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DESIGN STRATEGIES FOR STORM-WATER MANAGEMENT ON A MAJOR ROAD IN URBAN AREA (CASE STUDY: A SECTION OF JEND. SUDIRMAN ROAD, JAKARTA)

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ABSTRACT

Abstract. Jakarta as a metropolitan city, experiences rapid growth urbanization, is struggling remarkably with flooding disasters. Regarding this condition, it is inevitable whether caused by frequent flooding of rivers as consequences of gradual sea level rising or affected by flash-flooding due to high rain rate and the expansion of impervious areas. Another condition on the existing drainage system in most areas in Jakarta carried the collected storm-water offsite and commonly caused flash flooding downstream. The study case area is a section of Jend. Sudirman Road–a major road in Jakarta that had frequent flooding challenges. This paper studies an alternative approach to drainage system or storm-water management through more integrated methods. The purpose is to develop the design strategies of storm-water management within an integrated system, not only by installing some small infiltration sets but also by improving urban resilience. This schematic design result will be a possible recommendation, especially the drainage system, to the local government. It leads subsequently to substitute and improve the existing drainage systems along this major road in the *urban area.*

Keywords: *Storm-water management, Flood, Major road*

INTRODUCTION

Rapid growth urbanisation and the increased climate change has caused several serious environmental problems to most cities. Urbanisation and climate change also influence the modification of urban living (Grimm, et al., 2008). Severe weather affects the rising of rain rate; unplanned urban development (Irwansyah, Nursaniah, & Qadri, 2019) and the expansion of impervious areas degrade the precipitation capability (Brabec, Schulte, & Richards, 2002). The high rain rate and the degradation of precipitation cause the increase of storm-water runoff volume (Zhang, et al., 2021), water pollution, and flood disasters (Zhang, Villarini, Vecchi, & Smith, 2018). In general, the shifting function of open land/area is not followed by proper arrangement of waterways.

Jakarta as the capital city of the Republic of Indonesia is predicated as the centre of the business economy in Indonesia. As the implication, urbanisation depicts an influx of population from rural to urban area or city centre to get qualified job opportunities and better living standards. It might be exemplified by the increasing demands of new settlements or facilities to fulfil their basic needs as residents. This rapid proliferation of urbanisation in Jakarta causes declining open land/area as a place to absorb rainwater and other issues is the changing land use area from green area to housing area. These recently became the main reason for the floods problem which occurred, such as runoff or flash floods. However, there is still uncertainty about how to deal with this flood matter in an effective way.

Almost every year floods in Jakarta occur regularly in several locations, including Letjen Suprapto Road, Perintis Kemerdekaan Road, Bungur Raya Road, Jend. Sudirman Road, Angkasa Road, and other road sections. Jend. Sudirman Road is one of the major roads in Jakarta which is still struggling to manage flash-flooding disasters until recent days (Patnistik, 2021). The flooding on Jend. Sudirman Road is induced by the overflow of water from one area to other areas and the inability of the existing drainage system to handle it. The existing drainage system in most cities channelled rainwater from the paved surface directly to the city's waterways and brought it out of the location as quickly as possible. In spite of possible solutions, the exacerbating downstream floods affect erosion and pollution, especially local waterways.

This paper is an exploratory study to propose an effective drainage system and storm-water management based on a holistic and integrated approach. The aim of this paper is to develop storm-water management design strategies in an integrated system, not only by installing several small infiltration sets but also by increasing urban resilience. The research objectives include identifying the problems of existing drainage systems, evaluating the effectiveness of existing drainage systems in handling increasing storm-water runoff volume, and determining the design strategies of integrated drainage systems. The results of this paper are expected to become possible recommendations, particularly concerning the drainage system, for local governments.

