LID [9].

Table 1. Data Format for BMP Siting Tool

ArcGIS Layer	Format
DEM (Digital Elevation Model)	Raster file
Land use	Raster and Table file
Percent impervious	Raster file
Urban Land use	Shape file
Road	Shape file
Stream	Shape file
Soil	Shape and Table file
Groundwater Table Depth	Shape file
Land Ownership	Shape file

The data requirement in this study, according to the criteria specified in the BST is a thematic map, both in raster and shape format, for the data layer in ArcGIS. The thematic maps needed in the data layer include contour, land use, built-up land, land tenure, soil, road and river network maps, and groundwater table depth [1].

Then, a suitability analysis is performed by setting criteria for the nine parameters considered appropriate for each type of GI. The criteria used in this study are primarily based on predetermined criteria derived from guidelines for the use of BST [11]. However, these criteria can be adjusted according to preferences based on conditions, local knowledge, and rules at the study site [1].

2.2 Analysis of GI Effectiveness

The effectiveness analysis is done by comparison of the existing condition and after applied GI. So it can be analyzed the amount of flow coefficient or curve number (CN) which is used due to surface runoff potential. CN calculations on the existing conditions of all land cover at the study site, with the following formula [13] :

$$CN_C = \frac{CN_1 A_1 + CN_2 A_2 + ..+ CN_j A_j}{A_1 + A_2 + ..+ A_j} \quad (1)$$

Where : $\mathbf{CN_C}$ = CN Composite
$\mathbf{A_j}$ = Area of land cover
$\mathbf{CN_j}$ = CN of each land cover

Then calculation CN value of GI based on land connectivity to the impervious area. CN in the impervious area is calculated by observing a direct relationship between the area and with the drainage system [14].

$$\mathbf{CN_{lid} = CN_p + \left(\frac{P_{imp}}{100}\right) x \left(98 - CN_p\right) x \left(1 - 0.5\, R\right)} \quad (2)$$

Where : CN_{LID} = CN GI
CN_P = CN *pervious area*
R = The ratio of impervious areas that are not connected to the drainage system of the total area
P_{imp} = Percentage of *impervious area*

After that, the calculation of runoff flow volume, based on the value of the rainfall design, that becomes the input and the ability of the ground to retain or absorb water. Calculation of runoff flow using Soil Conservation Services (SCS) method calculation parameters [15] are:

$$Q = \frac{(P_2 - 0{,}2\ S)^2}{P_2 + 0{,}8\ S} \quad (4)$$

$$\text{with } S = \frac{1000}{CN} - 10 \quad (5)$$

Where : Q = Runoff flow (in/s)
P_2 = Daily maximum rainfall of 2 years (in)
S = Maximum retention potential of the land (in)

3. RESULTS AND DISCUSSION

3.1 Study Area Description

The study location is located in Tanjung Barat Subdistrict, South Jakarta, which is one of the water catchment of Ciliwung River Basin located in DKI Jakarta province. It has a fairly high rate of land cover change, with percentage of 53.99% or 179.84 ha [16]. Whereas based on the guidance in the city plan [17] that in the area functioned as water catchment area, so that with high percentage of the build area will reduce the hydrological function.

Geographically, Tanjung Barat Subdistrict is located at 06 ° 17'43.105 "- 06 ° 18'42.934" South Latitude and 106 ° 50 "27.077" - 106 ° 50'17.716 " East Longitude. The total area of Tanjung Barat Subdistrict is 366.8 ha. Based on the results of land use map processing, it is known that the housing occupies an area of 125.71 ha or 34.27% of the total area. Waterbody consists of the river, pond, and channel with an area of 14.12 ha (3.85%). Green open space consists of public and private open space, and also bare land, with an area of 113.61 ha (30.97%). The road consists of toll, national, provincial, arterial, and collectors with an area of 37.53 Ha (10.23%). Meanwhile, non-residential buildings consist of offices, commercials, and schools with an area of 10.41 Ha (2.84%).

Other physical conditions such as the slope of the land in the village of Tanjung Barat Subdistrict is relatively flat with a slope of 0-8%. The hydrological soil group (HSG) in Tanjung Barat Subdistrict is included in group C which has soil conditions with medium runoff potential and low infiltration rate with infiltration rate 1-4 mm / day [13]. While the groundwater table depth is in the range of 3.53-9.81 m from the soil surface.

Table 2. Physical condition at Tanjung Barat Subdistrict

Physical Criteria	Value
Area	366.8 ha
Slope	0-8%
Build area	69.03%
Green open space	30.97
HSG	C
Groundwater table depth	3.53-9.81 m

3.2 GI Distribution

Based on the analysis using input data and criteria processed by BST, the resulting layer in the ArcGIS software shows the location for each type of GI and a composite map layer showing all the appropriate combinations of GI types in each location.

