The 1st International Conference on Business and Management of Technology (IConBMT)
August 3rd 2019, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

Application of Bio-pore Infiltration Hole as an Urban Runoff Management

Searphin Nugroho[1] and Wahyono Hadi[1]

Abstract*—The application of bio-pore infiltration holes (BIH) can be one solution for urban runoff management by reducing surface runoff to the ground. But, the difference in soil types and characteristics could affect the runoff reduction that can be achieved by BIH. This research aims to determine the runoff reduction can be achieved by bio-pore infiltration hole (BIH) from different soil types and conditions. The methods in this study mainly focus on hydraulic conductivity calculations using Porchet method and the implementation of Minister of Environment Regulation Numb. 12/2009 for the BIH installations. Based on the implementation of Minister of Environment Regulation Numb. 12/2009, the required BIHs for the area of 500 m2 are 1,000, both for silt and clay soils. The runoff reductions that can be achieved with the application of BIHs are 38.98 - 95.73% for silt soils and 20.67 - 54.28% for clay soils, depends on the soil conditions.

***Keywords*—Bio-Pore Infiltration Hole, Runoff Reduction, Soil Types.**

I. INTRODUCTION

Urban areas developments that caused by the development of population, can potentially threaten natural dynamics, resource availability and environmental quality [1]. The decreased pervious areas in urban areas result in increased surface runoff and potentially caused flood and inundation [2]. In general, drainage is the most feasible and economical solution for managing surface runoff by diverting it as quickly as possible [3]. However, the conventional drainage concept is less effective to use in the long term because it has to be gradually expanded over time and requires a large amount of money, as well as designs that pay less attention to water quality [4]. Thus, a new concept of the drainage system is introduced called a sustainable urban drainage system (SUDS) [5]. This system is utilizing some portion of urban landscapes like vegetated land surfaces to replicate the natural hydrological cycle process [6]. The purposes of this system is to encourage infiltration of stormwater to the ground, filtering the pollutants from source, and also temporarily storing water [7].

Bio-pore infiltration holes (BIH) is a one of a kind of SUDS that can be one solution for urban runoff management by reducing surface runoff to the ground, and it is widely implemented because the required costs for the installations are affordable [8]. Nevertheless, the soil types and characteristics in an area are not exactly same as other location, even though it is in a city [9], and this means the permeability of soils are also different from one and the other. Thus, the application of BIH may have various results in terms of runoff reduction. The main objective of this study is to determine the runoff reduction can be achieved by BIH application from different soil types and conditions.

II. LITERATURE REVIEW

A. Sustainable Urban Drainage System

Sustainable urban drainage system (SUDS) is promoted as the main focus in urban development, especially for the water resource management in cities by using urban landscapes to provide spatial amenities and have ecological functions that facilitate hydrological processes [6]. It is because water quality has become an important key for the design of urban drainage, as a result of a wider political recognition of sustainability [5].

The aims of this concept on runoff or stormwater management mainly to reduce the quantity of runoff through source control and to slow the velocity of runoff. It also can be used to improve the quality of stormwater by providing passive treatment, and to enhance amenity and maintain biodiversity [4].

B. Bio-pore Infiltration Hole

Bio-pore infiltration holes (BIH) is one of the concepts for water conservation (rainwater harvesting) by storing some portion of surface runoff or stormwater to the ground, especially in the raining season [10]. This concept can be called as a part of sustainable urban drainage system mainly because it has the same aim, to reduce the quantity of runoff [8].

BIH has some set of criteria, mainly it is preferred to be installed in the settlement, park, parking area, around the tree(s), or in the area where the surface runoff flows through. It is created as a cylindric form in the ground with a diameter of 10 cm and the depth of 100 cm or not overlapping with the groundwater level. The gap between BIHs is also set between 50 – 100 cm. Sometimes, it needs to be strengthened by using a casing made from PVC pipe to prevent the collapse inside the hole [10].

[1]Searphin Nugroho and Wahyono Hadi are with Departement of Environmental Engineering, Institut Teknologi Sepuluh Nopember, 60111, Indonesia. E-mail: searphin91@gmail.com; wahyonohadi@yahoo.com.

III. METHODS

A. Preparation Stage

In this stage, it consists initial data collection, field surveys, soil compacting, and creating BIH. The required data for this study were the soil type map, rainfall height and intensity of Surabaya City from their respective city departments. Those data are used as the basis for surveying and determining some locations at Surabaya that will be used as field tests, especially for BIH tests. The chosen locations for this study are Kenjeran Beach Amusement Park and Lempung Urban Forest, Surabaya, that can be seen in **Figure 1**. Some soil were sampled from those locations to be tested in laboratorium to determine their texture soil class. Each of the locations will be divided into 4 test plots, where the conditioning on each plot described in **Table 1**.

Four out of eight areas will be compacted by stamper with durations around 30 seconds based on Gregory et al. [11]. Then, BIH will be constructed in every test plots by boring it using auger hand bore with the sizes of the hole about 10 cm of diameter and 100 cm of depth. After that, that hole will be covered using a pored casing pipe with the same size as the hole.