RELATED WORK

Previous work by researchers has been established in recent years to investigate incorporating storm-water quality improvement strategies, especially into road design purposes. The provided project exemplifies for a number of possibilities in the alternative implementation of water sensitive road design practises to adapt environmentally sensitive drainage elements (Wong, Breen, & Lloyd, 2000) and improve the quality storm-water of road runoff. Most techniques which discuss storm-water runoff can be divided into three instalments, such as above ground, underground, and at the ground surface (Qin, 2020). However, these instalments require sizable areas for the construction which are commonly unavailable in densely populated areas (Qin, 2020). Thus, the conventional storm-water management has been constructed to collect surface runoff in subsurface structures to capture water to the source and to separate combined litter overflows and roadway flooding (Garrison & Hobbs, 2011). In addition, other alternatives, such as green roofs, permeable pavements, infiltration trenches, trees, rainwater harvesting systems or swales, are considered to reduce peak flow of storm-water (Qin, 2020). The resilience of drainage systems also takes a significant part in reducing the possibility of flood events happening (Ahmad, Zin, & Alauddin, 2020). The conventional methods of flood risk management need a comprehensive review to solve the problems, increase urban ecological function and build the urban resilience, such as focusing on infiltration, detention, and overflow not only by trenches, but also by using street garden, roof garden, rain garden, bioswale, open trench, permeable pavement, while improving city connectivity (Lee, Lee, Kim, & Lee, 2018). Although these are good strategies, there are several challenges as in Sponge City strategies in China, which include challenges related to technical and legal aspects, municipal local regulations, building codes, plumbing and health codes, restrictions involving street width, drainage codes, and parking space (Li, Ding, Ren, Li, & Wang, 2017). This encourages grey infrastructure and it also concerns the triple bottom-line (social, economic, and environment) analysis to determine the impact of well-being, health and viability for community.

Floods/Puddles

Flood is an excess of water that inundates an area that is usually dry due to the capacity of the river not being able to accommodate the water flowing over it or excessive local rainwater (Somantri, 2008). Flood is an event of the sinking of dry land because the volume of water increases (Kementerian Pendidikan dan Kebudayaan, 2017). Meanwhile, according to the same source, standing water is water that stops flowing or is submerged in water. Puddles can also be defined as a condition where water that enters a lowland residential area cannot be drained directly out and does not seep into the ground so that the area is submerged for a certain time (Pratama, 2016).

Cause of Flood

There are two causes of flooding, namely due to natural factors and due to human activities. Some of the causes of flooding due to natural factors include high rainfall intensity, land subsidence, and silting of river mouths. The causes of flooding due to human activities include the poor habits of people who do not support cleanliness and like to litter, make small culverts, both road culverts and house culverts. Road culverts are built by the local authority. These culverts are needed when drainage channels want to cross city roads, especially at highway intersections. However, house culverts are built by every resident. Culverts that are built too small can implicate a large loss of hydraulic pressure or increase the water level upstream and cause flooding.

Drainage System

The drainage system is one part of the infrastructure in certain areas. Drainage has a function that is indispensable for the survival of life in an area where development is increasingly rapid which causes changes in land use. Drainage should be built with an environmentally friendly system perspective where environmentally friendly drainage functions to absorb surface water into the soil which will also increase soil water content during the dry season (Zulkifli, 2014). Drainage also has a function to absorb surface water to preserve groundwater. The drainage used for flood control should be environmental insight drainage that has the concept of developing rainwater retaining facilities in the ground and associated with green open spaces (Angelia, 2017).

Environmentally Friendly Drainage

Environmental insight drainage is an effort to manage excess water by soaking it into the soil naturally or flowing it into rivers without exceeding the capacity of the previous river. According to Syarifudin (2017), there are several methods of drainage that are environmental insight or environmental friendly, namely:

Conservation pool method

This method is done by making pools of water, either in urban areas, settlements, agriculture or plantations. This pool is made to collect rainwater by first infusing it and the rest being drained into the river slowly.

Infiltration wells

This method is a practical method by making wells to drain rainwater that falls on the roofs of housing or certain areas. The construction and depth of the well is adjusted to the condition of the surrounding soil layer.

Riverside polder

This method holds water by managing excess rainwater along the riverbanks. The construction of this polder is done by selectively widening the riverbanks in various places along the river. The construction of polders was pursued naturally, in the sense of not constructing polders with technical hydraulic doors and expensive hydraulic ring embankments.

Groundwater protection area

This method is carried out by establishing a protected area for groundwater (infiltration area), where the area is not allowed to build any buildings. The area is dedicated to soaking water into the ground. Research by Maas et.al. (2021) said that storm-water collected has a low level of salinity and the ground water absorption delays salt flowing upstream.

METHODS

The selection of the research object in this paper is the area of Jend. Sudirman Road, Jakarta was selected based on several characteristics as it is a road in the city centre which often experiences floods during the rainy season. The method used in this study is descriptive and qualitative methods. Qualitative descriptive method which in testing the analysis also uses qualitative data analysis. Descriptive means describing in writing what the phenomenon under study is and the results of the data that have been carried out. The existing data were analysed using qualitative descriptive analysis techniques. The identification is carried out through a literature review and a survey to observe the phenomena that occurred in the location. This method is divided into 3 stages, namely identification, observation, and generating the design strategies. The survey data collected for this paper include: (1) Primary data survey: observation (direct observation), observation is a data collection technique that is carried out by going down to the field to observe things related to research. Direct observation in the study area is to support data collection in identifying locations. Observations were made with writing equipment to record important things in the study area, cameras for documentation. (2) Secondary data survey: literature study, is to obtain data from the available literature to obtain a theoretical basis related to research. The research method of this study is limited in concept and is only at the preliminary stage. In order to generate a detailed design, the design strategies will need further calculation of the infiltration rate.

