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RESEARCH PAPER

The causal loop diagram model of flood management system based on eco-drainage concept

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Abstract. Flooding has been a recurrent problem in the Indonesian capital, especially in the northern part of Jakarta, along the Jakarta shore. The floods were caused by a number of sources. According to Renald et al. (2016), there are four critical factors in designing disaster-prone cities in Indonesia, namely spatial management, disaster adaptation, disaster mitigation, and technology innovation. Therefore, the development of infrastructure in Jakarta has started to use these four elements, by applying the concept of environmentally friendly drainage, specifically the concept of eco-drainage. This study aims to understand the general picture through the cause-and-effect relationship between all flood components. This study used a qualitative approach and was conducted using a dynamic system method to describe the Causal Loop Diagram (CLD) model, which provides information between interrelated variables and forms a complex system Rifaldi et al. (2021). The model generated from the dynamic system can be used for scenario analysis by showing how the interactions between the components that make up the structure of the system and the effects of feedback loops affect. The CLD model shown shows that the use of eco-drainage will directly affect the condition of 2 (two) other variables, both of which will lead to one main variable. The proposed settlement scenarios will result in policy and technical recommendations. This CLD model shows that the interaction between variables is very dynamic and affects each other massively and holistically. Combining dynamic system processes with SMWW can potentially improve the expected results in engineering and provide an alternative scenario.

Keywords: CLD; eco-drainage; flood; policy and technical recommendations

1. Introduction

Floods are a continuing problem in the Indonesian capital, particularly in the district of North Jakarta, which lies near to the city's north coast. North Jakarta has undergone a series of floods six times in the last two months, namely on January 1 and 24, 2020, and on February 8, 23, 25, 28, with flooding heights of up to 90 cm and inundation lengths of up to four months (Jakarta Open Data, 2020). Coastal areas are vulnerable to flood disasters (Ciampa et al., 2021). Floods in the area have a significant impact on health, social, economic and environmental factors (Aznar-Crespo et al., 2021; Kabir & Hossen, 2019; Pathak et al., 2020). Many coastal cities in different countries often experience the chronic danger of urban flooding, especially in large coastal

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cities/deltas such as the famous Japanese cities of Tokyo and Osaka, then in China, namely the city of Shanghai, Thailand, and the city of Bangkok, and the Philippines with its city of Manila (Yin et al., 2016).

Currently, there are more and more studies that describe the causes of flooding that are directly related to environmental degradation (Endreny et al., 2017; Majeed & Ozturk, 2020). The latest research has only enriched the technical aspects of green infrastructure engineering (Hamel & Tan, 2021; Maragno et al., 2018). Few studies have provided policy input on the potential (Albano et al., 2019) which should be well planned, simulated, and offers technical recommendations. The backdrop of this research will employ an innovative and holistic technique while getting directly to the core of the impact of eco-drainage, which is a component of green infrastructure.

1.1. Causes of Flooding

Many causes contribute to flood disasters in flood-prone areas. Several studies on floods have been published in journals, and the database has grown with information on population density (Rentschler et al., 2022). Similarly, population growth will rise flood risk (Nicholls et al., 2021). Humans use all available resources to fulfill their needs (Swaraj & Maheshwari, 2022), such as for meeting water needs for household, industry (Fauzi et al., 2018), agribusiness (Gunardjo, 2019), and cultural norms (Titisari et al., 2018). Taking groundwater in quantities that exceed period required for the replenishment will result in land subsidence. Based on the data, Jakarta experiences land subsidence of 0.1-8 cm per year (LAPAN, 2020). Land subsidence will increase the possibility of floods since sea level rises year after year. Global warming is considered to be the cause of rising temperatures and resulting in increased volume in the oceans (Syafitri & Rochani, 2021).

The development of infrastructure, hotel buildings and several massive buildings in the North Jakarta area has reduced the amount of accessible green open space (BKAT, 2013). This will prevent surface runoff in various places (DLH Provinsi DKI Jakarta, 2020). This condition makes the potential for flooding even greater (LAPAN, 2020).

Poor drainage is also a contributing factor to the cause of flooding in this capital city (Raharjo et al., 2016). According to several studies, drainage may refer to drainage system (Sinaga & Harahap, 2016) and a surface water disposal facility (Almahera et al., 2020), both by gravity and by pumps with the aim of preventing inundation, in order to maintain and lower the water level to avoid waterlogging (Krisnayanti et al., 2017).

