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September 23, 2024

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Abstract

High urban population growth causes cities to expand and impacts the global environment such as land use, water scarcity, increased runoff and the frequency and extent of flood areas. Increased inundation is also due to climate change or hydrological and hydrometeorological variations caused by environmental changes and accelerated human activities. Increased demand for clean water results in dependence on groundwater utilization to meet the clean water needsneeds in urban areas, feared to have an impact on land subsidence, seawater intrusion, decreased groundwater quality and vulnerability of groundwater services. Eco-friendly and sustainable runoff control and groundwater recharge can be done with the construction of underground water tanks, such as detention tanks, retention tanks to reduce flood peaks, store or harvest rainwater for utilization, infiltrated into the ground for groundwater recharge and the excess flowed into the city drainage network. This study aims to analyze the effect of underground tank to reduce surface flow and recharge groundwater through infiltration, analyze the relationship model between influential parameters and simulate the application of subsurface tank design results in reducing surface flow and groundwater recharge. The research was conducted experimentally in the laboratory using a flume (Length =240 cm; Width = 35 cm; Depth =110 cm), which consists of a detention tank, retention tank and circulation tank equipped with measuring instruments. The research parameters include discharge, rainfall, conveyance coefficient, catchment area, soil permeability, infiltration rate, water table elevation and tank capacity. The research simulation includes 4 variations of discharge, 3 variations of soil permeability and 3 variations of groundwater level. The expected results are the effect of underground tank to reduce runoff and groundwater recharge and the relationship model between influential parameters.

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* Masterminded EasyChair and created the first stable version of this document

† Created the first draft of this document

1. Introduction

High population growth in cities leads to urban expansion, which has serious environmental consequences such as significant land consumption, air pollution, a scarcity of clean water, poverty, social segregation, and vulnerability, as well as an increase in the frequency and extent of flood-prone zones. One of the major threats to urban areas that is difficult to predict today is the increasing risk of flooding due to climate change or hydrological and hydrometeorological variations caused by environmental changes and accelerated human activity, rising sea levels in coastal areas, as well as land subsidence in urban regions where much of the surface is covered by impermeable materials, resulting in reduced infiltration and increased surface runoff, which leads to flooding (Recanatesi et al., 2017).

In addition to being the primary cause of floods, water is an important land resource for people's livelihoods and long-term economic growth. Between 1900 and 2010, the global need for clean water surged eightfold. It is expected to increase by more than 50% by 2025, with over 65% of the world's population facing clean water scarcity (Alshehri et al., 2021). The scarcity of potable water is estimated to affect 6 billion people by 2050. With an expanding population and demand for water, initiatives are required to identify and sustain water resilience in urban areas. The insufficient and inconsistent supply of clean water has resulted in an increased reliance on groundwater to meet clean water needs in metropolitan areas, which is expected to affect half of the global urban population. Excessive groundwater extraction causes groundwater levels to drop, resulting in land subsidence, seawater intrusion, deterioration of groundwater quality, and increased vulnerability of groundwater services (Azis et al., 2019).

The usage of infiltration basins to mitigate flood risk and recharge shallow aquifers has spread throughout the world. The construction of underground water tanks, such as detention tanks, retention tanks, or a combination of the two, can reduce flood peaks, store/capture rainwater for use, infiltrate it into the ground for groundwater recharge, and gradually discharge the excess into the urban drainage network (Hosseinzadeh et al., 2023).

The purpose of the research is to assess the impact of using underground tank structures to reduce surface runoff and recharge groundwater through infiltration, as well as to examine the model of relationships among the parameters that influence the design of underground tanks for surface runoff reduction and groundwater recharge.

2. Literature

2.1. The hydrological cycle.

The hydrological cycle is a continual connection between the Earth and the atmosphere in which water goes from the Earth to the atmosphere before returning to the Earth, impacted by human activities and socioeconomic growth. Water on land and sea surfaces evaporates into the atmosphere (evaporation), where it condenses into water droplets that fall as rain (precipitation). When precipitation reaches the ground, it runs on the surface (surface runoff) and seeps into the ground (infiltration, percolation) to fill the pores and gaps in the soil. (aquifer) (Yang et al., 2021).

