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FLOOD MITIGATION EFFORTS IN THE CAPITAL REGION OF JAKARTA

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Abstract

A flood is a disaster with such highly negative impacts on the loss of life and property that it has to be mitigated. In this regard, the present research aims to: measure the rainfall volume that causes flood and analyze the efforts of reducing the flood volume caused by rainfall in the Region of Jakarta. An experimental method was applied to measure rainfall and run-off volumes stored in infiltration wells. The research was conducted in the following stages: analyzing land use and analyzing rainfall and surface runoff volumes. We found that changes in land cover negatively affect the land's ability to absorb rainfall. Land cover formed by vegetation will be different from impermeable land cover, such as houses, offices, pavements, and hotels. To reduce potential flood is achieved by reducing the surface runoff volume. Meanwhile, in order to reduce the runoff volume, an infiltration well that can accommodate $5m^3$ of water can be constructed for every $100m^2$ of developed area. With a number of 664,701,800 infiltration wells, as much as 3,323,509m^3 of rainfall volume can be collected in those wells. Finally, with these infiltration wells, the Special Capital Region of Jakarta will be free of flood.

Keywords: *Rainfall; Flood; Land cover; Impermeable layers; Infiltration wells*

Introduction

The environment is a space consisting of the elements of physical and social objects, human beings, and their activities. Those elements allow for interaction, relation, and interdependence to occur, which in turn form a unique environment. Therefore, it is important to promote a paradigm shift from the quantification of the hazard and primary focus on technical solutions towards the identification and assessment of the various vulnerabilities of societies, their economy and environment [1-3]. Human beings live in a certain area to meet their needs. In order to meet their needs, human beings have to utilize land, causing disturbance to the stability and equilibrium of the environment. Meanwhile, the environment is an entity of space along with all objects, powers, circumstances, and living beings, including human beings and their behavior, which affect the nature itself, the sustainability of life, and the well-being of human beings and other beings [4]. Human activities, in managing and cultivating land, will cause environmental degradation, because the more developed a population is, the higher the demand for the catering of human needs and the more damaged the environment will be. Furthermore, population growth is accompanied by a decline in the forest area, which is adapted for agriculture, where [5]. The utilization of land always changes together with the growth in

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number of residents, which is also causing the increasing needs of settlement areas, especially in forest and agricultural domains, which become people settlements and also other necessity [6].

Changes in land use, from forestry to agriculture or even settlements, will consequently change the ecosystem of the environment and cause damage to the elements of the environment. Environmental conversion triggers erosion and a degradation of water flow and quality, while any modification in land use causes changes in social, economic, and cultural aspects [7]. Causes of flooding are related with water sources that affect public health and safety. Sustainable water systems often comprise complex combinations of traditional and new system components that mimic natural processes. These green systems aim to protect public health and safety and restore natural and human landscapes. Green infrastructure elements such as most sustainable drainage systems trap storm water, but may contaminate groundwater [8-13].When the environment undergoes degradation, its sustainability will decline, threatening the sustainability of environmental benefits and functions for the sustainability of human life. The increase of soil sealing has led to the development of the best management practices, such as infiltration basins aimed to help storm water infiltrate the soil, in order to reduce the amount of collected and treated water in usual systems [10, 14]. Environmental degradation will take place slowly and bring about an impact on human sustainability. Signs of environmental degradation are observable in the emergence of various disasters, one of them being flooding. In this case, "environmental sustainability has to support the sustainability of life and development. Hence, conservation must be done to support the attempt of preserving the sustainability of the ecosystem. Flood and waterlogged disasters are frequent and serious, drought disaster occurs sometimes and meteorological disasters are diversified; finally, wetland resources have degraded and the ecological balance has been badly shaken. Flood and waterlogged disasters in the Dongting Lake occur due to the influence of artificial and natural factors, such as abnormal atmospheric circulation and the influence of land use change [15]. Thus, an integrated conservation must be done, by involving the inhabitants, the private and public institutions" [1-3,16]. The conversion of the forest area into agricultural field, settlements, and other land uses resulted in the increase of surface runoff. The increase of an area's surface runoff is caused by the failure of rainfall to permeate the soil, because the soil is covered by impermeable layers or lacks dense vegetation.

