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Evaluation Zero Runoff Concept in High-Rise Buildings

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ABSTRACT

The increasing need for land in urban areas has led to a reduction in green open spaces, limiting water infiltration and increasing surface runoff. Office areas in South Jakarta currently under construction exacerbate these issues due to limited green land. **This study evaluates** the application of the zero runoff concept by analyzing two key aspects: surface runoff and building wall contributions. Hydrological simulations were conducted to assess planned flood conditions at outlets before and after the construction of tall buildings (offices), with water management strategies involving infiltration wells, infiltration ponds, rainwater reservoirs, and detention reservoirs. Two scenarios were analyzed: the first based on the 95th percentile rainfall volume and the second on flood contribution volumes. Each scenario considered three water runoff management systems: normal outlets, orifice outlets, and pump-assisted drainage. **The results** show that under the 95th percentile volume, the zero runoff concept is achievable with a capacity exceeding 100% for both scenarios. However, when accounting for flood contributions, only surface runoff with normal outlet conditions meets the zero runoff criteria, achieving a capacity of 112%. Simulations using three models: 1A, 2A, and 3A, demonstrate that pre-construction conditions, characterized by green open spaces with dense vegetation, significantly influence runoff management. **These findings** emphasize the importance of eco-drainage strategies, such as infiltration wells and retention ponds, in mitigating urban runoff and achieving sustainable water management in high-density areas.

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1. INTRODUCTION

The development of community activities and population growth has triggered regional growth across various sectors, leading to significant changes in landuse characteristics within watersheds. These landuse changes play a dominant role in influencing surface runoff and river flood discharge, which in turn contribute to climate change conditions [1]. Surface runoff in a watershed is particularly significant due to its impact on peak flood timing and volume [2], both of which are influenced by land cover type, area [3], and soil characteristics. Changes in land cover and soil properties are critical components in assessing watershed behavior. In Jakarta, the 2021 La Niña phenomenon brought high-intensity rainfall, causing severe flooding across several urban areas.

The Krukut watershed, which flows into the Krukut River divides the Depok area (West Java Province) and DKI Jakarta Province (South and Central Jakarta). With a population density of 109 people/ha, it is the most densely populated watershed in Jakarta. The Krukut River's fast flow pattern frequently results in overflows and floods [4]. The most severe flood occurred in 2016, leading to the loss of more than ten lives and severe economic disruption in South Jakarta. Areas such as Pondok Labu Village, Cilandak Timur Village, and Bangka Village were among the hardest hit, with floodwaters reaching a height of 1.5 meters for three days [5].

Rainfall, a critical climate component, affects water availability and human activity in any region [5]. Climate change has intensified hydrological processes [6], including variations in rainfall patterns [7] and evaporation rates [8]. Rising global temperatures increase evapotranspiration, accelerating the water cycle [9], which causes uneven distribution of atmospheric water vapor resulting in heavy rainfall in some areas and severe droughts in others [10]. In Indonesia, changing rainfall patterns, coupled with regional development, have delayed the rainy season's onset and shortened its duration while increasing its intensity [11, 1]. Understanding the spatial and temporal variability of rainfall requires adequate data availability [12]. Factors such as elevation and land cover also significantly affect hydrological processes, including rainfall distribution [13].

Urbanization has profoundly reshaped metropolitan regions globally, including Jakarta, Indonesia. As one of the most densely populated cities, Jakarta faces numerous environmental challenges, with urban flooding being among the most pressing [14, 15]. The rapid development of high-rise buildings has increased impermeable surfaces, diminishing the natural land's capacity to absorb rainwater and intensifying flood risks [16, 17]. In such dense urban environments, effective rainwater management is crucial to prevent recurrent flooding, optimize water resources, and support sustainable urban development.

Urbanization's link to climate change is evident through various aspects, including greenhouse gas emissions, the replacement of green land [3], the urban heat island (UHI) phenomenon [17], and shifts in hydrological patterns [18, 19, 1, 20, 21]. This is evident in the recurring phenomena of flooding and drought in Indonesia. Jakarta, in particular, has been severely affected, underscoring the need for innovative water management approaches tailored to urban areas.

This paper evaluates the effectiveness of rainwater management systems in high-rise buildings in DKI Jakarta using the zero runoff concept. Specifically, the study focuses on assessing the performance of the zero runoff concept through eco-drainage management strategies.

2. LITERATURE REVIEW

2.1. Drainage System

Drainage is a critical urban infrastructure designed to control and safely discharge excessive rainwater runoff, while also managing wastewater that can negatively impact and pollute urban environments [22]. Efficient drainage systems are essential in urban areas to prevent flooding, maintain public health, and support sustainable development. However, conventional drainage systems often struggle to cope with increasing rainfall intensity and urbanization. This highlights the necessity for innovative approaches like eco-drainage systems.