2.2. Rainfall

Rainfall is the amount of water that falls on the ground over a given time period and is measured in millimeters above a horizontal surface. A rainfall of 1 (one) millimeter indicates that water accumulates to a height of one millimeter over a flat area of one square meter, which is equivalent to retaining one liter of water (Triatmodjo, 2008). The Meteorology, Climatology, and Geophysics Agency categorizes rain according to the amount of precipitation that occurs: light rain (0.50 - 20 mm/day), moderate rain (20 - 50 mm/day), heavy rain (50 - 100 mm/day), extremely heavy rain (100 - 150 mm/day), and extreme rain (> 150 mm/day). Rain intensity is the amount of rain that falls within a given time period. When just daily rainfall data is available, the Mononobe formula can be used to calculate rain intensity.

$$I = \frac{R_{24}}{24}\left(\frac{24}{t}\right)^{2/3} \tag{1}$$

2.3. Runoff Surface

Runoff Surface has a tremendous impact on both water management and the environment. Large surface flows can lead to flooding, soil erosion, water contamination, and other severe consequences. As a result, mitigating measures such as constructing drainage channels, planting vegetation, and good land use planning can help lessen the risk of excessive surface runoff. The surface flow coefficient, or C, is a quantity that represents the relationship between the magnitude of surface flow and the amount of rainfall (Triatmodjo, 2008)

$$C = \frac{h}{R} \tag{2}$$

Land Use	C	Land Use	C
Office Area		**Main road**	
City Center Area	0.70-0.95	Paved	0.70-0.95
Surrounding City Area	0.50-0.70	Concrete	0.80-0.95
		Brick	0.70-0.85
Housing		Sidewalk	0.75-0.85
Single-family home	0.30-0.50	Roofed area	0.75-0.95
Detached apartment	0.40-0.60		
Attached apartment	0.60-0.75	**Open land**	
Suburban area	0.25-0.40	Sandy, flat, 2%	0.05-0.10
		Sandy, somewhat level, 2-	0.10-0.15
Industrial area		7%	0.15-0.20
Less densely	0.50-0.80	Sandy, sloped, 7%	0.13-0.17
industrialized	0.60-0.90	Heavy soil, flat, 2%	0.18-0.22
Densely industrialized	0.10-0.25	Heavy soil, somewhat	0.25-0.35
Parks, cemeteries	0.20-0.35	level, 2-7%	
Playgrounds	0.20-0.40	Heavy soil, sloped, 7%	
Train station area	0.10-0.30		
Underdeveloped area			

Table 1: The value of the surface flow coefficient (C) in the rational equation (Triatmodjo, 2008).

The Rational Method is the most widely used approach for predicting surface runoff flow estimates in a watershed. In this example, the magnitude of the flow is determined by the watershed's extent, rainfall intensity, land surface condition as defined by the runoff coefficient, and slope. (Limantara, 2010). The flood debit using the Rational Method is expressed as follows:

$$Q = 0.278\ C.I.A \tag{5}$$

2.4. Infiltration

Infiltration is the movement of water into the soil through the surface, where it flows laterally as interflow to springs, lakes, and rivers, or vertically as percolation to groundwater. When rainfall is projected to remain continuous, the greatest infiltration happens at the start of the rain (fo), while surface runoff occurs after a certain amount of time has passed, notably when the rate of rainfall exceeds the rate of infiltration. Surface runoff will eventually reach a steady maximum, whereas infiltration will remain constant throughout time. (David et al., 2016). The Horton Model-based infiltration rate is computed using the following equation:

$$f = f_c + (f_o + f_c)\ e^{-kt} \tag{3}$$

$$k = \frac{f_o - f_c}{F_c} \tag{4}$$

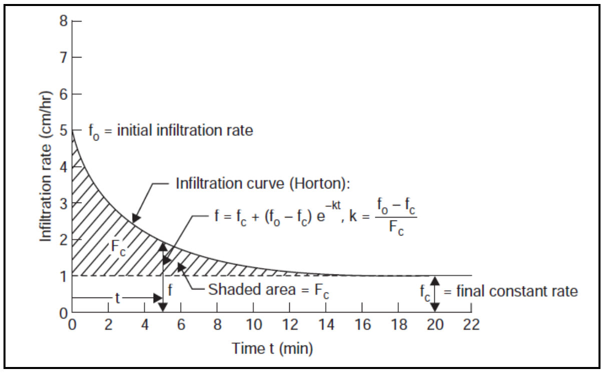

Figure 1: Horton describes the infiltration curve. [8]