In Indonesia, land and water damage continues to increase, especially in the upstream area that is used for agriculture [14, 17]. Land conversion has resulted in land degradation. Land degradation is not immediately apparent, but it will appear gradually, both in the surrounding areas and in other areas when disaster occurs. Hence, erosion will not be immediately observed in the upstream area, but it will take place in other areas with a plain morphology in the form of flood. Land conversion is, for instance, currently taking place in the watershed area of Kali Lamong, where on the upstream, the forest area is dwindling; while in the downstream area, the land has been converted into settlements or business sites [18]. Land conversion from forestry to agricultural or settlement areas will change the forest functions. Another problem that surfaces in Semarang in relation to housing development is the increase of flooded area [19]. Due to this condition, a good understanding of rainfall characteristics becomes important for the proper design of agricultural systems, runoff and water quality control systems. Intense rainfall of long duration is not uncommon in the peninsula and it often becomes disastrous to farmers and settlements near river courses [20]. Forests play important roles in preventing flood because the leaves reduce the effect of rain drops on the soil, while the roots will fertilize the soil. The fertile soil in forests will absorb rainfall, thus decreasing the rainfall-surface runoff. The changes undergone by forests due to human activity in catering to

their needs will continuously bring about negative impacts, whilst human needs fulfillment is only temporary.

Thus, the activities of the residents in cultivating and managing land should consider the possible impacts. The impacts will probably not be perceived immediately and timely; rather, they are indirect in nature, taking place in another area, and taking a relatively long time. The runoff flowing off the soil surface will be concentrated on flat land, while the rainfall flowing down the river will be concentrated on flat river basins. The movement of surface runoff can cause flooding. Meanwhile, the increased river volume will result in increased volume and overloaded the capacity of the river. Flooding frequently occurs in line with land development and rapid population growth. The rapid population growth will have an impact on the increasing need of space for settlements, public facilities, agriculture, and the like, so that the existing areas experience overloaded exploitation, exceeding the carrying capacity of the areas [21]. The initial system is intended to handle the frequent runoff events and nuisance flows. It is generally designed to serve runoff peak flows and volume not exceeding the 2 or 5 year return period. The definition of the initial system includes depth and velocity limitations for roadside swales, gutters, storm sewers, and open channels during the selected design event [11-13, 22]. The overflow of the river will cause flooding. This translates as flooding being caused by the surface runoff's inability to infiltrate and therefore getting concentrated on a plain morphology as well as by the overflow of the river.

Flooding occurs when water remains stagnant on a certain area of the Earth's surface. It is known as a natural disaster, but upon closer examination it is clear that flooding is caused by human activity in managing and cultivating the environment. The means by which they manage and cultivate the land that are inconsiderate to the environment have disturbed the interaction and interrelation of various environmental elements. When one environmental element is disturbed, its functions will consequently change. The changes trigger problems. Flooding then is basically a reflection of natural phenomena and the Earth's damage accelerated by human actions [23]. Meanwhile, the characteristics of flash floods in Indonesia, according to the Board of the Study and Implementation of Technology, show that in general such flooding is a phenomenon where the quantity of water in a stream increases and exceeds the stream's capacity [24]. The development of land conversion in the north-western parts of Surabaya, for instance, from open land to settlement, from lower elevation to higher elevation, from catchment area to runoff basins flowing to the drainage, is not accompanied by the increase in the capacity of the drainage due to low development budget [25]. Another case shows that the land conversion taking place in the watershed of Kali Lamong has caused shrinkage of forest area in the upstream and change of land use in the downstream into settlement or business sites before the 1980s [26].

Land management and cultivation should consider environmental components. Hence, development carried out by converting land's permeable surface consisting of soil into impermeable layers, such as walls, concrete, and asphalt, will change the functions of the surface layer, as shown in figure 1. The soil layers that serve the function of infiltration are transformed into layers of concrete, wall, and asphalt that are impermeable. As a result, when the rain falls, the rain drops will flow as surface runoff and become concentrated on areas with a plain morphology. The runoff flowing over areas with a plain morphology has a low speed and fine soil materials, so that areas with a plain morphology will be the center for water concentration. When high volume and discharge rates of water are disproportionate with the infiltration level, water will be concentrated on afloat area. The accumulation of water in the area will cause inundation and flooding. In other words, flooding is caused by human activities that disturb the environment. As increase of river basin land-use development condition leads to increase of imperviousness of the river basin and an increase

of the volume and peak discharge of the generated runoff hydrograph. On the other hand, increase of magnitude of rainfall event, the volume and peak discharge of the generated runoff hydrograph increase significantly [27].