2.2. Eco Drainage

Eco-drainage focuses on managing excess rainwater by maximizing natural absorption into the soil or channeling it into rivers without exceeding their capacity [23]. This approach aligns with sustainable urban development by mitigating surface runoff and enhancing groundwater recharge. Eco-drainage methods can be divided into three management zones:

- Upstream Area: Rainwater runoff is managed primarily through absorption techniques, such as retention patterns.
- Middle Area: Rainwater runoff is temporarily stored or absorbed using a combination of retention and detention systems [24, 25].
- Downstream Area: Excess runoff is channeled through drainage systems into reservoirs or ponds for temporary storage before being released or pumped into water bodies [26, 27].

Key eco-drainage techniques include:

- Biopore Infiltration Holes

- Infiltration Wells
- Conservation Ponds (retention or detention systems)
- Infiltration Ditches
- Rainwater Reservoirs
- Green Roofs and Rain Gardens

These systems enhance natural infiltration and reduce urban flooding risks, making them critical components in modern urban planning.

2.3. ZERO RUNOFF CONCEPT

Zero runoff is an approach in water management that aims to reduce rainwater runoff from an area, especially in urban areas so that the volume of air flowing into drainage channels or rivers is minimal or even zero. This is done by arranging for rainwater that falls in an area to be absorbed into the ground or managed at that location without causing puddles or flooding.

The zero runoff approach mimics natural hydrological conditions by maintaining or restoring the local air cycle. Here are some principles and strategies commonly applied: Air Infiltration into the Soil Using infiltration wells, biopores, and infiltration gardens to increase direct rainwater infiltration into the ground. Rainwater Harvesting Utilizes rainwater harvesting or rainwater collection to store air in tanks or pools so that it can be reused for other needs, such as watering plants or household needs. Use of Porous Materials pavement materials that can absorb air, such as porous paving blocks or asphalt, reduce airflow on the ground surface. Green Roofs and Rain Gardens Utilizing garden roofs and rain gardens that function as green areas to retain air and reduce surface flow. Spatial Planning and Landscape Arrangement arranges the landscape so that air can flow to lower areas to be absorbed, for example, by using swales (shallow green ditches) or natural drainage systems. Wastewater Management and Micro Drainage Integrate micro drainage systems, which include wastewater or rainwater treatment on a small scale, to minimize water flow into public channels.

Implementing zero runoff is expected to reduce flood risk, improve groundwater quality, and restore a more natural balance of the hydrological cycle, especially in areas that have experienced extensive land conversion, such as big cities. Table 1 outlines the criteria for implementing the zero runoff concept based on two main regulatory standards: SNI 03-2453-2002 and PERMEN PU 11/prt/m/2014. These standards define the parameters required to manage runoff in urban areas effectively, aiming to reduce flood risks, improve groundwater recharge, and maintain a sustainable hydrological balance.

Table 1. Zero Runoff Criteria

Criteria	SNI 03-2453-2002	PERMEN PU 11/prt/m/2014
Rainfall (I)	Daily Average	95% Percentile
Catchment Area (A)	Planning Area (PA)	Planning Area (PA)
Runoff Coefficient (C)	Built Condition	Built Condition
Outlet	None	None
Formula	$V_{ab} = 0.855 \times C \times A \times R$	$V_{wk} =$ Rainfall 95% $\times A$

Explanation:

- V_{ab}: Volume of stormwater to be captured by the infiltration well (m^3)
- C: Runoff coefficient from the catchment area (dimensionless)
- A: Catchment area (m^2)
- R: Average daily rainfall height (L/m^2/day)

The table highlights the criteria for implementing zero runoff concepts under two different standards, focusing on managing stormwater to prevent surface runoff and flooding. The formulas provided are essential for calculating the volume of rainwater that needs to be managed on-site using infiltration systems, ensuring that urban developments maintain hydrological balance while mitigating environmental impacts. This approach supports sustainable water management practices, particularly in high-density urban areas.

2.4. Recent Developments

Research on eco-drainage and zero runoff concepts has gained traction due to increasing urbanization and climate change impacts. Recent studies highlight the importance of integrating advanced simulation tools such as HEC-HMS to model hydrological responses effectively [28]. Furthermore, advancements in permeable pavement technologies and green infrastructure have improved the feasibility of applying these concepts in dense urban settings.

Studies on zero runoff systems in high-rise buildings have emphasized the need to account for vertical surfaces, such as building walls, as significant contributors to runoff. Research by [29] revealed that walls and roofs collectively contribute to approximately 15% and 85% of total runoff, respectively, necessitating targeted interventions.