Much of the current literature such as that of Cramer et al. (2018) pays attention to all of these phenomena which will regularly threaten coastal communities, environmental degradation and ecosystems, as well as food and the economy to extreme hydroclimate such as increased rainfall outside of the season and sea level rise due to global warming.

1.2. Theory of City Resilience

Floods occur in a short period of time and are repeated every year, and are predicted to pose an increasing threat to Jakarta; therefore, measures are required to anticipate these floods. As a result, in order to overcome the flood disaster, an optimal flood disaster mitigation system must be put in place so that it does not worsen (Widiachristy & Rachmanto, 2021).

(Barrow,2006) argues that resilience is the ability of an ecosystem to adapt to a continuously changing environment without breaking down. Similarly, (Dryzek et al., 2011) asserts that resilience is the ability of a system to absorb change while retaining essential function. Together, these theories provide important insights regarding resilience, which may be defined in many ways, including the ability to maintain a steady state of ecosystem and the speed with which a degraded ecosystem can be recovered by human or the ecosystem itself. Hence, Resilience can lead to the provision of city planning.

According to Renald et al. (2016), there are four critical factors in designing disaster-prone cities in Indonesia, namely Spatial Management, Disaster Adaptation, Disaster Mitigation and Technology Innovation. Spatial Management will force stakeholders and actors in spatial planning in Jakarta to provide infiltration or open space for runoff water. Disaster Adaptation is an adjustment to the system naturally and artificially in order to reduce the impact of the disaster (Public Safety Canada, 2015). Disaster Mitigation is a defense or prevention effort in reducing the potential for disasters that will occur (Renald et al., 2016). Technology Innovation is a combination or expansion of a science and technological progress to get new value in a product, process and service.

For this reason, the infrastructure development in the city of Jakarta has begun to apply these four concepts, namely the concept of eco-drainage, to the notion of environmentally friendly drainage. This drainage concept is a drainage system in which rainfall from road surface runoff flows directly into the water absorption system and immediately fills the ground surface water. It is envisaged that rainfallconservation can help create groundwater reserves, as well as indirect advantages such as preventing land subsidence and floods.

1.3. Research Purpose

This study aims to understand the general picture through the cause-and-effect relationship between all components in the flood control system. Whereas in ecology, there will be interrelated relationships that affect others. Given the complex and dynamic circumstances, it is important to see it broadly and comprehensively. This study is expected to produce the essence of engagement in a system that is the subject of the problem and can provide an appropriate recommendation for resolution. The use of system analysis in looking for system problems like these will be carried out holistically, and they will be described in a model so that alternative scenarios may be identified and recreated (Rifaldi et al., 2021).

2. Methodology

The research was being conducted in North Jakarta, using a qualitative approach. The supporting data was gathered by conducting a review of ten journals to obtain key variables and conducting in-depth interviews with a hydrologist, hydraulics expert, as well as geologist of the Indonesian Ministry of Energy and Mineral Resources (MEMR) to support the formation of The Causal Loop Diagram (CLD) model. This research demonstrated how to use the dynamic system method, which describes a model that provides information between interrelated variables and forms a complex system (Rifaldi et al., 2021). The model generated from the dynamic system can be used for scenario analysis by showing how the interactions between the components that make up the structure of the system and their effects include a combination of feedback loops (Firmansyah et al., 2019). The Powersim Studio Version 10 software was used in the preparation of the dynamic system model. The software was used to create causal loops and flow diagrams of a system to be studied, and the stages of model development.

Conceptualization of a system begins with a causal diagram. In this Causal Loop Diagram (CLD), there are variables that are interconnected with arrows according to the development of the black box model and show the influence of cause and effect. The causal relationship is mapped by making arrows between variables that have a cause-and-effect relationship.

Positive sign (+) and negative sign (-) were given to indicate the relationship between one factor and another. A positive sign (+) can indicate a mutually reinforcing relationship between factors. If the influencing factor or the cause increases, the affected factor or effect factor will also increase. Unlike the negative sign (-) which indicates an inverse relationship. If the influencing factor or the cause increases, the affected factor or effect factor will decrease.