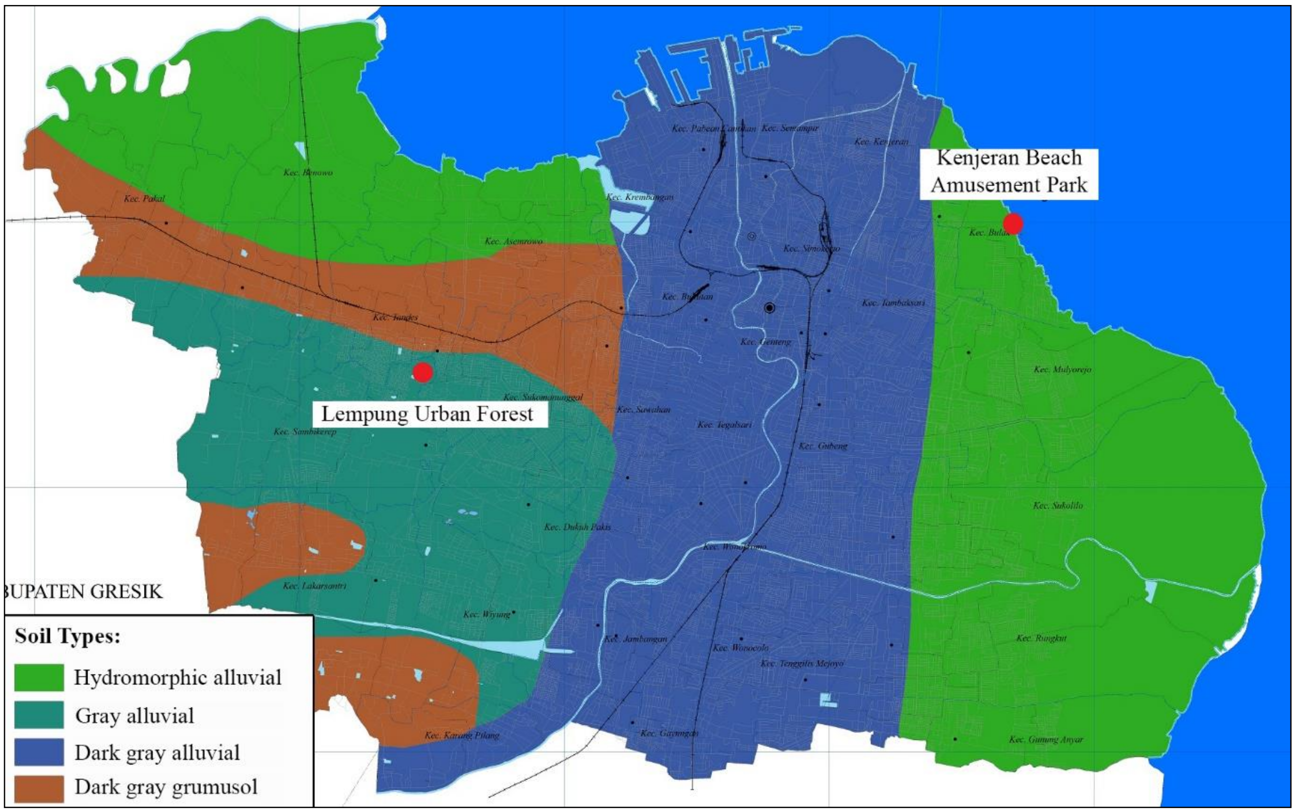

Figure 1. Test field locations on map of soil types at Surabaya City

TABLE 1.
COONDITIONING ON EACH TEST PLOTS

Numb	Location	Plot Conditioning		Plot code
		Vegetation	Compaction	
1	Kenjeran Beach Amusement Park	✓	-	K1
		✓	✓	K2
		-	-	K3
		-	✓	K4
2	Lempung Urban Forest	✓	-	L1
		✓	✓	L2
		-	-	L3
		-	✓	L4

B. Research Stage

This stage comprising the infiltration rate and hydraulic conductivity measurements along with calculations of hydraulic conductivity, BIH flowrate, rainfall heights and durations, and runoff coefficients from plot tests. Infiltration rate measurement conducted at every test plots by using single-ring infiltrometer. Hydraulic conductivity measured by using inverse auger hole method [12], [13], with some small modification, which single-ring infiltrometer and ruler are used to measure surface water level changes instead of using measurement tape. Water will be added to the system and maintained in the same water level after it changes in several minutes. Measurement will be stopped if changes in the surface water level of the system remain the same after the last three tries.