2.5. Limitations and Opportunities

While eco-drainage and zero runoff systems offer promising solutions, challenges remain. Low soil permeability, limited urban space, and the cost of implementing advanced systems are significant barriers. Future research should focus on optimizing these systems for cost-effectiveness and adaptability, particularly in high-density urban environments. Additionally, studies are needed to evaluate the long-term performance and maintenance requirements of eco-drainage systems under varying climatic conditions. By addressing these challenges, eco-drainage and zero runoff systems can be more effectively integrated into urban planning, contributing to sustainable and resilient cities.

3. METHODOLOGY

3.1. Study Area

The study was conducted in South Jakarta, focusing on a high-rise office building site located on Jl. Guru Mughni, Kuningan, Jakarta, which covers an area of 9,865 m². This location features two towers: Tower 1 (36 floors) and Tower 2 (46 floors), with a combined total floor area of 80,907.37 m². The study area lies within the Krukut watershed, a highly urbanized and densely populated region characterized by clay soil with low permeability, which poses challenges for rainwater management in Figure 1. The Krukut watershed's urban setting emphasizes the need for innovative water management strategies, such as the zero runoff concept.

To address these challenges, the eco-drainage system was designed to mitigate surface runoff and manage rainwater efficiently within the study area. Figure 2 provides a schematic representation of the planned eco-drainage system, which integrates multiple components:

- Infiltration Wells: Designed to increase groundwater recharge by allowing rainwater to percolate through the soil.
- Retention Ponds: Temporary storage areas for excess runoff, aiding in controlled water release during high rainfall events.
- Rainwater Reservoirs: Facilities for harvesting and storing rainwater for reuse in non-potable applications.
- Pump-Assisted Drainage Systems: Employed to discharge water efficiently during extreme rainfall, especially in areas with limited natural infiltration.

This system design aims to fulfill the zero runoff criteria by ensuring all rainwater within the site is absorbed, stored, or managed without contributing to surface runoff.

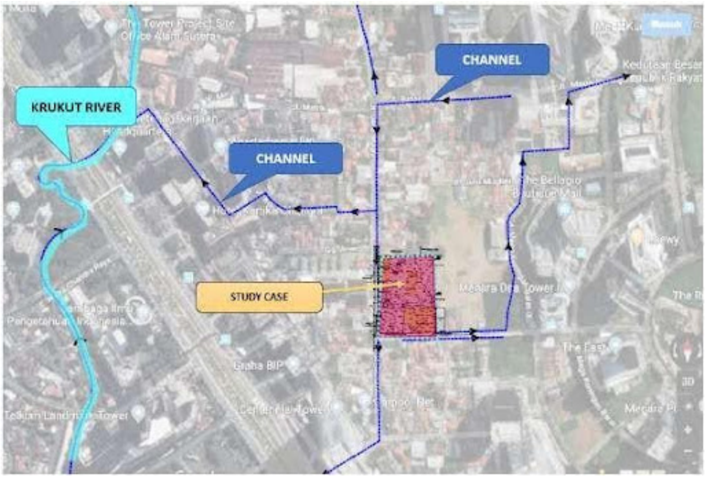


Figure 1. Map of the study area in South Jakarta, showing the location of high-rise office buildings within the Krukut watershed and nearby urban infrastructure

This Figure 1 illustrates the geographical location and boundaries of the study area, situated in South Jakarta within the Krukut watershed. The area encompasses a high-density urban environment with limited green spaces and features two high-rise office towers currently under development. The figure highlights the layout of the land, surrounding infrastructure, and its proximity to the Krukut River, emphasizing the challenges of implementing water management solutions in urbanized settings.

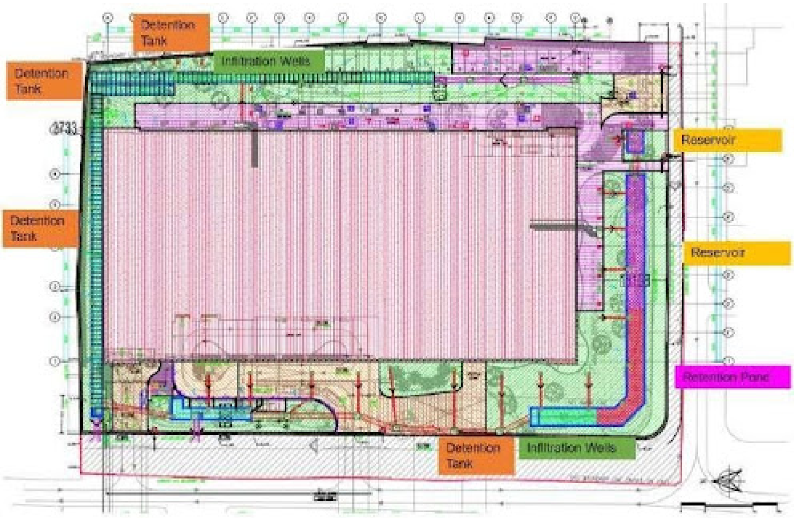


Figure 2. Ecodrainage System

Figure 2 depicts the eco-drainage system components planned for the study area, including infiltration wells, retention ponds, rainwater reservoirs, and pump-assisted drainage systems. It provides a schematic representation of how these elements are integrated to manage surface runoff and meet the zero runoff criteria. The system design addresses the limited permeability of the area's clay soil and emphasizes the role of innovative water management strategies in dense urban environments.