Identification

The research object in this paper is the area of Jend. Sudirman Road, Jakarta (Figure 1) from Semanggi Interchange to Kali Krukut (Figure 2) which is the major road of Jakarta in the central business district. This road was constructed between 1949 and 1953, it connects Central Jakarta with Kebayoran Baru. The road was also part of the vertical development strategy for the protocol street in the 1960s and 1970s. This corridor is mainly proposed to have conceptual balance between spatial and environmental capacity. However, this road infrastructure is evidently an integral excess part of urban development.

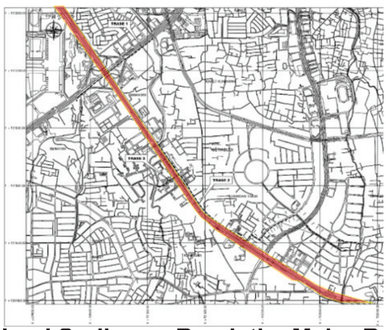

Figure 1: Jend Sudirman Road, the Major Road in Jakarta

Source: Author, (2022)

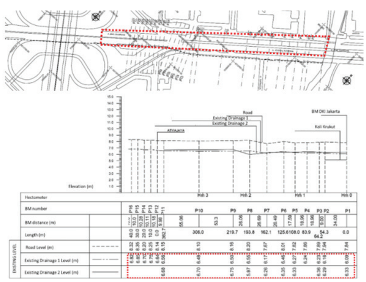

Figure 2: Study case of this paper, a section from Semanggi Interchange to Kali Krukut

Source: Author, (2022)

OBSERVATION

The area on Jend. Sudirman Road is a high-density residential area with a large outdoor area which allows rainwater absorption. However, the existing outdoor area uses paving blocks which make it difficult for rainwater to seep in. In addition, the drainage function of the city in this area is below the pedestrians' paths which are unable to accommodate rainwater runoff, resulting in rainwater overflowing onto the road. Moreover, some drainage problems in this area are unable to accommodate rainwater runoff; the water holes from roads and pedestrians' paths are too small so that they cannot quickly absorb runoff of water into the city drainage (Figure 3). Besides that, the small trench cover is also blocked by litter, such as leaves and domestic garbage (Figure 4). The growing trees area is also dominated by paving blocks and insufficient opening drainage to absorb rainwater (Figure 5), and the elevation of the green area is higher than the impervious area (Figure 6) which prevents the water from flowing into the green area. As a result, the flood rate of the area is medium to high (DKI Jakarta, 2021). Floods in the Jend. Sudirman Road area recently occurred in February 2021.

Figure 3. Holes from Roads and Pedestrians' Paths are Too Small
Source: Author, (2022)

Figure 4. The Small Trench Cover is also Blocked by Litter
Source: Author, (2022)

Figure 5. The domination of Impervious Area

Source: Author, (2022)

Figure 6. The Elevation of Green Area is Higher than the Walkway and Driveway

Source: Author, (2022)

Generating The Design Strategies

The identification and observation results were analysed to generate the alternative solution in storm-water management. In addition, the criteria of a liveable environment were added to the strategies to create more holistic problem solving. The strategy concepts are based on formulating some multi-disciplinary knowledge that involve a proactive process that leads to concern in urban design, landscape, and management. It provides techniques which are capable of delivering a wide-range of beneficial outcomes at both the regional and local levels (Wong, Breen, & Lloyd, 2000). The possibility of the success of this design strategy requires the concerted effort of several stakeholders so that it can produce a more holistic solution to realise a greener urban area (Kvamsås, 2021).

RESULTS

Roads and other infrastructure surfaces are able to constitute up to 70% of the total impact areas in an urban catchment. Those contribute a higher proportion of stormwater (Wong, Breen, & Lloyd, 2000). It can be seen in

Jenderal Sudirman Road development that there is a significant degradation of environmental values, such as poor stormwater quality being the main factor in urban deterioration. Therefore, design alternatives in road design are for enhancing the quality of road runoff from an important element.