The calculation of hydraulic conductivity conducted by using Porchet method from all gathered data measurements in the field. The equation for calculating hydraulic conductivity is as follows:

$$K = \frac{D}{4} \times \frac{\ln\left(h_0 + \frac{D}{4}\right) - \ln\left(h_t + \frac{D}{4}\right)}{t} \qquad (1)$$

Equation 1 can be modified to determining the water flowrate into the hole as follows:

$$Q = K.\pi.D\left(h_{BIH} + \frac{D}{4}\right) \qquad (2)$$

where Q is the BIH's water flowrate; K is hydraulic conductivity; h_{BIH} is the depth of BIH; h_0 is the initial surface water level; h_t is the constant surface water level; t is time; and D is the diameter of BIH.

From the calculations of hydraulic conductivity, it will be compared to the permeability classes from Natural Resource Conservation Service (NRCS), USA [14]. From these comparisons, the ability of the bio-pore infiltration holes to infiltrate and percolate the water from surface can be determined.

Meteorological data such as rainfall height in last 10 years and rainfall intensity in last 13 months gathered from nearest weather station, are used to determine the average value of each data and to calculate runoff coefficient from each test plot along with infiltration rate measurement on the field of study and depression loss values from UDFCD (Urban Drainage Flood Control District, USA) [15]. Based on Guo and Urbonas, the calculation of runoff coefficient is done by using some equations [16] which can be reviewed below:

1. The equation for calculating the rainfall volume is as follows:

$$V_P = PA \qquad (3)$$

2. The equation for calculating the runoff volume is as follows:

$$V_R = (P - D_L - F)\,A \qquad (4)$$

3. The equation for calculating the runoff coefficient is as follows:

$$C = \frac{V_R}{V_P} \qquad (5)$$

4. The **Equation 5** above can be modified to calculate the runoff volume as follows:

$$V_R = V_P.C \qquad (6)$$

where V_P is rainfall volume; V_R is runoff volume; P is the rainfall height; D_L is the depression losses; F is the infiltration height; A is the area of assumed watershed; and C is the runoff coefficient.

C. Analysis Stage

In this analysis, the analysis of runoff reduction from different soil types and conditions is conducted with the calculation of BIH application in the assumed area of 2,000 m^2 which consists of 75% impervious area and the rest is the pervious area. The impervious area is assumed to have a runoff coefficient value of 0.83 [17], and it has a sloppy surface that lean towards to the pervious area. Also, the pervious areas will be adjusted to the characteristics of plot tests. This analysis also includes the implementation of BIH installation based on Minister of Environment Regulation Number 12/2009. In this regulation, it states about the distance required between bio-pores, so it is assumed that the maximum number of BIH can be installed every 1 m^2 area is two pieces.

The equation that can be used to calculate the remaining surface runoff after the application of BIHs is as follows:

$$V_{R\,rem} = V_{R\,in} - [V_{BIH} \times (2.A)] \qquad (7)$$

As for the calculation of the percentage of runoff reduction that can be achived with the application of BIHs, it can be done with using the **Equation 8** as follows:

$$\%\ Runoff\ reduction = \frac{(V_{R\,in} - V_{R\,rem})}{V_{R\,in}} \times 100\% \qquad (8)$$

where $V_{R\,rem}$ is the volume of remaining surface runoff; $V_{R\,in}$ is the volume of initial surface runoff; $V_{R\,BIH}$ is the volume of bio-pore infiltration hole; and A is the area of the assumed watershed.

IV. Results and Discussion

A. Soil Texture of Test Fields

In this study, there are two sites to be tested, namely Kenjeran Beach Amusement Park and Lempung Urban Forest. These two sites are located on different types of soil based on the map of Surabaya's soil type, where the Kenjeran Beach Amusement Park belongs to the hydromorphic alluvial type, while in the Lempung Urban Forest area it belongs to the type of gray alluvial soil.

In reality, the soil conditions in both locations are landfilled soil, where the landfill covers the original soil surface. The soil in the Kenjeran Beach Amusement Park is a combination of silt loam-textured soil on its surface with padas pile at the bottom, while in the Lempung Urban Forest the clay is in the form of native land originating from the excavation of *boozem* (detention pond) around the forest. For the particle composition of the soil sampled can be seen in **Table 2**.

Based on **Table 2**, from the results of laboratory analysis, the soil sampled from the study site was dominated by fine-sized particles, where the soil in Kenjeran Beach Amusement Park was dominated by silt particles with the range around 64.026 – 81.456%, while Lempung Urban Forest was dominated by clay particles with the range around 56.643 – 61.362%. For its soil texture, the soil in Kenjeran Beach Amusement Park was classified as silt loam texture, while Lempung Urban Forest was classified as clay texture.

B. Hydraulic Conductivity and BIH Water Flowrate of Test Fields

Based on the field measurements of the decreased surface water level in the BIHs on test fields, the value of the hydraulic conductivity are determined using Porchet method using **Equation 1**. The results of the hydraulic conductivity calculation can be seen on the **Table 3**.

From the **Table 3** above, it can be seen that the plots with silt soil have a higher hydraulic conductivity with the plots with clay soils. In terms of the soil conditioning, the highest value of hydraulic conductivity are found in vegetated plots (K1 and L1). Then, followed by unconditioned plots (K3 and L3), compacted vegetation plots (K2 and L2), and only compacted plots (K4 and L4).