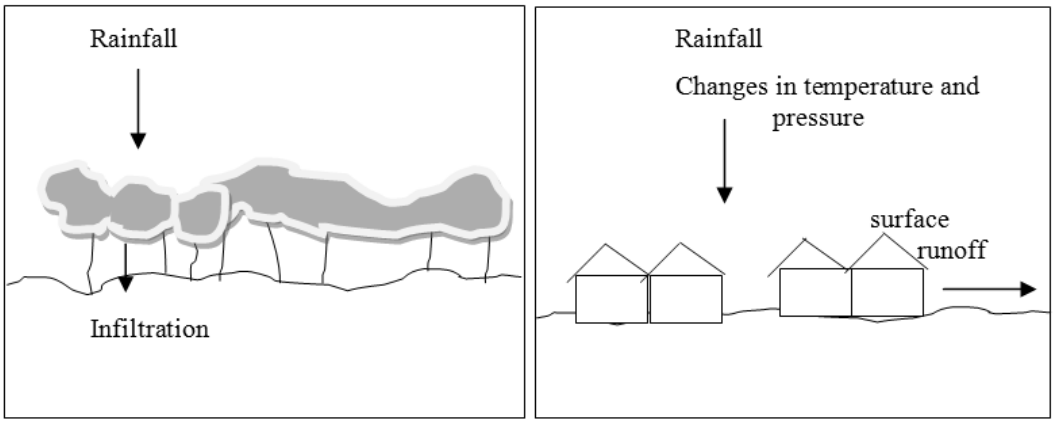

Fig. 1. The impact of land conversion into settlement

The factors causing flooding due to the rainfall's inability to infiltrate into the soil, hence creating surface runoff, are: rainfall, slope gradients, land elevation, soil texture and land use [28]. These factors show that land surface experiences changes, making the land lose its functions. Initially constant head tests were applied with fresh water, infiltration rate test were observed and degree of saturation profiles were determined [29]. Changes in the functions of land surface result in increased water discharge. These factors interact and are interrelated in causing flood. Nevertheless, flood mitigation of a certain region should also consider other aspects, ultimately the nature of the region's administration, which is different from one region to another. Thus, because mitigation efforts in a certain administrative region are constrained by administrative rules and regulations, integration should be implemented.

Flooding caused by environmental degradation requires studies of the factors that have caused it to occur in order to be able to mitigate it. This means that to solve flooding problem, the environment should be restored. To restore the environment, conservation of the damaged factors should be done. Conservation of natural resources and their ecosystems should be based on the harmonious and balance preservation of the natural resources' capacity and use in their ecosystem. Article 3 (three) of the law on Conservation states that conservation of the living resources and their ecosystems is intended to sustain living resources and balance ecosystem in order to enhance human welfare and quality of human life [30]. A city can be regarded as a living system that is made up of different interacting parts, and functioning through the interplay of different sectors. It has been acknowledged that cities are focal points that enhance economic and social activities of the people and society at large [31]. This stipulation shows that conservation is aimed at environmental preservation that can support the development and sustainability of human life. Hence, development should be carried out by considering environmental factors. A well-maintained environment will have appropriate functions, so that its exploitation and preservation will be in balance. Soil is an essential environmental component, as it can absorb the water flowing over its surface and in the subsurface through its pores. If soil is covered by impermeable layers, it will no longer serve the function of water infiltration, causing the soil to contain less water. The quality of groundwater in any aquifer is greatly influenced by its

geographical location on the earth surface and the impact of anthropogenic activities as well as the interaction between groundwater and the aquifer media [32].