One of the flood problems in urban areas is generally caused by the lack of effectiveness of the urban drainage system as in the study area of this research. Drainage development in urban areas is sometimes difficult to implement due to flat topography, high levels of rain from large impermeable areas, and damage/loss of shelter areas (Syarifudin, 2017). The design strategy produced in this paper is an effort to provide alternative solutions for flood control in the study area. The resulting design strategies are as follows:

Existing Drainage System

Most of the existing drainage channels in the study area are drainage channels that are not able to accommodate rainwater runoff, causing rainwater to overflow onto the roads. The pavement of the drainage channels causes water to separate from the soil and instead of increasing storm-water harvesting it increases water runoff (Qin, 2020). The water opening from the road to enter the drainage is also considered too small so that it is not able to maximally enter rainwater runoff from the highway. The design strategy for this drainage system is to apply some infiltration wells at several points at the study site.

Infiltrating

There are many ways to collect, treat and manage storm-water to be an asset. One of them is by incorporating a mix of elements which aim to minimise the stress of water on the systems, those are bioswales, porous pavements, greenways, and subsurface water storage (Chan et.al., 2018). Those methods are implemented in sponge city strategies in China. Porous materials are also useful in increasing the infiltration volume. The collected storm-water could be used for recycled water or infiltrated into the ground. This strategy prepares the environment in handling increased volume of storm-water and defeating flash-flooding disasters.

Another design strategy to slow and treat storm-water beside infiltration is storing the water underground. Underground tanks are helpful to collect water to be reused and recycled and in addition, they have no visual impact to the city.

Walkability

The implementation of storm-water management techniques needs an integrated and holistic approach to convert storm-water from disaster to asset. Instead of only implementing the infiltration methods, the storm-water management could also improve the city walkability and pedestrian experience. Walkability is a part of liveable and sustainable environment criteria. Furthermore, a walkable pedestrian walkway improves the accessibility, safety, and sociability of the environment and makes the city a liveable city.

The design strategies are to connect the major roads and the other corridor and also create a green spine along the way. These strategies aim to collect and improve the water quality through the green spine and also boost the quality of the urban environment. An urban environment that not only provides pedestrian paths but also pays attention to comfort and sustainable aspects will increase its liveability (Yassin, 2019).

Design Scenarios

In order to redesign the storm-water management and drainage system of the existing major road, simplicity is the key to make it possible, such as a modification of the road section, the details of drainage inlet and outlet, and some addition of underground tanks. The major dimension of the road is depicted in Figure 7. The construction and renovation process will be easier if the dimensions of the road are maintained. Significant design changes will result in longer road closures. Jalan Jend. Sudirman is the main road and it will cause a tremendous traffic jam if it is closed as the longer the construction time, the longer the congestion will be. In addition, construction costs are also a material consideration in redesigning. The Indonesian government in carrying out development has a budget standard that cannot be ignored. Utilisation of the existing area with the right slight modification will produce a significant impact at a relatively lower cost.

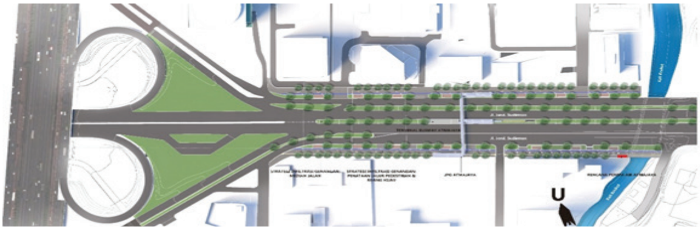

Figure 7. The Design Scenario Leave the Road Dimension as it is
Source: Author, (2022)

The main scenario is to collect storm-water into the underground tanks to be reused and let the excess water infiltrate to the ground (Figure 8). In order to make it possible, there are two focus areas. The first strategy is that the materials of the pavement should be porous. Pedestrian road material which was originally an ordinary pavement resulted in water not being able to absorb into the ground. The use of a porous material increases the absorption capacity of the pedestrian road surface so that there will be more conversions from runoff to water storage, creating a better water absorption level. The next strategy is to expand the green area and the level should be lower than the walkways and driveways. By lowering the elevation of the greener area than the pavement, storm-water will flow into the green catchment area (Chan, et al., 2018). This will promote storm-water storage and improve the water runoff in order to lower the chance of flooding from happening. In addition, storm-water runoff from the driveway is directed to a specially prepared underground channel under the pedestrian and bicycle paths. This channel will drain the runoff to the underground storage pond. The driveway does not use porous materials because there are other aspects in the pavement design of major road vehicles such as strength and durability to bear the weight of large vehicles.