For the plots located in Kenjeran Beach Amusement Park or the silt soils, the highest hydraulic conductivity value is in the K1 plot with vegetated soil about 20.89 cm/hr. Then, it followed by the K3 plot with no conditioning on the soil about 16.88 cm/hr, the K2 plot with vegetated dan compacted soil about 10.91 cm/hr, and the K4 plot with compacted soil about 8.88 cm/hr. As for the plots located in Lempung Urban Forest or the clay soils, it followed the same trends as in previous location. The highest hydraulic conductivity value is in the L1 plot with vegetated soil about 12.39 cm/hr.

TABLE 2.
SOIL TEXTURE OF THE TEST FIELDS

Plot	Soil Texture	Gravel (%)	Sand (%)	Silt (%)	Clay (%)
K1	Silt loam (0-25 cm) Landfill (26-100 cm)	0.011	0.12	76.242	23.627
K2	Silt loam (0-25 cm) Landfill (26-100 cm)	0.167	4.707	74.428	20.698
K3	Silt loam (0-30 cm) Landfill (31-100 cm)	5.387	13.96	64.026	16.627
K4	Silt loam (0-30 cm) Landfill (31-100 cm)	0.423	1.843	81.456	16.278
L1	Clay (0-100 cm)	0.284	20.308	19.376	60.031
L2	Clay (0-100 cm)	0.98	31.285	11.092	56.643
L3	Clay (0-100 cm)	0.713	14.759	23.166	61.362
L4	Clay (0-100 cm)	0.709	27.051	11.276	60.964

TABLE 3.
THE CONSTANT HYDRAULIC CONDUCTIVITY AND WATER FLOWRATE OF BIH FROM TEST PLOTS

Test plot	Soil type	Soil conditioning	K (cm/hr)
K1	Silt	Vegetated	20.89
K2		Vegetated and compacted	10.91
K3		No conditioning	16.88
K4		Compacted	8.88
L1	Clay	Vegetated	12.39
L2		Vegetated and compacted	5.40
L3		No conditioning	10.85
L4		Compacted	4.75

Then, it followed by the L3 plot with no conditioning on the soil about 10.85 cm/hr, the L2 plot with vegetated dan compacted soil about 5.40 cm/hr, and the L4 plot with compacted soil about 4.75 cm/hr.

Overall, from all test plots, the highest hydraulic conductivity value is on the K1 plot with silty and vegetated soil about 20.89 cm/hr. Meanwhile the smallest one is L4 plot with clayey and compacted soil about 4.75 cm/hr.

After that, the hydraulic conductivity values are classified based on permeability class from from Natural Resource Conservation Service (NRCS), USA. The classification of hydraulic conductivity from the eight test plots based on permeability class can be seen in **Table 4**.

TABLE 4.
THE CONSTANT HYDRAULIC CONDUCTIVITY CLASSIFICATION FROM TEST PLOTS

Test plot	K (cm/hr)	Class
K1	20.89	Moderately rapid
K2	10.91	Moderately rapid
K3	16.88	Moderately rapid
K4	8.88	Moderately rapid
L1	12.39	Moderately rapid
L2	5.40	Moderately rapid
L3	10.85	Moderately rapid
L4	4.75	Moderate

From **Table 4**, by reviewing the hydraulic conductivity of the eight test plots based on the permeability class, it can be seen that the four plots found in the Kenjeran Beach Amusement Park (K1, K2, K3, and K4) are in the "moderately fast" class range. As for test plots in Lempung Urban Forest, it is included in the class range from moderately fast to moderate. L1, L2, and L3 plots belong to the "moderately fast" class, while the L4 plot is classified in the moderate class.

Based on the classification, it can be concluded that the soils in those locations have a quite good permeability. It can be used or utilized for rainwater harvesting with the application of bio-pore infiltration hole, and can become a decent urban runoff management.

After that, the hydraulic conductivity value is used to calculate the water flow rate of bio-pore infiltration hole. As for the results of the water flowrate of bio-pore infiltration hole calculation can be seen on the **Table 5**.

TABLE 5.
THE WATER FLOWRATE OF BIH FROM TEST PLOTS

Test plot	Soil type	Soil conditioning	Q (cm^3/hr)
K1	Silt	Vegetated	67,285.21
K2		Vegetated and compacted	35,145.91
K3		No conditioning	54,392.61
K4		Compacted	28,591.34
L1	Clay	Vegetated	39,919.33
L2		Vegetated and compacted	17,384.65
L3		No conditioning	34,962.89
L4		Compacted	15,291.22

From the **Table 5** above, it can be seen that the plots with silt soil have a higher flowrate compared with the plots with clay soils. In terms of the soil conditioning, the highest value of the flowrate of BIH are found in vegetated plots (K1 and L1). Then, followed by unconditioned plots (K3 and L3), compacted vegetation plots (K2 and L2), and only compacted plots (K4 and L4).

