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Evaluation of Effectiveness and Efficiency of Green Infrastructure Siting on Existing Water Infrastructure in Urban Area of Jakarta

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Abstract:

It is important to analyze flood risks before assigning flood mitigation. Flood mitigations are classified into structural and non-structural approaches. Green infrastructure technologies are among of non-structural flood mitigations. The objective of this research is to evaluate the effectiveness and efficiency of green infrastructure (GI) siting on existing water infrastructure system in Jakarta's urban spatial detail planning scale of 1:5000. Since this is an ongoing research, this paper proposes the methodology consisting: (1) selection of research site based on typical urban areas, which are, the buildings density, and social and economic factors, (2) flood risk analysis based on hazard and vulnerability mapping, (3) simulation of GI siting using a tool based on Geographic Information System modeling, (4) rainfall runoff analysis, and (5), cost efficiency analysis. The evaluation is carried out in scenarios. The results for this preliminary research are (1) Pasar Rebo sub district is the selected research site, (2) risk mapping that shows the built up lands have the highest risk while vacant lands are the lowest, and (3) rainfall runoff simulation gives the magnitude of peak runoff (Qp) of 334,36 cms and runoff volume (Vr) of 132,03 mm (2.943.255 cubic-meters). The result also shows some vacant lands which are potential for detention ponds located next to the Cijantung River with the total area of 6,3 hectares and 2,75 m depth, that can store 154.350cubic-meters of runoff volume. A preliminary conclusion indicates that the methodology is feasible to proceed in order to achieve the objectives as stated.

***Keywords:** flood modeling, green infrastructure, Jakarta, spatial detail planning.*

I. INTRODUCTION

DKI Jakarta Province with 13 rivers that flow through it, naturally, positions it as an area that has high vulnerability to flooding. On the other hand, Jakarta's status as a metropolitan city is not spared from increasing urbanization. With a population of Jakarta that currently reaches more than 10 million people and the population growth in 2017-2018 is 0.9%[1] triggering an increase in the need for urban and residential facilities. So that it is not uncommon for flood-prone areas to become a choice of residence for some people. One of the areas that is a flood-prone category is the riverbanks. This area becomes vulnerable if siltation and narrowing occur so that when there is rain with high intensity it is no longer able to accommodate and drain runoff, which eventually occurs overflowing rivers that inundate settlements [2].

The impact of the current and future floods urgently demands to make flood risk management in urban areas at high priority of the policy agenda. Effective and efficient flood disaster management requires knowledge of hazards and risks in watersheds. Flood information with a mapping display helps better planning. Geographic Information System (GIS) can be used to display flood areas, and is also used to analyze flood inundation maps to produce maps of estimated flood damage and flood risk [3].

Flood mitigation can be interpreted as a series of efforts made in order to minimize the risks posed by flood disasters. Flood mitigation efforts can be carried out before, during and after a flood. Flood mitigation can be classified into two forms, namely structural mitigation and non-structural mitigation. Structural mitigation actions can be carried out including dam construction, river normalization, river channel cutting, and drainage improvement. In addition, non-structural mitigation can be carried out through zoning of potential hazard and flood risk, providing socialization and early warning of rescue efforts, and regulation of spatial use policy in hazard zones and flood risk [4].

This research aims to evaluate the green infrastructure siting plan on their effectiveness and efficiency integrated with existing water infrastructure system in Jakarta's urban spatial detail planning scale of 1:5000. This research later is using three scenarios: (1) current condition without GI (2) current condition with GI (3) GI implementation on the detail spatial planning. As a preliminary research, this paper presents the research methodology and proposes a hypothetical flood mitigation design that can be carried out in flood-prone areas.

II. DATA AVAILABILITY

Collection of data were gathered in the form of secondary data included:

a. Daily rain data. Rain data collected from 2003 to 2018 were obtained from UI Rain Station.
b. Topographic data are in the form of contour data sourced from the DKI Jakarta Provincial Disaster Management Agency and point of elevation data from the Geospatial Information Agency. Both data are processed to create a digital elevation model (DEM).
c. Land cover data. Identification of land cover types using data from the Geospatial Information Agency (BIG) in year 2019.
d. Land use and road network data sourced from agrarian and spatial plan office/ national land agency (ATR/ BPN Jakarta)
e. Building parcel map sourced from https://openstreetmap.id/en/data-dki-jakarta/

III. RESEARCH METHOD

This research is carried out in several stages of methodology includes:

3.1 Selection of research site

The research location was designated as typical urban sub-district in DKI Jakarta selected by scoring methods based on the criteria of building density, citizen education and economic level. These social and economic criteria are important in terms of socialization regarding the application of green infrastructure in rainwater management program. After that, additional criteria were scored based on whether the shortlisted sub-district were in the recharge area and part of the Ciliwung watershed.