There are two types of GI that can be developed in accordance with the physical conditions in Tanjung Barat Subdistrict, namely bioretention and rain barrels. The distribution of location and type of GI from this suitability analysis is presented in Figure 1. The limitation of selected GI is due to the criteria of the HSG, which in the Tanjung Barat Subdistrict is included with the HSG type C criteria. This causes the type of GI that serves to infiltrated such as infiltration basin, infiltration trench, and porous pavement can't be applied because the HSG required is criteria A or B. In addition, the limited land and regulations related to road, rivers and buildings borders cause the limited number of selected GI.

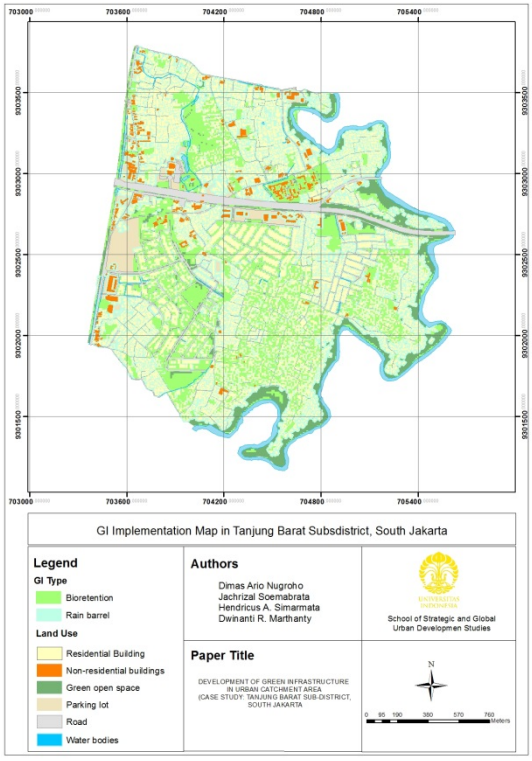

Fig.1 Map of distribution and type of GI in Tanjung Barat Subdistrict

Bioretention is selected because it does not require large land and can be used in any soil condition because there is soil treatment by bringing more fertile soil and greater infill capacity if needed. Rain barrel was also chosen because the criteria are not too tight, which is limited only by the criterion of the building border only.

The total area of bioretention that can be applied is 45.48 ha and placed in the existing green open space both public and private. The application of bioretention is flexible, applicable in house yards, median road, sidewalks, parking lots,

and in small alleys in densely populated housing [18].

Bioretention becomes an additional feature in green open space in increasing infiltration capacity. It has an infiltration rate of 7 mm / h with a capacity of 6 inches [5]. It can be estimated that the volume of bioretention capacity is 69,130 m^3.

Meanwhile, for rain barrel, it can be used in rainwater harvesting as a reservoir. It is useful to meet the needs of water outside drinking water, bathing and washing, such as watering plants, flushing toilets and other.

3.3 Analysis of GI Effectiveness

3.3.1 Flow coefficient (CN)

The flow coefficient or curve number (CN) is a number that shows the ratio between the extent of runoff to rainfall [15]. The calculation of the effectiveness of GI based on the flow coefficient can be assessed based on the comparison of the existing condition and after the applied of GI. So It can analyze the amount of flow coefficient used due to potential runoff. The flow coefficient analysis uses calculation parameters: (1) type of ground cover; (2) percentage of impervious area; (3) hydrological soil group; and (4) the hydrological condition (average humidity or runoff).

Tabel 3. CN Value of Existing Land Use in Tanjung Barat Subdistrict

Land Use	Area (km^2)	CN	CN*Area
Water bodies	0.141	0	0
Green open space	1.136	74	84.064
Parking lot	0.654	98	64.092
Road	0.375	98	36.750
Non-residential buildings	0.104	94	9.776
Residential buildings	1.257	90	113.130

The calculation of the value of the flow coefficient based on land use within the catchment area of Tanjung Barat Subdistrict is based on the coefficient value of each type of land cover based on the National Resources Conservation Service (NRCS) classification [13] as listed in table 3. The results obtained are:

$$CN_C = \frac{86.064+64.092+36.750+9.776+113.130}{3.667}$$

$$CN_C = 83.94$$

After known the placement of GI based on map modeling, it can be calculated CN value of GI based on land connectivity to the impervious area. The CN in the impervious area is calculated by observing a direct relationship with the drainage system [14].

Tabel 4. CN Value of GI implementation in Tanjung Barat Subdistrict

Land Use	Area (km^2)	CN	CN*Area
Water bodies	0.141	0	0
Green open space	0.681	74	50.394
Bioretention	0.455	61	27.450
Parking lot	0.654	98	64.092
Road	0.375	98	36.750
Non-residential buildings	0.104	94	9.776
Residential buildings	1.257	90	113.130

From table 4, calculations can be done to determine the percentage of impervious area (Pimp) and is equal to 65.176%. CN value of impervious land (CNu) is 93.618 and CN land value of pervious area (CNp) is 68.524. From the ratio of CN value on the impervious and pervious area are known ratio (R) of 1.37.