3. Result

In the structure test stage, each related variable/pattern must be based on the structure of the information system in which there are variables, sources of information and the information flow network that connects the two variables. Thus, the structural test in this model will use information systems/theories and literature to find causal relationships. The references in this article were selected based on the content, year of publication and the ranking of the journals. In Figure 1 there are four key variables in the causes of flooding; land cover, rainfall, drainage and land subsidence. Table 2 provides descriptions of the suitability of the variables. The diminishing ground water quantity will suppress the aquifer layer, making it a support for the falling ground surface elevation.

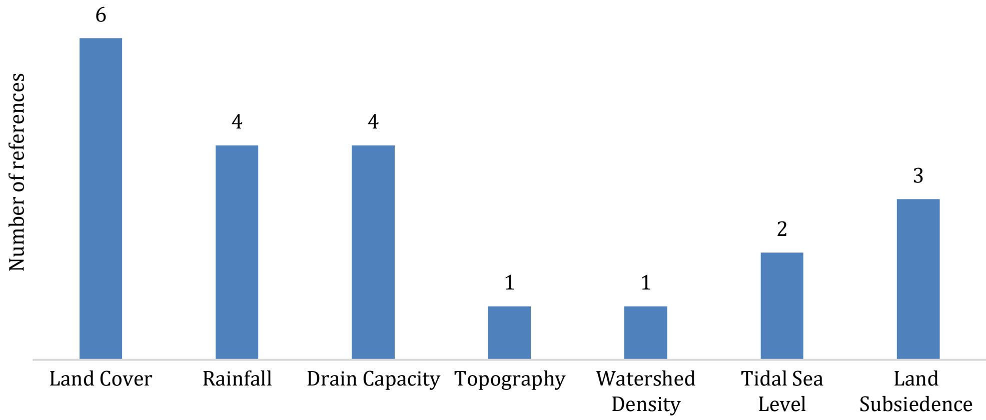

Figure 1. Theory of causes of flooding

Table 1. Analysis of the theory of need for variable ground surface elevation with groundwater quantity in Jakarta

Factor	(Abidin et al., 2014)	(Hutabarat, 2017)	(Cyntia & Pudja, 2018)	(PCLS Jakarta, 2020)	Total
Natural subsidence/geology	√	√	√		3
Water extraction/reduce of Water quantity	√	√	√	√	4
Building load			√		1
Mining activities					0

Table 2. Analysis of the theory of need for ground surface elevation variable with groundwater quantity

Factor	(Miklas Scholz, 2015)	(Pongtuluran & Jayadi, 2018)	(M. A. Putri et al., 2018)	(Subekti et al., 2019)	(A. Putri, 2019)	Total
Groundwater conservation	√		√	√		3
Waste management/filters						0
Green open space		√		√		2
Groundwater use control			√		√	2
Sustainable drainage system/eco-drainage	√	√	√	√		4

During the in-depth interviews, the hydrologists and hydrogeologists provided input by describing the flow of relationships between selected variables in the form of flow charts.