3.2. Method

The steps of the research carried out were as follows:

1. **Hydrological Analysis:** Collecting rainfall data for 10 years (2000-2022) from Kemayoran Rain Station.
2. **Soil Data:** Collecting soil permeability data and groundwater elevation measurements.

3. **Design Rainfall Analysis:** Analysis of the design rainfall by return period using Normal, Gumbel, Log Normal, and Log Pearson Type III methods. The resulting design rainfall must comply with the requirements of the:
   - Skewness coefficient (C_s),
   - Variation coefficient (C_v), and
   - Kurtosis coefficient (C_k).

   After performing the frequency analysis calculations, the next step involves conducting goodness-of-fit tests using the Chi-square and Smirnov-Kolmogorov tests. These tests determine whether the selected distribution type is appropriate for the given data [22, 30].

4. **Hydrological Model Setup:**
   - The Soil Conservation Service (SCS) method was used to calculate direct runoff. The model incorporated curve numbers (CN) derived from landuse and soil characteristics.
   - HEC-HMS (Hydrologic Engineering Center's Hydrologic Modeling System) software was employed to simulate the hydrological response of the site to various rainfall events [23, 31].

5. **Rainfall Analysis for Zero Runoff System:** Based on the Standard of Indonesia (SNI-03-2453-2002) and Ministerial Regulation of Public Works And Public Housing No. 11/prt/m/2014.
   - **Catchment Area Calculation:** The catchment area included both the building's surface (roof and ground) and its vertical surfaces (walls).
   - **Simulation Scenarios:** Several simulation scenarios were developed to evaluate the effectiveness of the rainwater management system:
     - Scenario 1: Initial conditions (empty retention systems), assessing zero runoff compliance.
     - Scenario 2: Conditions after previous rainfall events, assessing the system's capacity under zero delta runoff.
     - Scenario 3: Inclusion of runoff from building walls in addition to surface runoff.
     - Scenario 4: Varied outlet types were considered, including normal outlets, orifice systems, and pump-assisted drainage, to assess their effectiveness in controlling runoff.

6. **Performance Metrics:**
   - The effectiveness of the rainwater management system was evaluated based on its ability to meet zero runoff criteria. This was measured by the percentage of runoff volume that could be managed on-site without exceeding the design discharge limits.
   - **Key performance indicators included:**
     - Volume of rainwater managed (m^3).
     - Peak discharge rates (m^3/s).
     - Effectiveness of detention and infiltration systems (%).

4. RESULT AND DISCUSSION

4.1. Hydrology Analysis

The calculation of rainfall distribution uses four methods for each station, namely the Normal, Log-Normal, Log-Pearson Type III, and Gumbel distribution methods. The results were obtained using the chi-square and Smirnov Kolmogorov tests. A summary of the design rainfall analysis is in Table 2. The distribution to be used must comply with the requirements of the skewness coefficient (C_s), variation coefficient (C_v), and kurtosis coefficient (C_k) according to Table 3.

Table 2. Rainfall and Return Period Recapitulation (200-2023)

No.	R_t (Year)	Gumbel	Normal	Log-Normal	Log-Pearson III
1	2	137.13	146.30	135.21	132.62
2	5	200.85	197.60	189.43	188.27
3	10	243.04	224.48	226.03	228.60
4	25	296.36	250.64	268.43	283.66
5	50	335.90	271.51	307.90	327.75
6	100	375.16	288.62	344.53	374.31
7	200	414.27	303.89	380.90	423.88
8	500	465.88	322.21	429.65	494.73
9	1000	504.88	335.04	467.44	553.28

Table 2 presents the rainfall data calculated for various return periods (R_t) using four different probability distribution methods: **Gumbel**, **Normal**, **Log-Normal**, and **Log-Pearson Type III**. These distributions are widely used in hydrology to analyze extreme rainfall events and design flood discharges.

Table 3. Chi Square Test Recapitulation

Probability Distribution	Chi Square (%)	Smirnov-Kolmogorov (%)	Average (%)	Rank
Gumbel	53%	39%	46.0%	3
Normal	37%	61%	49.0%	4
Log-Normal	32%	38%	34.6%	2
Log-Pearson III	32%	33%	32.4%	1

Rainfall was based on the recurrence period of the results of four methods, namely the Normal, Log-Normal, Log-Pearson Type III, and Gumbel distribution methods. Testing was carried out using the Chi-square and Smirnov-Kolmogorov tests. The Chi-square test can compare two or more groups of categorized data, while the Smirnov-Kolmogorov test is used to test the goodness of fit between the sample distribution and other distributions and to compare a series of data on the sample against the normal distribution of a series of values with the same mean and standard deviation. The flood plan was calculated using the Log Pearson III Method, based on the analysis results presented in Table 2.