3.2 Green infrastructure siting simulation

A Geography Information System (GIS)-based is used to determine the suitable placement of green infrastructure within a catchment.Tools named "Green Infrastructure Tool Based on Location Analysis" or GITBoLA for short, uses spatial multicriteria andwill be used to simulate the ideal locations for green infrastructure. The GI technology that will be simulated are constructed wetland, infiltration trench, bioretention and vegetated swales. However, this research only modelsdetention pond, while others will be carried out in subsequent studies. Data needed for the tool include digital elevation models, land use, impervious cover, land ownership, stream network, soil type, and groundwater table depth.

3.3 Hydrological modelling

Win TR-55 was chosen for hydrological modeling in this preliminary research. Win TR-55 was developed by the United Stated Soil Conservation Service (SCS) as a simplified procedure for calculating runoff volumes, peak discharges and storage volumes in rainwater management structures. Win TR-55 is a rainfall-runoff modeling for single event rain in small watersheds with area less than 100.000 Ha [5]. The further research will use the Storm Water Management Modelling (SWMM) in order to quantify the green infrastructure (GI) performance within research area.

3.4 Cost efficiency analysis

This analysis will be done in the further research and describe the benefit of GI implementation for stormwater management if it is integrated with existing water infrastructure. The cost parameters will be investigated are GI development cost and drainage development cost with respect to each scenario.

3.5 Flood Risk Analysis

Determination of the disaster risk level consisted of the process of determining the level of hazard and vulnerability level of floods by weighting methods. The weighting of flood hazard level was based on the topography of the watershed which experienced floods which were determined to an elevation less than +44.00. Weighting the level of vulnerability was determined based on the type of land use using land cover data. Then, the weighting resulted from those two parameters were made a matrix of flood risk level which was the result of multiplication of each parameter's weight.

3.6 Flood mitigation planning

The commonly adopted measures of flood mitigation are classified into structural and nonstructural varieties. Non-structural flood mitigation measures such as land use regulations; flood forecasting and early warning system; and preparedness and response mechanisms as well, while structural flood mitigation measures conducted by building infrastructure either grey or green infrastructure technology. Green infrastructure technology serves to extend time of concentration and increase infiltration volumes. By integrating green infrastructure in the existing grey infrastructure system, it will be able to effectively reduce peak flood discharge. This paper will focus on an infrastructure that serves to extend the concentration time (Tc) which is a detention pond or retention pond. The detention or retention ponds located next to a channel will be designed on this research. Non-cultivated and non-settlement vacant land has good potential as a location for the placement of detention or retention ponds so that it will be more efficient in its implementation.In this research, the design of the pond capacity using the AASHTO (1991) formula with illustrations such as Fig. 1.

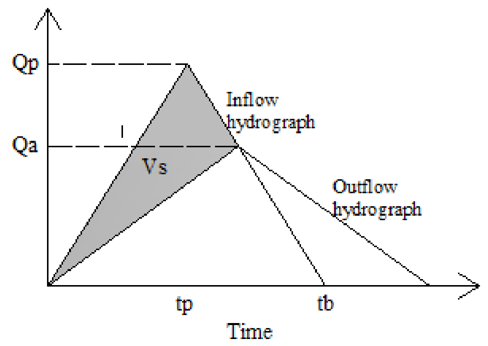

Fig. 1Detention/ retention pond volume requirements

$$\frac{V_s}{V_r} = 1.29 \frac{\left(1 - \frac{Q_A}{Q_P}\right)^{0.153}}{\left(\frac{t_b}{t_P}\right)^{0.411}} \quad (1)$$

where:

Q_P : Peak outflow discharge
Q_a : designed outflow discharge
Vs : Pond volume
V_r : runoff volume

$$t_b = 2t_P - \frac{0.05Q_P}{Q_P} \quad (2)$$

where:

t_b : base time
t_P : peak time

IV. RESULT AND DISCUSSION

Stages that have been done in this research include as follows:

4.1 The selection of the research site

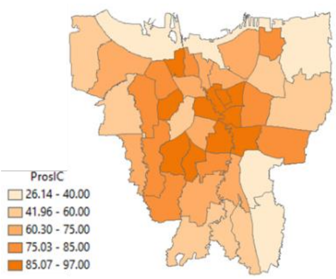

Fig. 2Distribution of building density by sub-district

The criteria for building density (Fig. 2) were based on a land cover map issued by the Geospatial

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Information Agency on the website http://tanahair.indonesia.go.id/ with the scale of 1: 25,000. Building density was calculated from the ratio between the area of built land and the area. This criterionwas divided into 5 classes and each class was scored with a range of 1 to 5, where the lowest score was the region class with the highest building density while the highest score was the region with the lowest building density classification. For the assessment of building density criteria, the weight was 40%.

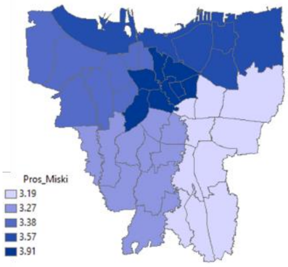

Fig. 3Distribution of percentage of poverty by Municipal

For the economic level criteria (Fig. 3), it was described as the percentage of poor population, that was, the population who have an average per capita expenditure per month below the Poverty Line, based on Jakarta data in Figures for 2017 released by Central Bureau of Statistics of DKI Jakarta. These criteria were grouped into 5 classes and each class was scored with a range of 1 to 5, where the lowest score was the class of regions with the highest percentage of poor population while the highest score was the region with the lowest percentage of poor population. For the assessment of the percentage of poor people, the weight is 30%.

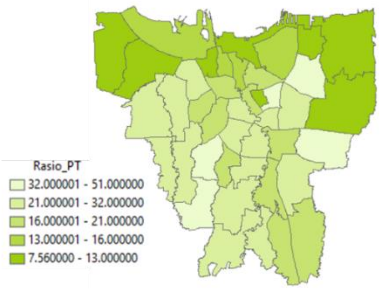

Fig. 4Distribution of the ratio of tertiary education level by sub-district

The criterion for the ratio of education level (Fig. 4) was a comparison between the number of people with tertiary education and those without tertiary education. The criteria were grouped into 5 classes and each class was scored with a range of 1 to 5, where the lowest score was the regional class with the lowest ratio of tertiary education level while the highest score was the region with the highest ratio. For the assessment of building density criteria, the weight is 30%.

From the results of scoring urban criteria then 5 sub-districts with the highest score were taken, namely: Makassar (score 4.7), Cipayung (score 4.4), Pasar Rebo (score 4.3), Ciracas (score 4.0), and Jagakarsa (score 4.0). Selected sites based on additional criteria, which are situated ina recharge area (Fig. 5) and in the Ciliwung watershed (Fig. 6), are Pasar Rebo, and Jagakarsa sub-districts.

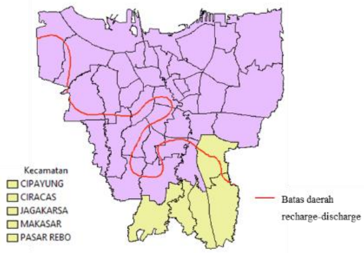

Fig. 5The overlay of the main criteria results with the recharge area

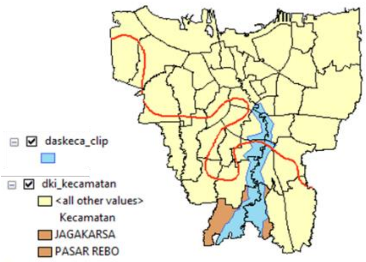

Fig. 6 The overlay of the recharge areasiteswith the Ciliwung watershed

Of the two sub-districts selected, Pasar Rebo was designated as the researchsite with the consideration that this location is intended as a residential, commercial and industrial area. In addition, based on the 2016 Flood Area Map released by the Jakarta Regional Disaster Management Agency, Pasar Rebo sub-district experienced flooding with a wider inundation area coverage than Jagakarsa sub-district.

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4.2 Green Infrastructure Siting Modeling

The spatial data obtained for the simulation of green infrastructure siting comprise sub-catchment map, DEM map, landcover map, land-use map, road network, drainage network, water table elevation map, hydrology soil group map and landownership map.Those are then processed in ArcGIS using the Green Infrastructure Tool Based on Location Analysis (GITBoLA).