For the plots located in Kenjeran Beach Amusement Park or the silt soils, the highest flowrate of BIH is found in the K1 plot with vegetated soil about 67,285.21 cm^3/hr. Then, it followed by the K3 plot with no conditioning on the soil about 54,392.61 cm^3/hr, the K2 plot with vegetated dan compacted soil about 35,145.91 cm^3/hr, and the K4 plot with compacted soil about 28,591.34 cm^3/hr. As for the plots located in Lempung Urban Forest or the clay soils, it followed the same trends as in previous location..

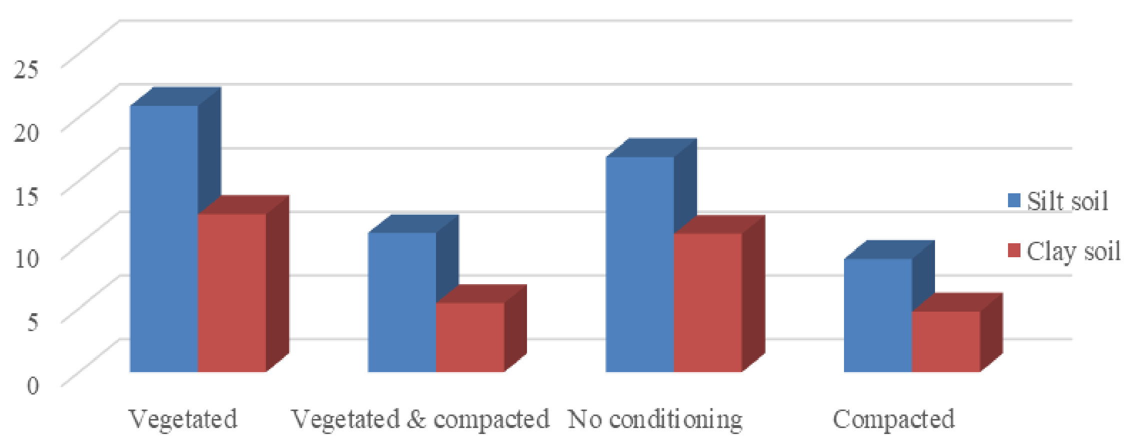

Figure 2. Hydraulic conductivity value from test plots

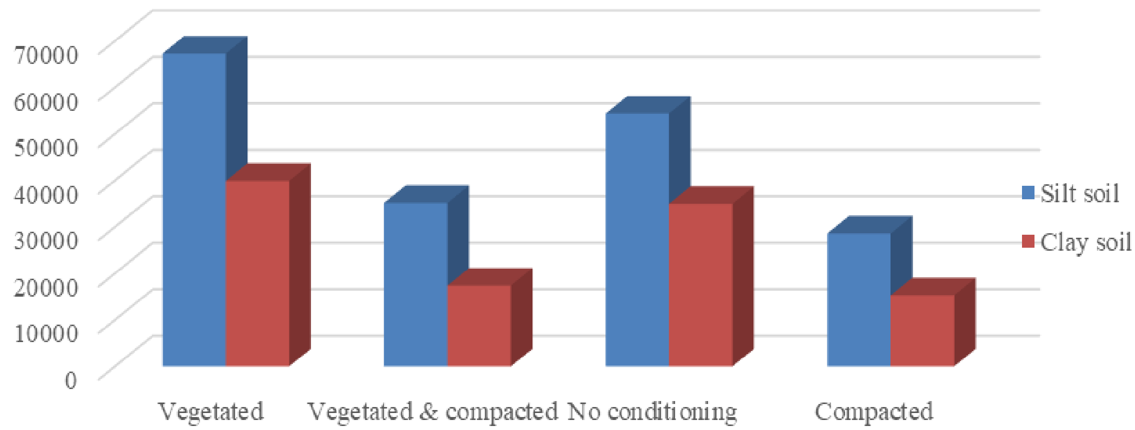

Figure 3. Water flowrate of bio-pore infiltration holes from test plots

The highest flowrate of BIH is found in the L1 plot with vegetated soil about 39,919.33 cm^3/hr. Then, it followed by the L3 plot with no conditioning on the soil about 34,962.89 cm^3/hr, the L2 plot with vegetated dan compacted soil about 17,384.65 cm^3/hr, and the L4 plot with compacted soil about 15,291.22 cm^3/hr

Overall, from all test plots, the water flowrate of BIHs are have a linear correlation with the hydraulic conductivity value, with the highest flowrate is plot K1 about 67,285.21 cm^3/hr and the smallest one is plot L4 about 15,291.22 cm^3/hr. The visualization of hydraulic conductivity and water flowrate of bio-pore infiltration hole from test plots can be seen in **Figure 2** and **Figure 3** respectively.

C. Runoff Coefficients of Test Plots

The average of rainfall height in the last 10 years and rainfall duration in the last 13 month calculated by data from nearest weather stations at Surabaya City are 99.61 mm and 2.28 hours, respectively.