The Special Capital Region of Jakarta, as the capital city of Indonesia, is a mascot of a country that is always attacked by floods. Hence, it is urgent to make efforts to save Jakarta from flooding. The present research is limited to the administrative region of the Special Capital Region of Jakarta, because to study floods it is necessary to analyze the region in which the flood takes place, before moving on to the investigation of the flood itself and other areas. The aims of this research are as follows:

a. To measure rainfall volume that causes flooding in the Special Capital Region of Jakarta.
b. To analyze efforts of reducing flood volume that occurs due to rainfall in the Special Capital Region of Jakarta.

Methods

The method employed in this research was the experimental method. This method was applied in order to measure the rainfall accommodated by infiltration wells. In analyzing Jakarta's floods, the research has conducted the following stages: analyzing land use and analyzing rainfall. The area under investigation was the Special Capital Region of Jakarta with a sample of one infiltration well. To map the area, Geographic Information System (GIS) was used, allowing for the calculation of rainfall volume and area in Jakarta. The analysis techniques deployed were: measurement of rainfall volume and measurement of rainfall accommodated by infiltration wells. Assuming that evaporation and soil infiltration cannot be measured because of their extremely small amount, these two aspects were not analyzed.

The measurement of *rainfall volume* was evaluated by using the formula:

$$V = R \times A,$$

where V = volume (m^3), R = rainfall (mm) and A = area (km^2).

The measurement of *infiltration well's volume was done using*:

$$V = A \times d,$$

where, V = volume (m^3), A = area of the circle (m^2) and d = well's depth (m).

Results and Discussions

Land cover is the key factor affecting floods, because the types of land cover will determine the interaction among factors of land. The disturbed factors of land cause changes in the land's ability to infiltrate rainfall. Land cover formed by vegetation will be different from the one formed by impermeable cover. The vegetation cover formed by rice field, dry land, plantation or non-agricultural field will infiltrate water differently. The vegetation with dense leaves will reduce the effect of raindrops on soil, while roots help make the soil fertile, so that some of the rainfall will infiltrate into the soil. Land cover with a vegetation of rice field has low infiltration ability, because the rice plants should be inundated. The inundation will form impervious or impermeable soil layers. Similarly, land cover of concrete, buildings, pavements, and the like, will form impermeable layers, so that rainfall cannot infiltrate into soil. This means that changes in land cover from vegetation into impermeable layers will cause the rainfall to run off and turn into surface runoff.

Meanwhile, morphologically, the Jakarta Special Capital Region is categorized as a plain area, so that the soil has a soft texture. The soil formed is the result of sedimentation

developed on higher areas, such as Bogor Regency, Cianjur Regency, and Depot City. Even though physically and socially the area of Jakarta is interconnected to other areas, administratively it is independent. Physically, Jakarta is covered by alluvial soil with low infiltration speed, because the soil covering the land is a result of sedimentation. Nevertheless, the soil surface in the area is largely covered by impervious layers, so that the runoff from the rainfall is collected on the lower level land areas. Under natural conditions, rivers continuity migrates across their floodplain belt and changes the configuration of the landform. Flow and sediment regimes, interacting with bed and bank materials and with revering vegetation, create and destroy fluvial features, thereby providing a variety of habitats for diverse biotic communities [33]

The land surface with less permeability for rainfall and some impermeable layers cause the rainfall to be unable to infiltrate into the soil. Rainfall impermeable cause rainfall flooded and flowed on the surface, as shown in figure 2. The rainfall that does not infiltrate becomes potential for causing flooding if the river capacity is not proportional to or smaller than the discharge flowing on the area. Hence, in an attempt of solving the flooding problem, land use of the area should be examined. Land use in Jakarta is shown in Table 1.

The area of the Special Capital Region of Jakarta is divided into 5 municipalities and 1 (one) regency. The Thousand Islands (*Kepulauan Seribu*) Regency is an administrative area separated from the island of Java. From table 1, it can be observed that Jakarta area is covered by impermeable layers. Hence, the rainfall will run off and can potentially cause inundation and flooding. This means that the rain is falling on impermeable land surface. Development has changed soil function, rendering it impermeable.