4.3 Hydrological Analysis

a) Design storm analysis

Regional rainfall was calculated from rainfall data of the UI rain station. After calculating the average regional rainfall, then the calculation of frequency analysis was taken to determine the type of rainfall distribution and the compatibility of the frequency distribution using the Chi-square and Smirnov-Kolmogorov methods [6]. Based on frequency analysis, the distribution of Log Pearson Type III matching frequency distribution was Do (0.114) <Dcritical (0.33) for Smirnov-Kolmogorov and X2 (3,375) <Xcritical (3,841) for Chi-square. This means that the Log Pearson Type III distribution was acceptable. The results of the rainfall intensity for each return period were shown in Table I. To obtain a design storm, the daily rainfall value was changed into rainfall intensity. In this research, the rainfall hyetograph in West Java [7] was used to compute the design storm for 4 hour duration of rainfall [7] under various return periods of rainfall as shown was presented in Table II.

Table IReturn period of rainfall depth

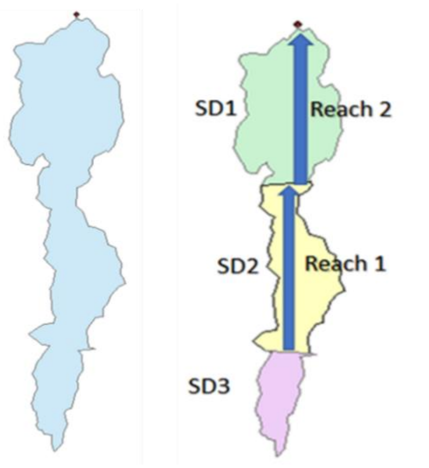
Return periods (yr)	Rain intensity (mm)
2	115.56
5	136.07
10	149.25
25	165.61
50	177.68
100	189.68

Table IIDesign storm for return period of rainfall (mm/hour)

Return periods (yr)	Rainfall depth (mm)	Rainfall distribution for duration 4 hour (mm/ho)			
		26%	61%	10%	3%
2	115.56	30.05	70.49	11.56	3.47
5	136.07	35.38	83.00	13.61	4.08
10	149.25	38.80	91.04	14.92	4.48
25	165.61	43.06	101.02	16.56	4.97
50	177.68	46.20	108.38	17.77	5.33
100	189.68	49.32	115.70	18.97	5.69

b) Sub area dividing

In order to process WinTR-55, the Cijantung sub-watershed Division was divided into 3 sub-areas and 3 reach segments as described in Fig. 6. Sub-area 1 is at the downstream of the Cijantung sub watershed, sub-area 2 is the central part and sub-area 3 is at the upstream. Pasar Rebo sub-district is a part of sub-area 1.



(a) (b)

Fig. 7Cijantung sub-watershed (a) Watershed delineation, (b) Sub area dividing

Sub-area parameters include the area, weighted CN value and time of concentration (Tc). The weighted CN value was estimated based on land cover mapping using data from the Geospatial Information Agency as shown in Table III.

Table IIISub Area parameters

Sub area (S.D)	Downstream reach	Area (km2)	Land use CN (HSG:C)	Tc (hr)
S.D 1	Outlet	11.25	90	2.17
S.D 2	Reach 2	7.98	87	2.88
S.D 3	Reach 1	3.05	88	1.88

c) WinTR-55 modeling results

Fig. 7 shows the runoff discharge hydrograph that occurred at the Cijantung Outlet for 2-year, 5-year, 10-year, 25-year, 50-year and 100-year return periods. As shown in Table IV, the peak time occurs in2.89 hour - 3 hour.