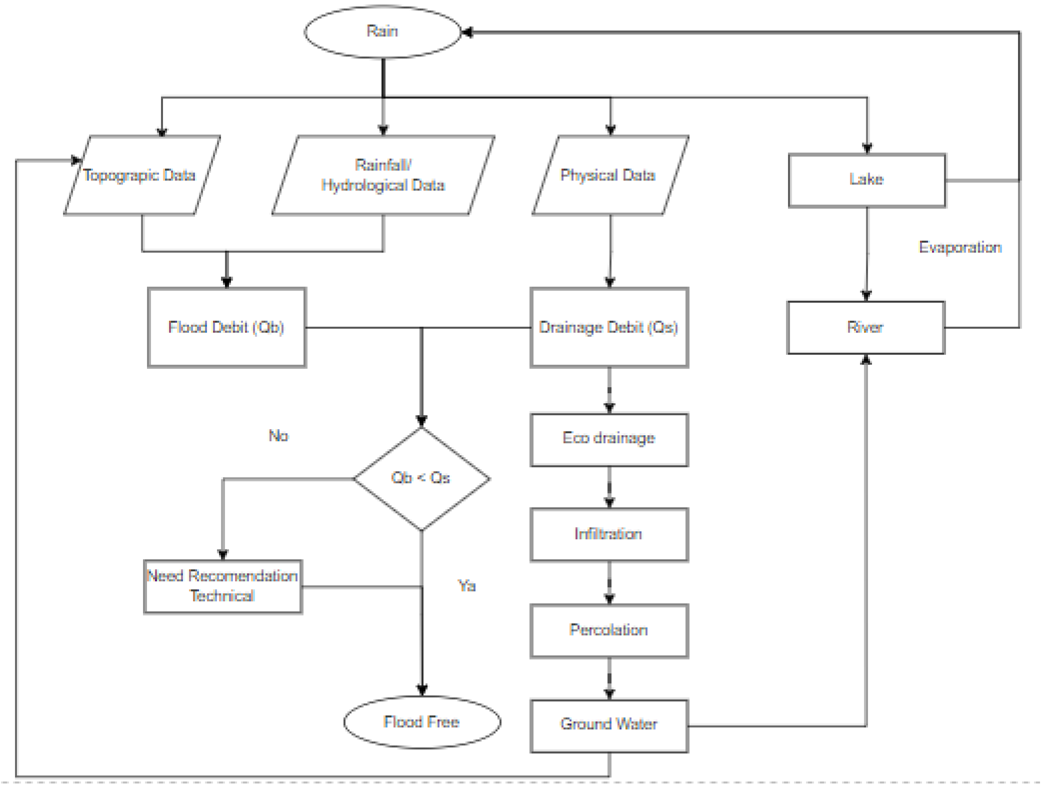

Figure 2. Flowchart between variables from expert judgment

The flowchart above can be formulated into a black box (Figure 3). Modeling concepts like these can summarize the core points of expert judgment in providing specific opinions such as the hierarchy of sub-elements in a system (Rifaldi & Sumargo, 2021). The unique function of this black box is to test the functionality or accuracy of the model that we want to create as well as a limitation and guide in determining the model. Both charts (flowchart and black box) indicate that a model is depicted in its relationship in the form of CLD, as seen in Figure 4. An explanation of the variables and the use of the plus and minus symbols can be seen in Table 3.

Starting from the meaning of the plus sign in the population, it illustrates that as population grows, so will the amount of groundwater usage in Jakarta, reducing the quantity of ground water. The reduction in the supply of ground water will cause the aquifer layer to decrease and cause the ground to subside, potentially resulting in floods. With the addition of the eco-drainage variable, it is expected that runoff water will seep into the ground, increasing the quantity of ground water and preventing land subsidence, reducing the possibility of increased floods if eco-drainage is not implemented. Eco-drainage will also increase drainage capacity and reduce runoff/flood water. Relationship between variables in the constructed loop: Purple loop: This loop is a balancing (B) loop with a positive value. It has flood components, soil infiltration, use of eco-drainage, ground water quantity and surface elevation. Red loop: Has a positive loop or balancing (B) loop as well. Flood components, infiltration rate, eco-drainage and drainage capacity are all included. Orange Loop: Has a negative loop reinforcement (R) which consists of flood, river discharge and drainage capacity components.