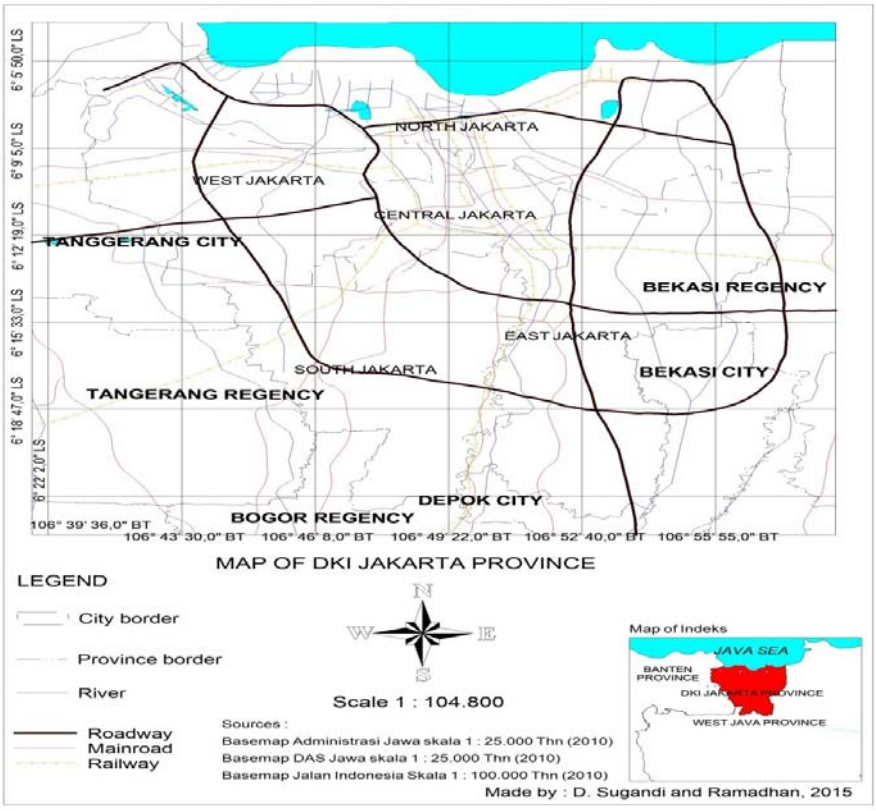

Fig. 2. Land Use region of Jakarta, 2011

Table 1. Area of Jakarta closed due to construction of waterproof coating

No	Regency/City	Land Area (ha)						
		Non-agriculture	Rice field	Dry land	Plantation	Forest	Other	Total
1	South Jakarta	11,452.45	-	741	-	394	1,545.00	14,132.45
2	East Jakarta	17,118.09	325	109	-	121	1,129.00	18,802.09
3	Central Jakarta	4,667.42	-	2	-	13	130	4,812.42
4	West Jakarta	10,841.50	297	283	-	18	1,515.00	12,954.50
5	North Jakarta	13,165.72	593	-	-	200	877	14,835.72
		57,245.18	1,215	1,135	-	746	5,196.00	65,537.18
6	Thousand Islands	869	-	-	-	63	1	933
	Total	58,114.18	1,215	1,135		809	5,197.00	66,470.18

Source: Central Bureau of Statistics of Jakarta Province, 2011 [34].

The above effect of development proves that construction of the land has been done with impermeable layers. It has to be noted that development should be carried out with the aim of providing space for the community life, but it has to consider the environmental factors in order not to damage them. The development in the area of Jakarta is predominantly done horizontally. If the construction is made of impermeable layers, the more construction will mean the larger the area that is covered with such layers. Considering the land functions, construction should be done vertically, so that land use will be effective and efficient. Vertical development for housing, offices, trading sites, and hotels will make the land become more efficient. Horizontally, a settlement is built for 100 family units; therefore, if one family needs 100m^2, horizontally, the area of the land to be used will be:

$$\text{Area} = 100 \text{ Family units x } 100\text{m}^2 = 10{,}000\text{m}^2 \text{ (1 ha).}$$

If housing construction is done vertically with 4 floors, then 100 family units will require an area of:

$$Area = \frac{100\ Family\ units\ x\ 100\ m^2}{4} = 2{,}500\text{m}^2 \text{ (0.25 hectares).}$$

With vertical construction, the land can be used effectively and efficiently because the remaining 7,500m^2 (0.75 hectares) can be used for other purposes, ultimately for green open space and catchment areas. Hence, development can be carried out and may progress by not sacrificing the land function. The availability of green open space for infiltration will serve to reduce surface runoff and inundation.