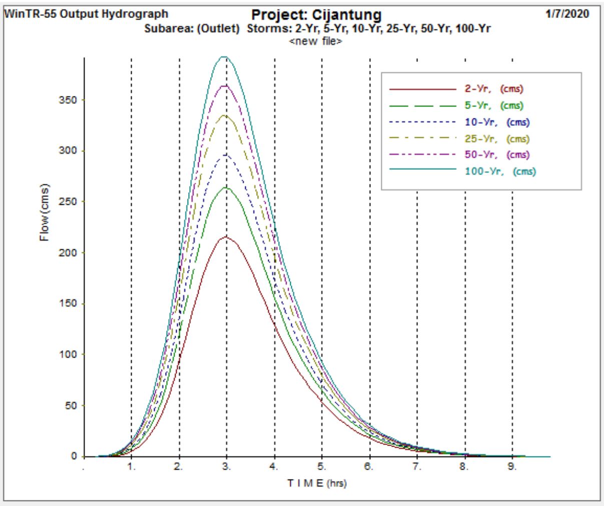


Fig. 8Runoff discharge hydrograph at the watershed Outlet

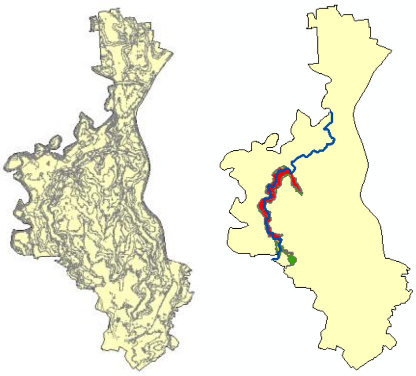
Table IVWin TR-55 Modelling Result

Return periods (year)	Runoff Volume (mm)	Peak flow (cms)	Peak time (hour)
2	84.027	215.09	2.97
5	103.58	263.75	2.94
10	116.267	295.17	2.92
25	132.103	334.36	2.9
50	143.847	363.35	2.89
100	155.553	392.44	3.00

4.4 Flood Risk Analysis

a) Flood hazard mapping

A flood hazard map was determinedby overlaying the contour map with the flooded area map during the flood event on 17 June 2016 as shown in Fig.9in Pasar Rebo sub-district. Thus, areas that prone to flooding were atthe Cijantungriverbankwhere the contour elevation is lower than +44.00.



(a) (b)

Fig. 9The process of overlaying a flood hazard area (a) a contour map, (b) a flood area map

According to the elevation of the area on the Cijantungriverbank, the flood hazard level can be mapped as shown in Fig.10.

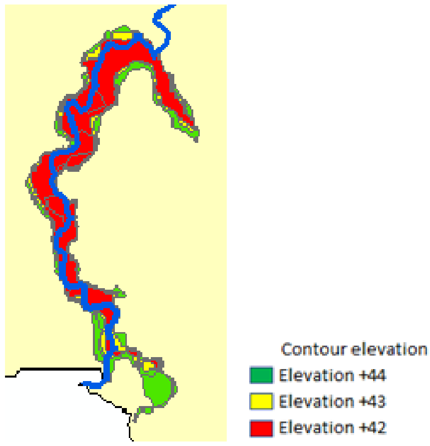


Fig. 10Flood hazard map of Cijantung riverbank

From the flood hazard map, the level of hazard can be classified as follows:

Table VClassification of flood hazard levels

Elevation	Weighted	Level of hazard
<42	3	High
42 - 44	2	Medium
>44	1	Low

b) Flood vulnerability mapping

A flood vulnerability map was created by overlaying a contour map with a land cover map. According to the overlaid map, types of land cover on the area below +44.00 are identified as built-up land, gardens or plantations and vacant land.

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Determination of the level of vulnerability by weighting the land cover with the assumption that land cover that potential to experience greater damage and losses classified as higher vulnerability, and vice versa. Thus, the built-up land was considered to have the greatest loss and damage compared to other types of land cover. The results of flood-vulnerabilityweighting are shown in Fig. 11. From this map, the level of vulnerability can be classified as shown in Table VI.

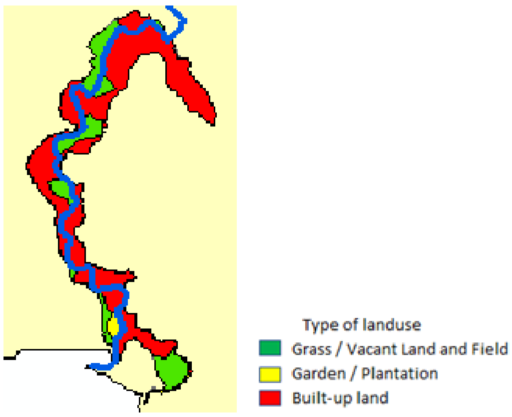

Fig. 11Flood vulnerability map of Cijantung river bank

Table VIClassification of flood vulnerability level

Type of Land use	Weighted	Level of Vulnerability
Built-up land	3	High
Garden/ plantation	2	Medium
Grass/ vacant land and field	1	Low

c) Flood risk mapping

A flood risk map was made by calculating the multiplication between the weight of the flood hazard level (Table V) and the weight of the flood vulnerability level (Table VI). Calculations like this made it easier to classify risk classes. The classification results are presented in Table VII and a map of flood risk levels is shown in Fig.12.