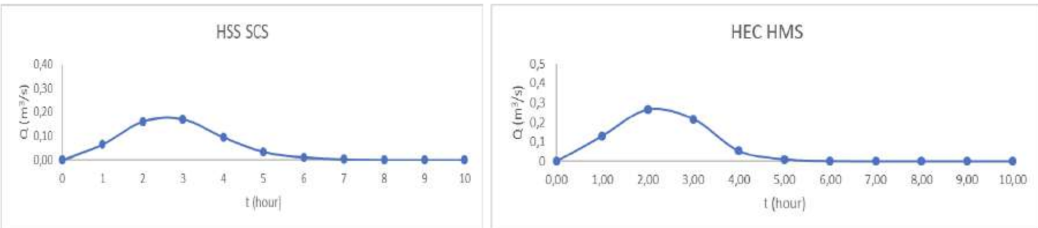


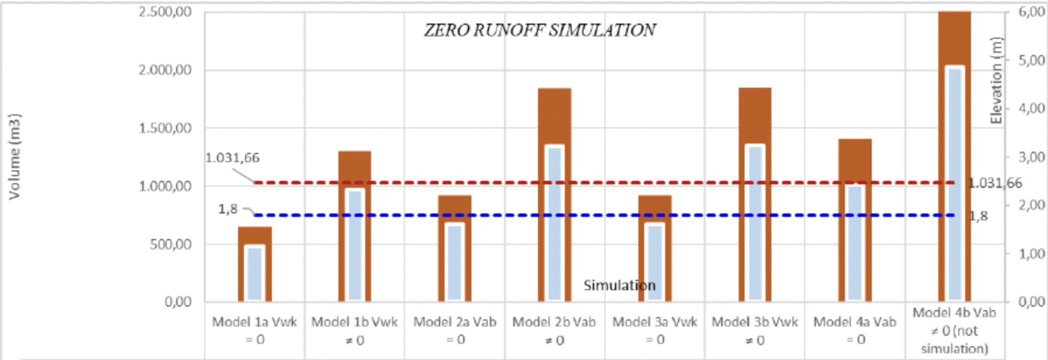
Figure 3. Hydrograph SCS and HMS Models

Based on the analysis results presented in Figure 3, the design flood discharge that is close to existing conditions, namely at a 25-year return period using the HEC HMS method, has a peak discharge of 2,46 m3/s.

4.2. Zero Runoff Analysis

Zero Runoff, namely rainwater that falls on the building plot, is calculated as part of the mandatory rainwater management status, which must be attempted to prevent overflowing out of the building plot. The catchment area used in the zero runoff concept is in accordance with the plot planning area and the area of the building walls, in accordance with the Standard of Indonesia (SNI—8153-2015) Plumbing Systems in Buildings. Based on these regulations, the criteria used in the zero runoff analysis consist of rainfall, catchment area, runoff coefficient, and outlet type. The calculation of the planned flood discharge at the outlet is based on two criteria; each criterion has 2 analyses of the outlet design. Criteria 1 consists of surface runoff, and Criteria

2 consists of surface runoff and building walls. Analysis of each criterion is based on percentile volume and flood contribution volume.



	Model 1a Vwk = 0	Model 1b Vwk ≠ 0	Model 2a Vab = 0	Model 2b Vab ≠ 0	Model 3a Vwk = 0	Model 3b Vwk ≠ 0	Model 4a Vab = 0	Model 4b Vab ≠ 0 (not simulation)
Water Required	650,10	1.300,17	919,60	1.839,15	922,92	1.845,80	1.411,54	2823,074029
Elevation Required	1,16	2,33	1,61	3,23	1,62	3,24	2,43	4,86
Water Availability	1.031,66	1.031,66	1.031,66	1.031,66	1.031,66	1.031,66	1.031,66	1.031,66
Elevation Normal (m)	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8

Figure 4. Simulation zero runoff condition

Based on the simulation results, the models that meet the zero runoff concept are model 1A, model 2A, and model 3A. All three models had an initial condition of 0 (no high-rise buildings had been built), whereas, at that time, it was still a green open space area with a majority of lush green trees. The flow of water/drainage load from the upstream that enters the high-rise building area is channeled to the outlet through the existing drainage with a square cross-sectional shape of concrete masonry. The planned flood discharge at the outlet was obtained at 2.46 m3/sec.