To measure rainfall volume in the area of Jakarta requires data on the average rainfall. Although the calculation is only done for a one year period, it will represent the rainfall volume potential for flooding and inundation. Data on the rainfall volume for 2013 in the area of Jakarta Special Capital Region are presented in Table 2.

Table 2. Jakarta Rainfall Summary in 2013 (Meteorology Station 745 Kemayoran)

Rainfall	Monthly average rainfall (mm)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation (mm)	275.1	157.9	173.6	196.2	118	67.2	13.6	2.4	16.2	44.3	252	254
Rainy days	24 D	17 D	18 D	14 D	11 D	5 D	2 D	1 D	4 D	5 D	19 D	20 D
Daily average	16.2	9.3	9.6	14.0	10.7	13.4	6.8	2.4	4.1	8.9	13.3	12.7

Source: Head Office of Bureau of Meteorology and Geophysics, Kemayoran Jakarta, 2013 [35].

The rainfall rate in the area of the Special Capital Region of Jakarta has the potential to cause inundation and flooding, especially if the rainfall does not infiltrate into the soil or flow down the river. Since the morphology of the area under research is classified as plain, rainfall will be concentrated in the area. Jakarta is directly bordering with the Java Sea with an

elevation of less than 100 meters above the sea level. The morphology and elevation of the area causes the flow of Ci Liwung River to get obstructed by the waves from the Java Sea, thereby blocking the river flow and halting the flow of surface runoff. Consequently, the stream will be concentrated in the plain area of Jakarta, resulting in flooding.

Table 3. Jakarta Monthly Average Rainfall for 2013

Rainfall	Monthly Average Rainfall (mm)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A (m^2)	66.470.180.000											
R/D	16.2	9.3	9.6	14	10.7	13.4	6.8	2.4	4.1	8.9	13.3	12.7
Vol (m^3)	1076817	618172.7	638113.7	930582.5	711230.9	890700.4	451997.2	159528.4	272527.7	591584.6	884053.4	844171.3

The water volume estimated from rainfall density is multiplied by the area. Hence, to prevent the rainfall from running off on the surface area, the rainfall should be able to infiltrate into the soil. The volume of the infiltrated rainfall should be adjusted to the area of the building or impermeable layer. The impermeable layers that are built either for roads, settlements, offices, or other purposes, are of different characteristics, so that the rainfall volume infiltrated will be different as well. Therefore, the means to infiltrate the rainfall into the soil will also be different. To solve high rainfall volume requires different approaches, which is a hindrance in itself. The rainfall has to be measured based on a $100m^2$ land area.

Table 4. High Rainfall Volume in Jakarta in 2013

Rainfall	High Rainfall (mm)							
	Jan	Feb	Mar	Apr	May	Jun	Nov	Dec
				66,470.18				
A (m^2)				66,470,180,000				
Unit/100 m^2				664,701,800				
r/d	16.2	9.3	9.6	14	10.7	13.4	13.3	12.7
Vol (m^3)	1,076,817	618,172.7	638,113.7	930,582.5	711,230.9	890,700.4	884,053.4	844,171.3

A: area, r/d : rainfall/day, Vol: volume; Source: Analysis Results, 2015.

For every $100m^2$ of constructed land, water should be absorbed by the soil. On the said land, infiltration wells should be built, so that the water can infiltrate into the wells and does not overflow the impermeable surface. The constructed infiltration wells can be covered with concrete or any cover that can be opened and closed. Wells that are covered with concrete and soil can be covered with vegetation, such as grass and other garden plants. This means that one infiltration well should be able to collect rainfall for every $100m^2$ of land, as shown in figure 3.