Infiltration rate measurement is conducted to determine the constant infiltration rate from each test plot. After that, those data will be multiplied with average rainfall duration at Surabaya City to find the constant infiltration height. The result of measurements and infiltration height calculations can be seen at **Table 6**.

TABLE 6.
THE CONSTANT INFILTRATION RATE AND HEIGHT FROM TEST PLOTS

Test plot	*f* (mm/hr)	F (mm)
K1	8.000	18.24
K2	1.999	4.5372
K3	1.999	4.5372
K4	1.333	3.03997
L1	1.500	3.42
L2	0.125	0.285
L3	1.000	2.28
L4	0.0625	0.1425

From **Table 6**, it can be seen that test plot with the highest constant infiltration rate is K1 plot with silty and vegetated soil about 8.000 mm/hr. Meanwhile the smallest one is on the L4 plot with clayey and compacted soil about 0.0625 mm/hr. It also correlates with the infiltration height from each plot test. Using the average rainfall duration data, the highest infiltration height with the rainfall duration around 2.28 hr is plot K1 about 18.24 mm/hr and the smallest one is plot L4 about 0.1425 mm/hr. Generally, the plots with silt soil have a higher constant infiltration rate and infiltration height compared with the plots with clay soils.

In terms of the soil conditioning, the highest value of constant infiltration rate and infiltration height are found in vegetated plots (K1 and L1). Then, followed by unconditioned plots (K3 and L3), compacted vegetation plots (K2 and L2), and only compacted plots (K4 and L4).

Based on test plot conditions, using UDFCD guideline book, the depression losses value for every vegetated soil are 0.35 in or 8.89 mm and 0.4 in or 10.16 mm for bare soils [15]. The runoff coefficient of each test plot can be calculated together from all those data above, along with the calculation of infiltration height, rainfall height and rainfall duration. For the result of runoff coefficient calculation can be seen in **Table 7**.

TABLE 7.
THE RUNOFF COEFFICIENT OF TEST PLOTS

Plot	F (mm)	D_L (mm)	(P-D_L-F) (mm)	V_R (m^3)	C
K1	18.24	8.89	72.48	0.07248	0.727638
K2	4.5372	8.89	86.1828	0.086183	0.865202
K3	4.5372	10.16	84.9128	0.084913	0.852453
K4	3.03997	10.16	86.41003	0.08641	0.867483
L1	3.42	8.89	87.3	0.0873	0.876418
L2	0.285	8.89	90.435	0.090435	0.907891
L3	2.28	10.16	87.17	0.08717	0.875113
L4	0.1425	10.16	89.3075	0.089308	0.896572

TABLE 8.
THE RUNOFF REDUCTIONS BY BIH FROM EACH SOIL TYPES AND CONDITIONS

Plot	Soil types	Conditons	V_R in (m^3)	V_{BIH} (m^3)	Number of BIHs	V_R rem (m^3)	Runoff reductions
K1	Silt	Vegetated	160.25	0.15341	1,000	6.84	95.73%
K2	Silt	Vegetated and compacted	167.11	0.08013	1,000	86.97	47.95%
K3	Silt	No conditioning	166.47	0.12402	1,000	42.46	74.50%
K4	Silt	Compacted	167.22	0.06519	1,000	102.03	38.98%
L1	Clay	Vegetated	167.66	0.09102	1,000	76.65	54.28%
L2	Clay	Vegetated and compacted	169.23	0.03964	1,000	129.60	23.42%
L3	Clay	No conditioning	167.60	0.07972	1,000	87.88	47.56%
L4	Clay	Compacted	168.67	0.03486	1,000	133.80	20.67%