The results obtained from the calculation of the flow coefficient of the application of GI (CN_{LID}) are:

$$CN_{LID} = 68.524 + (65.176/100) \times (98-68.524) \times (1 - 0.5\ (1.37))$$

$$= 74.57$$

In this calculation, bioretention becomes an additional feature in the green open space in increasing the infiltration capacity. Bioretention has an infiltration rate of 7 mm/h, so that green open space with bioretention device has a soil condition with infiltration rate such as the HSG B condition, with a value of CN 61.

CN_{LID} value is lower than CN_C due to using GI. The purpose of applying GI is to increase the ability of infiltration and reduce or decide surface runoff from the impervious area. So as to decrease the runoff coefficient and extend the concentration time. CN_C value of existing condition is equal to 83.94. Meanwhile, the CN_{LID} value is 74.57. It showed significant decreases, which approached CN values on land cover in the form of green open space in good condition with soil hydrological group C (CN value 74). This indicates that the application of GI can reduce the negative impact of a region that is dominated by impervious area, especially related to the stormwater management. In this case in green open space with the use of bioretention more effective in reducing surface runoff compared to regular ones.

3.3.2 Runoff flow discharge

The calculation of runoff flow based on the value of the rain design that becomes the input and the ability of the soil to hold or infiltrated water. Since GI only works effectively in initiating direct runoff and channel protection from sedimentation and erosion, it is used two annual rain design [5]. Rainfall data is obtained from the University of Indonesia (UI) Campus Station, Depok. From the calculation results with frequency analysis with normal distribution method, obtained the value of maximum daily rain return period of two annual average of 124.12 mm or 4.89 inches.

Tabel 5. Rainfall data from UI Campus Station 2008-2017

No	year	Rainfall Max (mm)
1	2008	152.00
2	2009	137.00
3	2010	109.00
4	2011	117.40
5	2012	128.20
6	2013	101.70
7	2014	151.50
8	2015	97.20
9	2016	141.50
10	2017	105.70

Calculation of runoff flow at the existing condition, with a value of CNc at existing condition, is equal to 83.94. So the results of the runoff flow calculation on the existing conditions are:

$$Q = \frac{(4.89-(0.2 \times 1.9))^2}{4.89+(0.8 \times 1.9)}$$

= 3.17 inch/s = 80.6 mm/s = 0.08 m/s

with $\boldsymbol{S} = \frac{\mathbf{1000}}{\mathbf{83.94}} - \mathbf{10}$ = 1.9 inch

With the area of Tanjung Barat Subdistrict is 3.667 km^2 or 3,667,000 m^2, the peak discharge for the whole area under the existing condition can be calculated as follows:

Qp = A x Q = 3,667,000 x 0.08 = 293,360 m^3/s

Where : Qp = Peak discharge in an area (m^3/s)
A = Area (m^2)
Q = Runoff discharge (m/s)

Then on the runoff calculation on conditions after applied GI, with the CN_{LID} value of 75.58, the result of the runoff flow is as follows:

$$Q = \frac{(4.89-(0.2 \times 3.41))^2}{4.89+(0.8 \times 3.41)}$$

= 2.32 inch/s = 58.93 mm/s = 0.059 m/s

with $\boldsymbol{S} = \frac{\mathbf{1000}}{\mathbf{74.57}} - \mathbf{10}$ = 3.41 inch

It can be known that the peak discharge for the whole area under the conditions of GI can be calculated as follows:

Qp = A x Q = 3,667,000 x 0.059 = 216,353 m^3/s

The peak discharge value in an area, in the existing condition, has a greater value than the condition using GI. Application of retention increases the ability of land retention potential and decreases the value of the flow coefficient.

In accordance with the calculation that has been done, it is known that the peak discharge value at the existing condition is 293,360 m^3/s. While the peak discharge value after applied bioretensi is equal to 216,353 m^3/s. There is a difference of 77,007 m^3/s of water discharges impregnated to the ground or accommodated in a GI. The efficiency rating of the flow rate reduction was 26,25%.

4. CONCLUSIONS

Based on the results of land suitability analysis model using BST, it is known that GI that can be applied in Tanjung Barat Subdistrict is bioretention and rain barrel. Meanwhile, from the results of the effectiveness analysis of the application of GI, it is known that the value of the flow coefficient (CN) on the existing conditions and after applied GI is 83.94 and 74.57 respectively. Then from the calculation of peak discharge at the existing condition and after applied GI respectively equal to 293,360 m^3/s and 216,353 m^3/s, with efficiency value equal to 26.25%. So the application of GI is quite effective in increasing the infiltration capacity in Tanjung Barat Subdistrict.

There needs to be integration and equality of perceptions of all relevant stakeholders, of the importance of GI implementation. The location of bioretention that spreads in all green open spaces both public and private and the provision of rain barrel in each building as an effort to rainwater harvesting needs to be supported and implemented by all stakeholders, both government agencies, the private sector, and household.

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