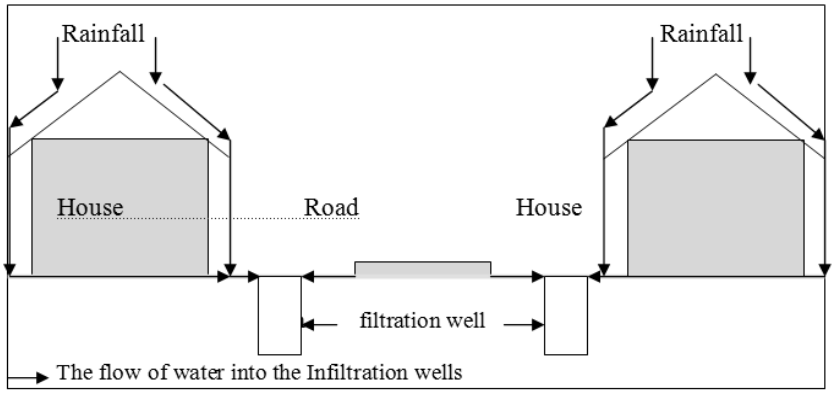

Fig. 3. The Infiltration Well to accommodate rainfall of land area house

Thus, if the area of the Special Capital Region of Jakarta is 66,470,180,000m^2, then the number of infiltration wells made should be as many as 664,701,800 (Table 4). In addition, the infiltration well should be 5 meters in depth. With a well of 5 meters in depth and 1 meter of diameter, the whole wells constructed will have the ability to store 3,323,509m^3 of rainfall.

Table 4. The Ability of Infiltration Wells in Collecting Rainfall Volume

Rain	Jan	Feb	Mar	Apr	May	Jun	Nov	Dec
IW (Number)	664.701.800							
Vol (m^3)	1,076,817	618,172.7	638,113.7	930,582.5	711,230.9	890,700.4	884,053.4	844,171.3
Ability (m^3)	3,323,509							
Remaining Vol (m^3)	2,246,692	2,705,336	2,685,395	2,392,927	2,612,278	2,432,808	2,439,456	2,479,338

IW: infiltration well, Vol: volume; Source: Analysis Results, 2015.

Hence, on average, 1 infiltration well can collect 5m^3 of water, so that with 664,701,800 wells, as much as 3,323,509m^3 of water can be collected. This means that in the rainy season, when the highest rainfall volume for 2013 in February is 2,705,336m^3, the volume can be collected by the 664,701,800 wells, because the wells can in total collect 3,323,509m^3 of water. This can also mean that the whole rainfall volume can be collected by the wells, so that the rainfall can infiltrate into the soil before it gets concentrated and becomes prone to flooding. However, the construction of infiltration wells does not mean that flooding will not occur, for there are other issues, such as trash or other objects that can block the infiltration wells. Hence, constructing infiltration wells needs community participation in waste management, namely by being careful in throwing the trash away, so that it will not block the wells. Furthermore, the wells should be maintained in order to keep its functions, especially when there is heavy rainfall that is potential to cause flood. In addition to the wells' maintenance, drainage should be maintained, so that surface runoff will keep flowing and does not become concentrated on lower level lands.

Conclusion

The area of the Special Capital Region of Jakarta undergoes annual flooding during the rainy season with heavy rainfall. Naturally, the climate and rainfall volume is relatively constant. However, the declining ability of the land to infiltrate rainfall, due to the construction of impermeable layers has aggravated the situation. Development should continue to progress, while still maintaining the land functions, so that flooding can be prevented. In this regard, the research concludes that:

- The ongoing development should consider environmental factors. The kind of development that makes efficient and effective use of land should be prioritized. Alternatively, the development can be done vertically, so that open space serving as rainfall infiltration can be made available.
- High rainfall volumes in Jakarta usually occur in January (1,076,817mm), February (618,173mm), March (638,114mm), April (930,582 mm), May (711,231mm), June (890,700mm), November (884,053mm), and December (844,171mm). The rainfall does not infiltrate into the soil; rather, it runs off on the surface, causing floods to take place.

- The construction that is carried out for every $100m^2$ of land should be accompanied by an infiltration well with the ability to collect $5m^3$ of water. With an area of $66,470,180,000m^2$, the number of infiltration wells to be constructed is 664,701,800. With that number, infiltration wells can in total collect rainfall volume of $3,323,509m^3$, thus making the Special Capital Region of Jakarta free of flooding.

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