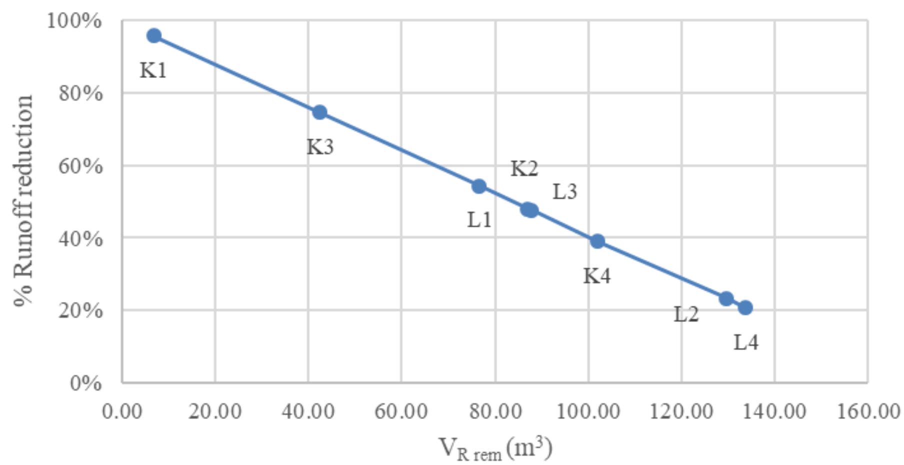

Figure 4. The correlation between V_R rem and percentage of runoff reduction

Based on **Table 7** data, the range of runoff coefficient (C) from each soil type are quite different, and the runoff coefficient of silt soils are lower compared to the clay soils. For the plots with silt soil, the value of C ranges from 0.728 – 0.867. Meanwhile, at the plots with clay soil, the range is a bit closer compared to the silty ones. The value of C in those location ranges from 0.876 – 0.908. This may related to the infiltration height from each sites. At Kenjeran Beach Amusement Park with silt soils, the infiltration height range between its plots in there (K1, K2, K3 and K4) are quite wide compared to those in Lempung Urban Forest with clay soil. The infiltration height on silt soil ranges from 3.039 – 18.24 mm, while on the clay soil it ranges from 0.143 – 3.42 mm.

The plot that generates the highest runoff is the L2 plot with clay-textured, vegetated and compacted soil at 0.090435 m^3, while the plot with the lowest runoff volume is on K1 plots with silt-textured and vegetated soil by 0.07248 m^3. The same trends also happened with the runoff coefficient. The plot that has the biggest runoff coefficient value is the L2 plot with 0.907891, while the plot with the lowest runoff coefficient value is on K1 plot with 0.727638.

D. Analysis of The Runoff Reduction from Bio-pore Infiltration Hole Application

Based on the implementation of Minister of Environment Regulation Numb. 12/2009, maximum number of BIH installed in the area of 1 m^2 is two pieces. From the assumed area of 2,000 m^2 and only 25% from it or 500 m^2, that can be used for the application of BIH. Thus, the BIHs required in an area of 500 m^2 are 1,000, both for silt and clay soils.

With including all calculations of BIH's flowrate, rainfall height, rainfall duration, runoff coefficient, along with other assumptions mentioned in the methods sections, the number of runoff reduction can be achieved from assumed areas can be seen in **Table 8**.

From **Table 8**, with the implementation of BIHs based on the Minister of Environment Regulation Numb. 12/2009, silt-type soils can reduce surface runoff greater than clay type soils. The percentage of surface runoff reduction for silt-type soils ranges from 38.98 - 95.73%, depending on the treatment of the soil, both the influence of soil compaction and or vegetation cover. In clay-type soils, the percentage of surface runoff reduction ranged from 20.67 - 54.28%.

The soil conditioning that has the highest runoff reduction is found in the vegetated soil (plots K1 and L1), then followed by unconditioning soil (plots K3 and L3), soils with variations in combinations of compaction and vegetation (plot K2 and L2), and only compacted land (plots K4 and L4). This is related to the ability of recharge by the BIH of each land condition, where land whose soil is compacted tends to reduce the absorption of water [11] and land that has vegetation cover tends to increase water absorption [18]. For the effect of soil compaction, this confirmed with the previous study by Gregory et al. Compaction affects the physical properties of the soil while reducing the porosity and pore distribution in the soil [11]. As for the influence of vegetation cover, this was confirmed by Gadi et al. that higher vegetation density in the soil results in higher hydraulic conductivity value [18].

The variable combination of vegetation cover with soil compaction (K2 and L2) has a greater water absorption than the soil which is only compacted (K4 & L4), but not greater than the land that is not given any treatment (K2 and L2). Thus, the greater the absorbency of the water, the more runoff can be reduced.

The type of land that can reduce the biggest runoff after the BIH installation is the land with K1 plot characteristics with silt textured soil conditions, with vegetation cover and not compacted at 95.73%. While the land that can reduce runoff or lowest runoff after the BIH installation is the land with L4 plot characteristics with clay, compacted and non-vegetated soil conditions of 20.67%. This also correlates with the remaining surface runoff voulme ($V_{R\ rem}$) from each soil characteristics, where the value of $V_{R\ rem}$ has a negative correlation with the runoff reduction, which can be seen in **Figure 4**. The higher the runoff reduction, the value of $V_{R\ rem}$ becomes more lower, and vice versa. The lowest $V_{R\ rem}$ is happened in the land with K1 plot characteristics about 6.84 m^3, while the highest $V_{R\ rem}$ is happened in the land with L4 plot characteristics about 133.80 m^3.

Because the compaction was only based on the duration and only have two variations between compacted and non-compacted soils, potentially the soils are not compacted enough or have a low degree of compaction. Thus, the area needed for BIH installation and the amount of BIH may be higher on the land or soil with higher degree of compaction for reducing the surface runoff or stormwater, especially in big cities with high land uses and in the tropical climate.

V. Conclusion

The result of the study shows that with the implementation of Minister of Environment Regulation Numb. 12/2009, silt soils have higher runoff reductions compared to the clay soils, if it is compared with the same soil conditions. Overall, runoff reductions that can be achieved with the application of this regulation are 38.98 - 95.73% for silt soils and 20.67 - 54.28% for clay soils. As for the soil conditioning, the highest runoff reduction is achieved in the vegetated soil, then followed by unconditioning soil, combination of compaction and vegetation on soil, and only compacted land. However, this may be only applicable to the land or area that not have a high degree of compaction because the compaction variables were not on the wide range. And, that possibility requires further research.