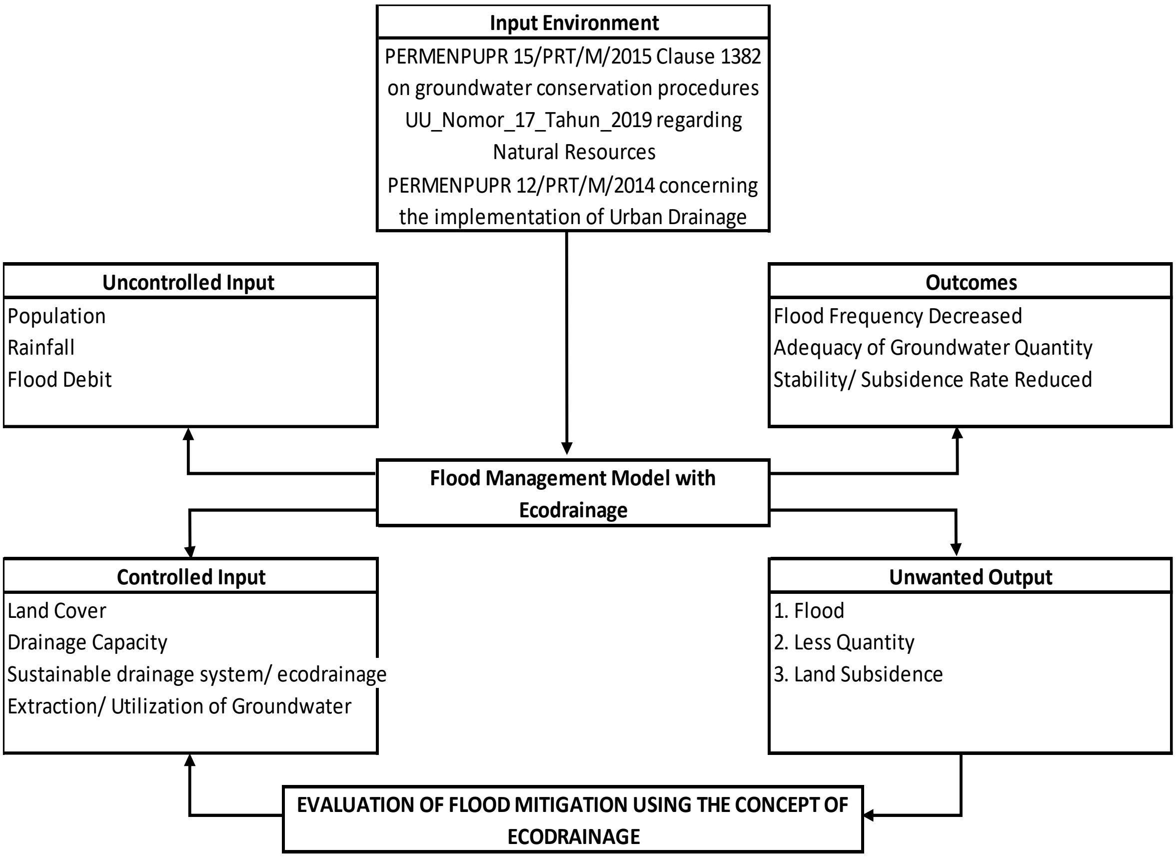

Figure 3. Black box as a guide

Table 3. Causes and effect relationships variables

"+"	"-"
Population:	Ground Water Usage:
1. Ground Water Usage	1. Quantity Ground Water
2. Land Use	
Land Use:	Capacity Drainage:
1. Coefficient runoff	1. Flood
coefficient runoff:	Ground Level:
1. Capacity Drainage	1. Flood
Quantity Ground Water:	Flood:
1. Ground Level	1. Flood Debit
Flood:	
1. Flood Debit	
Infiltration Rate:	
1. Eco-drainage	
Eco-drainage:	
1. Quantity Ground Water	
2. Capacity Drainage	
Flood Debit:	
1. Capacity Drainage	
Rainfall:	
1. Quantity Ground Water	
2. Flood Debit	
3. Flood	