Eco-drainage management, with a simulation of a rainwater management system at various rainfall intensities, is needed to fulfill the concept of zero runoff with an eco-drainage system. Based on the conditions of the research area, the eco drainage management used each has a function in rainwater management to anticipate surface runoff, including:

- **Infiltration Wells:** Infiltration wells play a crucial role in managing 60-70% of the total runoff during moderate rainfall, demonstrating their effectiveness. However, during extreme events (eg, a 10-year storm), the infiltration capacity is exceeded, necessitating the use of retention ponds and pumps. The limited effectiveness due to low soil permeability at the site (especially clay) is a challenge highlighted in previous research [32, 26].

- **Infiltration Ponds:** Retention ponds are effective in most rainfall scenarios, successfully accommodating excess runoff that cannot be absorbed by infiltration wells. This system, when combined with a pump system during high-intensity storms, allows for controlled water release. These findings align with the study by [28], which demonstrated the efficiency of detention systems in urban stormwater management.

- **Pumping System:** The pumping system is a crucial addition to ensure the zero delta runoff criterion is met during extreme rainfall events. Pumps effectively discharge excess water that cannot be handled by the natural drainage system, preventing flooding at the site. Similar results have been observed in high-rise construction where space for infiltration is limited.

In addition, the contribution of vertical surfaces (building walls) to the total runoff is quite significant. The system initially met the zero runoff criterion in simulations where runoff from walls was not considered. However, after including runoff generated by walls, the total runoff increased by an average of 10-15%, especially during heavy rainfall events. These results are consistent with the findings, which showed that vertical surfaces in high-rise buildings can contribute significantly to the total runoff. Roof vs. Wall Contribution: Simulations showed that roofs contributed about 85% of the total runoff, while walls contributed 15%. This additional runoff increases the load on the infiltration wells and detention systems, reducing their effectiveness in extreme scenarios.

5. MANAGERIAL IMPLICATIONS

Urban planners and policymakers should prioritize implementing the zero runoff concept in high-density urban areas by integrating eco-drainage systems such as infiltration wells, retention ponds, and rainwater reservoirs. These systems can effectively mitigate urban flood risks and support sustainable water management. Developers should design high-rise buildings with rainwater management strategies that address both horizontal (roofs) and vertical (walls) runoff contributions. Additionally, establishing regulatory frameworks and offering financial incentives, such as subsidies or tax benefits, can encourage the adoption of such systems in new developments.

Municipal governments must create a robust monitoring and maintenance framework to ensure the long-term performance of eco-drainage infrastructure under changing climatic conditions. Scaling these strategies to other urban areas with similar challenges can further enhance urban resilience. By embedding zero runoff approaches into broader climate adaptation and urban development plans, cities can better manage hydrological risks while promoting sustainable and livable urban environments.

6. CONCLUSION

The study evaluated the application of the zero runoff concept in high-rise office building areas within the Krukut watershed, focusing on managing surface runoff and rainwater contributions from building walls. By simulating the peak flood discharge for a 25-year return period, the research compared pre and post-construction conditions to assess the effectiveness of various water management systems. **The findings** demonstrated that models 1A, 2A, and 3A successfully met the zero runoff criteria, achieving complete on-site management of rainwater. Pre-construction conditions, characterized by dense vegetation and open green spaces, played a significant role in mitigating surface runoff. However, the transition to urbanized land use introduced challenges in managing drainage loads effectively.

Key insights from the simulation emphasize the critical role of integrating eco-drainage systems, such as infiltration wells, retention ponds, and pump-assisted drainage, in urban water management. These systems proved capable of handling peak runoff volumes under normal and extreme rainfall scenarios. However, the study also underlined that achieving zero runoff is more complex in highly urbanized settings with low soil permeability, such as the clay-dominated soil in the study area. Challenges like limited space for infiltration infrastructure and increased vertical runoff from high-rise buildings necessitate innovative approaches to ensure sustainable water management.

In conclusion, **this research provides** valuable insight into the implementation of the zero runoff concept in dense urban environments. It reinforces the importance of eco-drainage strategies in mitigating urban flood risks and highlights the need for more studies addressing long-term performance, cost-effectiveness, and adaptability of these systems to climate variability. Policymakers and urban planners are encouraged to incorporate these strategies into urban development projects to achieve sustainable and resilient water management solutions for rapidly growing cities like Jakarta. **Future work** should explore optimizing these systems for broader applications, particularly in regions facing similar urbanization and hydrological challenges.

7. DECLARATIONS

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7.2. Author Contributions

Conceptualization: AC; Methodology: AC, EK and AR; Software: EK dan AR; Validation: AR; Formal Analysis: AC, EK, and DP; Investigation: AC, EK, and AR; Resources: DP; Data Curation: DP;

Writing Original Draft Preparation: AC and AR; Writing Review and Editing: AC, EK, and AR; Visualization: DP; All authors, AC, EK, AR and DP, have read and agreed to the published version of the manuscript.