Acknowledgement

I would like to express my gratitude to my supervisor, Prof. Ir. Wahyono Hadi, M.Sc., Ph.D., for his constructive critics, advices, and support on this project on the topic "Application of Bio-pore Infiltration Hole as an Urban Runoff Management", which also helped me in doing a lot of research and I came to know about so many new things that I never experienced before. Secondly, I would also like to thank my parents and friends who helped me a lot in finalizing this project within the limited time frame.

References

[1] S. J. McGrane, "Impacts of urbanisation on hydrological and water quality dynamics, and urban water management: A review," *Hydrol. Sci. J.*, vol. 61, no. 13, pp. 2295–2311, Oct. 2016.

[2] C. Apollonio, G. Balacco, A. Novelli, E. Tarantino, and A. F. Piccinni, "Land use change impact on flooding areas: The case study of Cervaro Basin (Italy)," *Sustainability*, vol. 8, no. 10, pp. 1–18, 2016.

[3] M. Boller, "Towards sustainable urban stormwater management," in *Water Science and Technology: Water Supply*, 2004, vol. 4, no. 1, pp. 55–65.

[4] P. Mguni, L. Herslund, and M. B. Jensen, "Sustainable urban drainage systems: examining the potential for green infrastructure-based stormwater management for Sub-Saharan cities," *Nat. Hazards*, vol. 82, no. Supplement 2, pp. 241–257, Jun. 2016.

[5] Q. Zhou, "A review of sustainable urban drainage systems considering the climate change and urbanization impacts," *Water*, vol. 6, no. 4. MDPI AG, pp. 976–992, 2014.

[6] L. Liu and M. B. Jensen, "Green infrastructure for sustainable urban water management: Practices of five forerunner cities," *Cities*, vol. 74, pp. 126–133, Apr. 2018.

[7] L. Hoang and R. A. Fenner, "System interactions of stormwater management using sustainable urban drainage systems and green infrastructure," *Urban Water J.*, vol. 13, no. 7, pp. 739–758, Oct. 2016.

[8] M. Anggraeni, G. Prayitno, S. Hariyani, and A. Wahyuningtyas, "The effectiveness of bio-pore as an alternative eco drainage technology to control flooding in Malang City (case study: Metro Sub-Watershed)," *J. Appl. Environ. Biol. Sci.*, vol. 3, no. 2, pp. 23–28, 2013.

[9] T. H. Phillips, M. E. Baker, K. Lautar, I. Yesilonis, and M. A. Pavao-Zuckerman, "The capacity of urban forest patches to infiltrate stormwater is influenced by soil physical properties and soil moisture," *J. Environ. Manage.*, vol. 246, pp. 11–18, Sep. 2019.

[10] PerMen Lingkungan Hidup, *No. 12 Th. 2009, tentang Pemanfaatan Air Hujan*. .

[11] J. H. Gregory, M. D. Dukes, P. H. Jones, and G. L. Miller, "Effect of urban soil compaction on infiltration rate," *J. Soil Water Conserv.*, vol. 61, no. 3, pp. 117–124, 2006.

[12] J. W. van Hoorn, "Determining hydraulic conductivity with the inversed auger hole and infiltrometer methods," in *25th International Drainage Workshop*, 1979.

[13] M. Noshadi, H. Parvizi, and A. R. Sepaskhah, "Evaluation of different methods for measuring field saturated hydraulic conductivity under high and low water table," *Vadose Zo. J.*, vol. 11, no. 1, Feb. 2012.

[14] P. J. Schoeneberger, D. A. Wysocki, E. C. Benham, and Soil

Survey Staff, *Field Book for Describing and Sampling Soils, Version 3.0*. Lincoln, Nebraska: Natural Resources Conservation Service, National Soil Survey Center, 2012.

[15] Urban Drainage and Flood Control District, *Urban Storm Drainage Criteria Manual: Volume 1 – Management, Hydrology, and Hydraulics*. Denver: Urban Drainage and Flood Control District, 2016.

[16] J. C. Y. Guo and B. Urbonas, “Volume-based runoff coefficients for urban catchments,” *J. Irrig. Drain. Eng.*, vol. 140, no. 2, 2014.

[17] N. Dhakal, X. Fang, T. G. Cleveland, D. B. Thompson, W. H. Asquith, and L. J. Marzen, “Estimation of volumetric runoff coefficients for texas watersheds using land-use and rainfall-runoff data,” *J. Irrig. Drain. Eng.*, vol. 138, no. 1, pp. 43–54, Apr. 2011.

[18] V. K. Gadi *et al.*, “Spatial and temporal variation of hydraulic conductivity and vegetation growth in green infrastructures using infiltrometer and visual technique,” *Catena*, vol. 155, pp. 20–29, Aug. 2017.