2.5. Groundwater

Groundwater is defined as all water found in the aquifer layer beneath the earth's surface, filling the pore spaces of rocks and positioned below the water table. The porosity of a basin's rocks and their ability to conduct and convey water have a significant impact on its groundwater potential. Groundwater moves at varying rates in different types of soils. In sandy soil, groundwater travels faster than in other types of soil. Groundwater can be classed as confined or unconfined. Confined groundwater is also known as artesian water. Unconfined groundwater, also known as free groundwater or shallow groundwater (soil water), is groundwater that is not contained by an impermeable layer. This is the type of groundwater that we generally find while digging a well. The top limit of free groundwater is known as the water table (WT), and it also acts as the saturated zone border. The ability of soil to transfer water is known as hydraulic conductivity (K), and it is measured in the same units as velocity (length/time). The value of K for a soil type is determined by the solid's qualities (particle diameter and effective porosity) as well as the fluid's properties (kinematic viscosity, υ). The wider the diameter of the soil particle, the higher the K value, whereas clay has a very low K value (Rotz, 2021)

Soil types	Price K (m/day)
Clay (surface)	0.01- 0.20
Inner clay (deep clay beds)	10^{-8} - 10^{-2}
Surface clay	0.1 - 1.0
Fine sand	1.0 - 5.0
Medium sand	5.0 - 20
Coarse sand	20 - 100
Gravel	100 - 1000
Gravelly sand	5.0 - 100
A mixture of clay, sand, and gravel	0.001 - 0.1

Table 2: K represents the price range for various types of land (Rotz, 2021)

2.6. Groundwater Recharge

Artificial groundwater recharge is the process of increasing the amount of water that enters the ground or improving the infiltration of precipitation or surface water bodies into subsurface formations through a variety of approaches. This condition may lessen the likelihood of flooding and groundwater shortages. Natural groundwater recharge is simply a hydrological process that begins with infiltration and continues with percolation. Infiltration is the passage of water (typically rainwater) into the soil via capillary action (lateral movement of water) or gravity (vertical movement of water). Percolation happens when the topsoil layer becomes wet and gravity drags additional water downhill. (Asdak, 2010). The pace of groundwater recharge varies dramatically and is determined by a variety of factors, including the thickness of the unsaturated zone. If the unsaturated zone is thinner, the water table will replenish faster. The thinness of the unsaturated zone is usually determined by how low the topography is, as seen in places near lakes, beaches, or lowlands (Eko Aryanto & Hardiman, 2017).

2.7. Reduced surface flow and groundwater recharge

The rapid development and growth of cities due to urbanization has resulted in the loss of infiltration zones, reducing water's ability to seep into the earth. This leads to increased surface runoff during rainfall, peak discharge, and sedimentation, which increases the likelihood of urban flooding or waterlogging. Integrated flood management measures can be approached from both structural (in the form of grey and green infrastructure) and non-structural perspectives. The grey structure approach must be accompanied by long-term flood management efforts through environmentally friendly green infrastructure approaches such as river and coastal restoration, and by applying the Low Impact Development (LID) concept in residential areas, such as green roofs, retention ponds, rainwater harvesting, bioretention, rain gardens, temporary water storage, and others, which function to utilize rainwater (because rain is seen as an asset that needs to.

3. Materials and Methods

3.1. Tools and materials.

The studies were carried out in a flume built to imitate a pool constructed of a steel frame with fiber walls. The pool's overall dimensions are 240 cm long, 35 cm wide, and 140 cm high, including a circulation pool (20x35x110 cm), a detention pool (70x35x110 cm), a retention pool (50x35x110 cm), and a storage pool. (100x35x110 cm). The flume experiment includes a flow measuring device in the form of a triangle weir (V-notch) to monitor each pool's inflow and outflow rates, an infiltration rate sensor, a flow control valve, and a pump based on flow capacity. The simulation requires a non-viscous fluid (water) and soil with three different permeabilities.