7.3. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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7.5. Declaration of Conflicting Interest

The authors declare that they have no conflicts of interest, known competing financial interests, or personal relationships that could have influenced the work reported in this paper.

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Evaluation Zero Runoff Concept in High-Rise Buildings

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Evaluation Zero Runoff Concept in High-Rise Buildings

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ABSTRACT

The increasing need for land in urban areas has led to a reduction in green open spaces, limiting water infiltration and increasing surface runoff. Office areas in South Jakarta currently under construction exacerbate these issues due to limited green land. **This study evaluates** the application of the zero runoff concept by analyzing two key aspects: surface runoff and building wall contributions. Hydrological simulations were conducted to assess planned flood conditions at outlets before and after the construction of tall buildings (offices), with water management strategies involving infiltration wells, infiltration ponds, rainwater reservoirs, and detention reservoirs. Two scenarios were analyzed: the first based on the 95th percentile rainfall volume and the second on flood contribution volumes. Each scenario considered three water runoff management systems: normal outlets, orifice outlets, and pump-assisted drainage. **The results** show that under the 95th percentile volume, the zero runoff concept is achievable with a capacity exceeding 100% for both scenarios. However, when accounting for flood contributions, only surface runoff with normal outlet conditions meets the zero runoff criteria, achieving a capacity of 112%. Simulations using three models: 1A, 2A, and 3A, demonstrate that pre-construction conditions, characterized by green open spaces with dense vegetation, significantly influence runoff management. **These findings** emphasize the importance of eco-drainage strategies, such as infiltration wells and retention ponds, in mitigating urban runoff and achieving sustainable water management in high-density areas.

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1. INTRODUCTION

The development of community activities and population growth has triggered regional growth across various sectors, leading to significant changes in landuse characteristics within watersheds. These landuse changes play a dominant role in influencing surface runoff and river flood discharge, which in turn contribute to climate change conditions [1]. Surface runoff in a watershed is particularly significant due to its impact on peak flood timing and volume [2], both of which are influenced by land cover type, area [3], and soil characteristics. Changes in land cover and soil properties are critical components in assessing watershed behavior. In Jakarta, the 2021 La Niña phenomenon brought high-intensity rainfall, causing severe flooding across several urban areas.

The Krukut watershed, which flows into the Krukut River divides the Depok area (West Java Province) and DKI Jakarta Province (South and Central Jakarta). With a population density of 109 people/ha, it is the most densely populated watershed in Jakarta. The Krukut River's fast flow pattern frequently results in overflows and floods [4]. The most severe flood occurred in 2016, leading to the loss of more than ten lives and severe economic disruption in South Jakarta. Areas such as Pondok Labu Village, Cilandak Timur Village, and Bangka Village were among the hardest hit, with floodwaters reaching a height of 1.5 meters for three days [5].

Rainfall, a critical climate component, affects water availability and human activity in any region [5]. Climate change has intensified hydrological processes [6], including variations in rainfall patterns [7] and evaporation rates [8]. Rising global temperatures increase evapotranspiration, accelerating the water cycle [9], which causes uneven distribution of atmospheric water vapor resulting in heavy rainfall in some areas and severe droughts in others [10]. In Indonesia, changing rainfall patterns, coupled with regional development, have delayed the rainy season's onset and shortened its duration while increasing its intensity [11, 1]. Understanding the spatial and temporal variability of rainfall requires adequate data availability [12]. Factors such as elevation and land cover also significantly affect hydrological processes, including rainfall distribution [13].

Urbanization has profoundly reshaped metropolitan regions globally, including Jakarta, Indonesia. As one of the most densely populated cities, Jakarta faces numerous environmental challenges, with urban flooding being among the most pressing [14, 15]. The rapid development of high-rise buildings has increased impermeable surfaces, diminishing the natural land's capacity to absorb rainwater and intensifying flood risks [16, 17]. In such dense urban environments, effective rainwater management is crucial to prevent recurrent flooding, optimize water resources, and support sustainable urban development.

Urbanization's link to climate change is evident through various aspects, including greenhouse gas emissions, the replacement of green land [3], the urban heat island (UHI) phenomenon [17], and shifts in hydrological patterns [18, 19, 1, 20, 21]. This is evident in the recurring phenomena of flooding and drought in Indonesia. Jakarta, in particular, has been severely affected, underscoring the need for innovative water management approaches tailored to urban areas.

This paper evaluates the effectiveness of rainwater management systems in high-rise buildings in DKI Jakarta using the zero runoff concept. Specifically, the study focuses on assessing the performance of the zero runoff concept through eco-drainage management strategies.