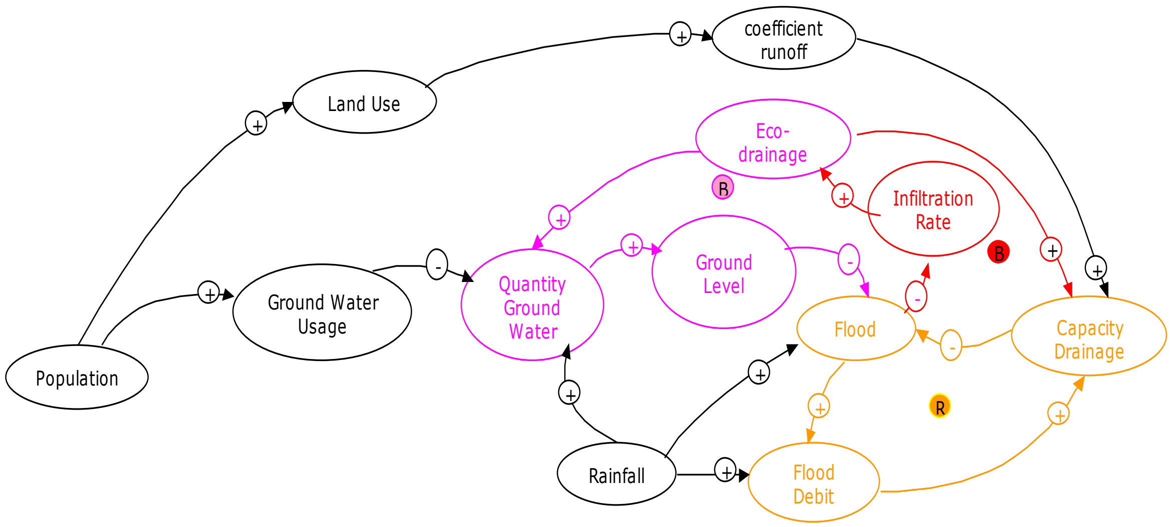

Figure 4. CLD model system approach in flood management using of eco-drainage

4. Discussion

Interrelated conditions will mutually influence other environmental variables. According to the CLD model, the use of eco-drainage will have a direct impact on the condition of two other variables, namely the quantity of ground water and the increase of drainage capacity, both of which will lead to one main variable. Finally, the usage of eco-drainage and other linkages will contribute to the effective process of minimizing floods. High rainfall will directly affect the rate of soil infiltration, groundwater quantity and river discharge. In this study, rainfall will be the control variable for an extreme condition.

The benefits of using causal loop diagrams are that they directly reduce the complexity of clothe system and determine the core system variables of a problem. Therefore, the emphasis of problem solution will be on controlled input variables. The proposed solutions will result in policy and technical recommendations. This research will contribute to the discussion of policy research on flood disaster reduction strategies that originate from the source of the problem, it will further narrow down the efficacy of environmentally friendly innovation and mitigation. Based on the policy recommendations, it will prioritize green open space and ground water limitations.

The data that has been collected in Figure 5 illustrates that an increase in the tariff for the use of ground water by 46% will reduce the use of groundwater significantly by 45%. This will force groundwater users to reduce their use of ground water and switch to surface water. The next policy that can be developed from the CLD point is the limitation of open space in Jakarta.

The data in Figure 6 shows that the implementation of the policies contained in PP no. 15 of 2010, which requires providing 30% green open space in each owned area, is ineffective. As a result, the government will restore critical land in 2018-2019, raising the IKTL index by 0.66% (Figure 6). One policy that can be implemented is to restore critical land by buying land owned by locals or abandoned land and converting it into open space.

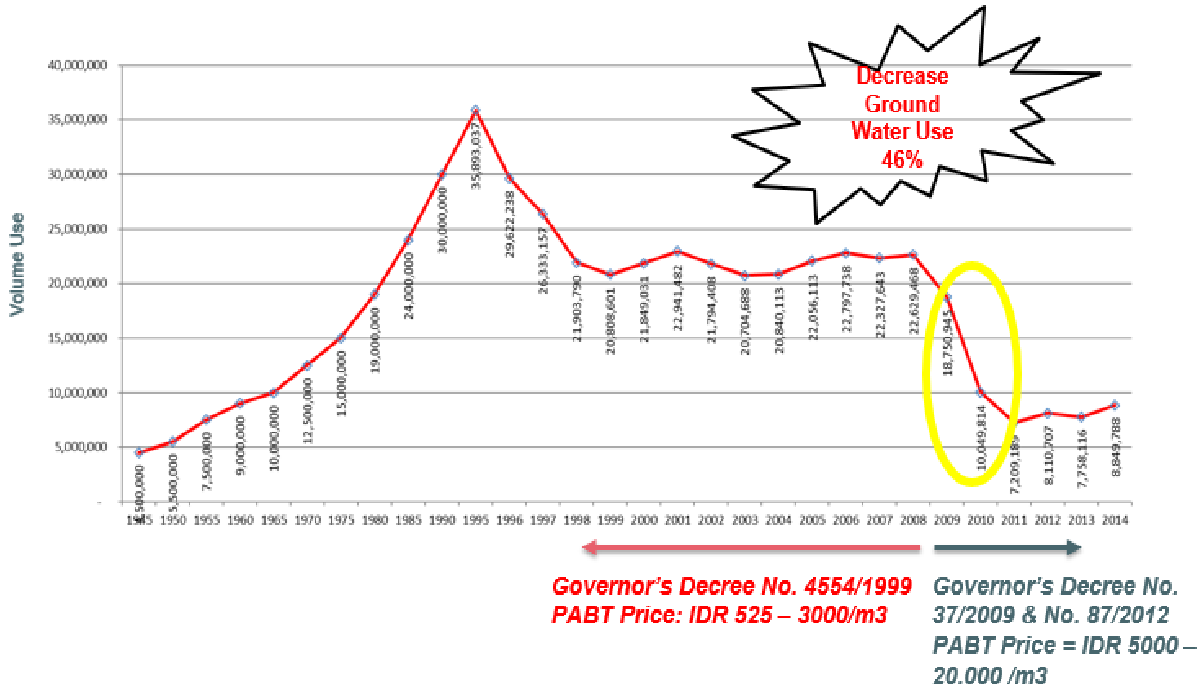

Figure 5. Decrease of ground water volume (Balai Konservasi Air Tanah, 2021)