Table VIIFlood Risk Classification

			Level of vulnerability		
			Low	Medium	High
			1	2	3
Level of hazard	Low	1	1	2	3
	Medium	2	2	4	6
	High	3	3	6	9

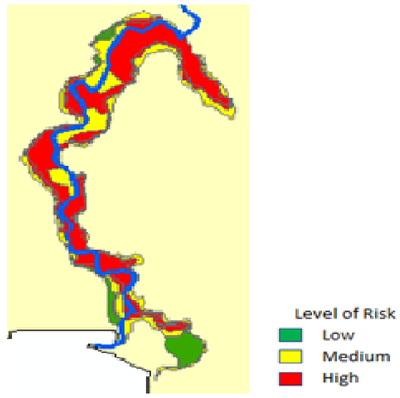

Fig. 12Flood risk map of Cijantung river bank

4.5 Potential flood mitigation activities

Flood mitigation actions with structural measure can be carried out,for instance, with the construction of detention ponds, dredging and cliff reinforcement This research propose on the detention or retention pond plan that can be built in flood prone areas in Pasar Rebo sub-district. The challenge in making detention or retention ponds is the need for large enough area to accommodate the runoff volume so that it will require a very large cost for land acquisition. To minimize the land acquisition budget, it is necessary to avoid residential areas as detention or retention ponds. Therefore, vacant lands are potential to be used as a detention or retention pond as shown in Fig.13.

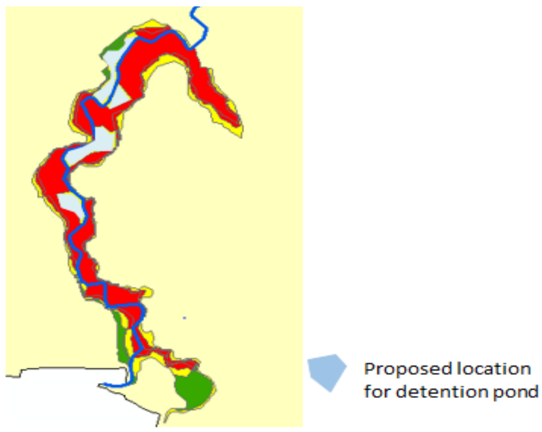

Fig. 13Potential location for detention/ retention pond

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4.6 Detention or retention pond capacity planning

This detention or retention pond design took the standard city drainage planning with the 25-year return periods based on the typology of the city and the catchment area. To find the magnitude of the required storage volume (V_s), then use Table IV, where the runoff discharge for 25-year return period (Q_p) is 334.36 cms, runoff volume (V_r) is 132.03 mm (2,943,255 m3) and peak time (t_p) of 2.9 hours.

Thus, the calculation of required pond storage to reduce 30% of peak discharge (Q_A=70%Q_p), as follows:

$$t_b = 2 * 2.9 - \frac{0.05 * 334.36}{334.36} = 5.75\ hour$$

$$Q_A = 70\% Q_P = 234.05\ cms$$

$$\frac{V_s}{V_r} = 1.29 \frac{\left(1 - \frac{Q_A}{Q_p}\right)^{0.153}}{\left(\frac{t_b}{t_p}\right)^{0.411}}$$

$$\frac{V_s}{2.943.255} = 1.29 \frac{\left(1 - \frac{234,05}{334,36}\right)^{0.153}}{\left(\frac{5.75}{2.9}\right)^{0.411}} = 0,809$$

$$V_s = 0,809 * 2,943,255 = \ 2,383,632.21\ m^3$$

The potential area of detention/ retention pond was 0.0637 km^2 and was able to accommodate runoff volume of 154,350 m^3, with a pond depth of 2.75 m including a 30-cm-high freeboard.

V. CONCLUSION

This paper is a preliminary researchthat proposes methodology for evaluating theeffectiveness and efficiency of green infrastructure siting plan on existing water infrastructure system in Jakarta’s urban spatial detail planning scale of 1:5000. The initial results for this research are Pasar Rebo sub district as a selected research site, risk mapping shows the built up lands have the highest risk while vacant lands have the lowest, runoff simulation gives peak discharge (Qp) by 334,36 cms and peak volume (Vr) by 132,03 mm (2.943.255 cubic-meters), and the 6.3 hectares of vacant lands are potential for detention pond that can accommodate runoff volume of 154,350 cubic-meters. The observation indicates that the methodology is feasible to proceed. The next research will use a GIS-based modeling for green infrastructure siting tools and SWMM to simulate for rainfall runoff analysis.

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