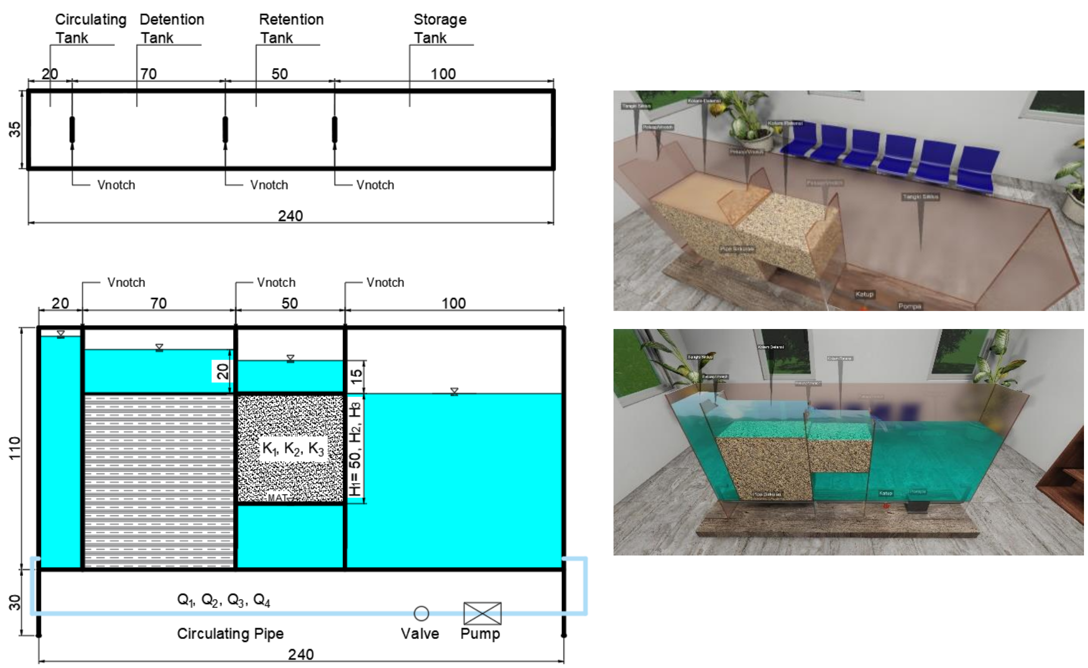

Figure 2: The notion of research model planning

3.2. Variables for research

In accordance with the research objectives and to test the hypothesis presented in the previous chapter, the underground tank in the form of a detention and retention tank is evaluated for its ability to reduce surface flow concentration by capturing or storing rainwater in the tank, allowing it to flow or infiltrate into the ground, and partially directing it to the surface drainage system. The research variables for this study are collected from the characteristics that influence surface runoff, surface runoff decrease, and groundwater flow, such as: The parameter debit (Q) is influenced by the height of rainfall (R), the catchment area's land cover, which determines the runoff coefficient (c), the area of the rain catchment to be studied (A), soil permeability (k), which is related to the infiltration rate (i), the elevation of the groundwater table (WMAT), which is assessed to affect the groundwater recharge capacity, and the dimensions/capacity of the planned detention and retention tanks. (v).

3.3. Design simulations for research models

The simulation used four flow rate changes to reflect the discharge from moderate, heavy, extremely heavy, and extreme rains. Soil permeability in relation to infiltration rates was varied in three ways, and groundwater table height was also varied in three ways, demonstrating that groundwater table elevation is not constant in all areas and can fluctuate depending on season.

4. Hypothesis

The use of underground detention and retention tanks is thought to be helpful in minimizing surface runoff while also serving as a medium for capturing and channeling water into the earth in metropolitan settings. The optimality and performance of underground tanks for flood control and sustainable, environmentally friendly groundwater recharge are determined by the basin's dimensions, which are impacted by rainfall/runoff rates, soil permeability, and groundwater table elevation. These are the primary parameters in the implementation of this study. The equations developed in this study by creating correlations between the influencing parameters can be used to design the utilization of subsurface tanks in various locations.

5. Conclusion

The anticipated results of the research on the utilization of subsurface tanks are:

1. Analyzing the impact of underground tank structures on decreasing surface runoff and recharging groundwater through infiltration;

2. Developing a model to understand the characteristics that impact the utilization of underground tanks for surface runoff reduction and groundwater recharge;

3. The effectiveness of using underground tanks in minimizing surface runoff and replenishing groundwater.

6. Acknowledgments

This Research Was Supported by Hydraulic Laboratory Civil Engineering Hasanuddin University, The Higher Education Funding Center (BPPT) Kendikbudristek and The Education Fund Management Institute (LPDP) for Providing Funding for This Research.

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