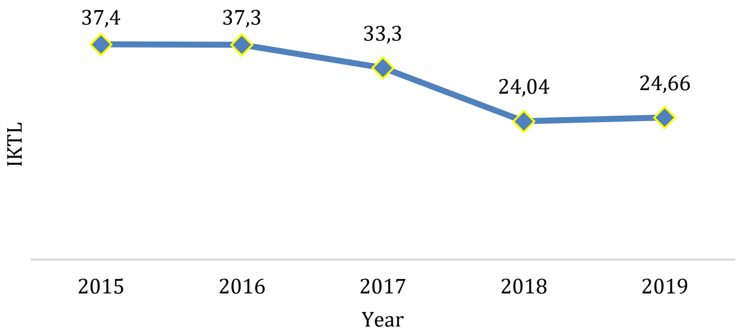

Figure 6. Land Cover Quality Index (IKTL) DKI Jakarta 2015 -2019 (DINAS LINGKUNGAN HIDUP PROVINSI DKI JAKARTA, 2020)

The use of infiltration drainage is becoming more popular nowadays. It is supported by modular (Figure 7) and material technologies. PT Geosintetik Mandiri Indonesia (2022) has already announced the advantages of adopting modular tank. They are linked, light but extremely robust, low cost, environmentally friendly, large in capacity, have 95% infiltration rate, save space, have strong structural design and efficiency, able to withstand loads of up to 40 tons, effective life of more than 40 years. The improvement of infiltration drainage aims to make the installation easier, environmentally friendly, and resistant to alkalis and acids and with a higher capacity. Modular infiltration drainage can handle huge loads, allowing the land above to be used for buildings or other purposes, such as shops, parking, playgrounds, jogging tracks and so on. It is hoped that this would result in the successful use of eco-drainage in various open spaces in

Jakarta. Of course, the use of eco-drainage must adhere to requirements such as those made by Badan Standarisasi Nasional (2002). Eco-drainage with the concept of infiltration must be installed on a relatively flat area. The water that goes into it must not be contaminated with harmful or poisonous substances. The eco-drainage area should also consider the safety of the building structure (Irawan et al., 2017).

Figure 7. Modular tank

From a technical point of view, the recommendations based on the established CLD model are the use of eco-drainage with current, modular technology. Nowadays, the use of sustainable eco-drainage is becoming more popular. This eco-drainage concept is part of the SUDS (sustainable drainage system). It works by controlling the quantity and quality of water by storing it through the processes of sedimentation, filtration and biodegradation. Thus, it can be an alternative in reducing surface water runoff and integrating it in improving its ecological habitat (Ellis et al., 2003). The use of drainage with the concept of infiltration is thought to be able to reduce 3 -13% of the runoff volume (Januriyadi et al., 2019).

The existing natural channels such as reservoirs, rivers, swamps and other water areas must also be taken into account. The main cause of the formation of these water areas is the overflow of surface water, which causes sedimentation to be carried into rivers, reservoirs and swamps (Maryono, 2008). The ecological components of rivers and wetland habitats are also important components that must be considered integratively. Restoring a river can be interpreted as renaturalizing or conserving its habitat. What is achieved after restoring reservoirs, rivers or similar wetland areas will provide 3% increase in drainage capacity (Coletta et al., 2021) and floods prevention (Rizzo et al., 2018). This is of course based on the CLD in Figure 3, which will directly have an impact on the variables of river discharge and flood discharge.

5. Conclusion

This CLD model demonstrate how variables interact in a dynamic manner, affecting each other massively and holistically. Improvements to the strategy per point severely limit the efficacy of eco-drainage in preventing floods; it would be preferable if the government and the community supported other policies simultaneously. All the recommendations that have been described will enter the simulation phase of the merging of virtual reality and planning through computing, resulting in timely and accurate information (Rahmayanti et al., 2019). Combining dynamic system processes with Strom Water Management Modal (SMWW) can also improve engineering outcomes and provide an alternate scenario.

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