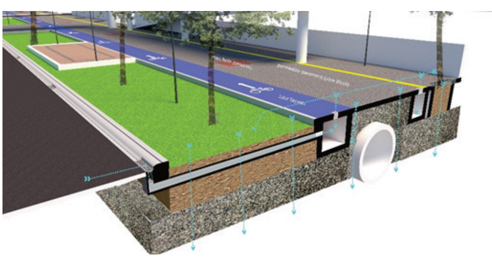

Figure 8. The Design of Storm-water Infiltration
Source: Author, (2022)

Furthermore, the strategies also need simple modification of the walkway to enhance walkability and promote a liveable city. Some additions are needed, such as the bicycle path, guiding-block, space of interaction, adjustment of plant selection, and street lighting (Figure 9). The condition of the existing pedestrian road already has a wide dimension for pedestrians to walk comfortably. The modifications made were the addition of bicycle lanes and several gathering spots. Cycling has recently become something that Jakarta residents often do, especially during this pandemic. So far, people do not have special bicycle lanes and use the same path as cars. This activity needs to have infrastructure that accommodates users to ride bicycles comfortably and safely. In addition, pedestrians also need a meeting point or resting point to just rest after a long journey. This resting point is also an element that increases user comfort and promotes walkable pedestrian ways. This resting point is also a compensation for reducing the width of the pedestrian road which is converted into a green catchment area. With the resting area, the width of the pedestrian way becomes efficient for pedestrian paths and the gathering area has another dedicated area. Street lighting is also an aspect that needs to be considered for pedestrian safety and comfort. The position of the street light is every 10 meters along the pedestrian street. The selection of tree species is a shade tree on the side of the pedestrian road and a guiding tree on the side of the driveway. Shade trees aim to increase the shading of pedestrian roads and reduce the temperature of the road surface. In order to facilitate the maintenance of underground waterways, manholes leading to the canal are placed on the pedestrian path every 20 meters along the road. This man hole at the same time reduces the frequency of demolition of roads when carrying out periodic maintenance.

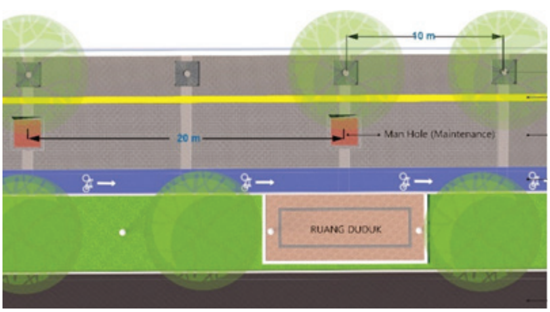

Figure 9. The Addition of Bike Path, Guiding-blocks, and Space of Interaction

Source: Author, (2022)

Supporting utility buildings such as electrical substations are an absolute must in every public road. But often the design of this building ignores the aesthetic aspect and only emphasises the functional feature. One of the efforts to promote a more liveable urban area is to increase its attractiveness. Therefore, an additional strategy that needs to be implemented is upgrading the MEP-installation to be an attractive streetscape (Figure 10).

Figure 10. The Attractive Streetscape

Source: Author, (2022)

DISCUSSION AND CONCLUSION

This paper produces a design strategy to reduce the danger of flooding that often occurs on major roads in Jakarta, especially on Jalan Jend. Sudirman. In compiling this design strategy, there are several factors to be considered which include: infiltration, walkability, simplicity, and attractiveness. The most important aspect in supporting the success of this method is infiltration. Therefore, it is important to ensure the selection of a porous pavement material that has a high absorption capacity while maintaining the strength to support pedestrian and bicycle loads. In addition, in the construction process, it is necessary to ensure the elevation of the green catchment area is lower than the driveway and pedestrian way. This is to ensure that water can flow into the catchment area to be infiltrated into the soil. The water channel that drains water runoff from the driveway also needs to have a clear elevation and path in directing water to the ground water tank so that the water is not stuck in the channel and instead of flowing towards the water tank it re-distributes water to the driveway and causes flooding. Altogether, the design scenario will improve the storm-water management and prevent flash-flooding disasters by achievable methods because the scenario only involves upgrading the existing details rather than building a new alternate solution.

Those design strategies must require some maintenance. However, they typically have lower frequency of maintenance compared with the conventional strategies. The local government should set funds for the installation and the operational maintenance to make sure the scenarios work successfully. The costs are probably high at the beginning of the project, nevertheless it is likely to be a successful scenario in preventing flooding disaster and managing storm-water well. Those strategies are at the stage of the schematic design. Therefore, they need further calculation in the infiltration rate of the storm-water and the volume of the effective underground water tanks. Application of those design strategies in other major roads and cities need adjustment to suit the context of urban development.

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AUTHOR CONTRIBUTIONS

All authors contributed to the design of the research, the questionnaire, and the write-up. The on-line survey, data cleaning and tabulation was undertaken by researcher. All authors have read and approved the final manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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