2. LITERATURE REVIEW

2.1. Drainage System

Drainage is a critical urban infrastructure designed to control and safely discharge excessive rainwater runoff, while also managing wastewater that can negatively impact and pollute urban environments [22]. Efficient drainage systems are essential in urban areas to prevent flooding, maintain public health, and support sustainable development. However, conventional drainage systems often struggle to cope with increasing rainfall intensity and urbanization. This highlights the necessity for innovative approaches like eco-drainage systems.

2.2. Eco Drainage

Eco-drainage focuses on managing excess rainwater by maximizing natural absorption into the soil or channeling it into rivers without exceeding their capacity [23]. This approach aligns with sustainable urban development by mitigating surface runoff and enhancing groundwater recharge. Eco-drainage methods can be divided into three management zones:

- Upstream Area: Rainwater runoff is managed primarily through absorption techniques, such as retention patterns.
- Middle Area: Rainwater runoff is temporarily stored or absorbed using a combination of retention and detention systems [24, 25].
- Downstream Area: Excess runoff is channeled through drainage systems into reservoirs or ponds for temporary storage before being released or pumped into water bodies [26, 27].

Key eco-drainage techniques include:

- Biopore Infiltration Holes

- Infiltration Wells
- Conservation Ponds (retention or detention systems)
- Infiltration Ditches
- Rainwater Reservoirs
- Green Roofs and Rain Gardens

These systems enhance natural infiltration and reduce urban flooding risks, making them critical components in modern urban planning.

2.3. ZERO RUNOFF CONCEPT

Zero runoff is an approach in water management that aims to reduce rainwater runoff from an area, especially in urban areas so that the volume of air flowing into drainage channels or rivers is minimal or even zero. This is done by arranging for rainwater that falls in an area to be absorbed into the ground or managed at that location without causing puddles or flooding.

The zero runoff approach mimics natural hydrological conditions by maintaining or restoring the local air cycle. Here are some principles and strategies commonly applied: Air Infiltration into the Soil Using infiltration wells, biopores, and infiltration gardens to increase direct rainwater infiltration into the ground. Rainwater Harvesting Utilizes rainwater harvesting or rainwater collection to store air in tanks or pools so that it can be reused for other needs, such as watering plants or household needs. Use of Porous Materials pavement materials that can absorb air, such as porous paving blocks or asphalt, reduce airflow on the ground surface. Green Roofs and Rain Gardens Utilizing garden roofs and rain gardens that function as green areas to retain air and reduce surface flow. Spatial Planning and Landscape Arrangement arranges the landscape so that air can flow to lower areas to be absorbed, for example, by using swales (shallow green ditches) or natural drainage systems. Wastewater Management and Micro Drainage Integrate micro drainage systems, which include wastewater or rainwater treatment on a small scale, to minimize water flow into public channels.

Implementing zero runoff is expected to reduce flood risk, improve groundwater quality, and restore a more natural balance of the hydrological cycle, especially in areas that have experienced extensive land conversion, such as big cities. Table 1 outlines the criteria for implementing the zero runoff concept based on two main regulatory standards: SNI 03-2453-2002 and PERMEN PU 11/prt/m/2014. These standards define the parameters required to manage runoff in urban areas effectively, aiming to reduce flood risks, improve groundwater recharge, and maintain a sustainable hydrological balance.

Table 1. Zero Runoff Criteria

Criteria	**SNI 03-2453-2002**	**PERMEN PU 11/prt/m/2014**
Rainfall (I)	Daily Average	95% Percentile
Catchment Area (A)	Planning Area (PA)	Planning Area (PA)
Runoff Coefficient (C)	Built Condition	Built Condition
Outlet	None	None
Formula	$V_{ab} = 0.855 \times C \times A \times R$	$V_{wk} =$ Rainfall 95% $\times A$

Explanation:

- V_{ab}: Volume of stormwater to be captured by the infiltration well (m^3)
- C: Runoff coefficient from the catchment area (dimensionless)
- A: Catchment area (m^2)
- R: Average daily rainfall height (L/m^2/day)

The table highlights the criteria for implementing zero runoff concepts under two different standards, focusing on managing stormwater to prevent surface runoff and flooding. The formulas provided are essential for calculating the volume of rainwater that needs to be managed on-site using infiltration systems, ensuring that urban developments maintain hydrological balance while mitigating environmental impacts. This approach supports sustainable water management practices, particularly in high-density urban areas.

2.4. Recent Developments

Research on eco-drainage and zero runoff concepts has gained traction due to increasing urbanization and climate change impacts. Recent studies highlight the importance of integrating advanced simulation tools such as HEC-HMS to model hydrological responses effectively [28]. Furthermore, advancements in permeable pavement technologies and green infrastructure have improved the feasibility of applying these concepts in dense urban settings.

Studies on zero runoff systems in high-rise buildings have emphasized the need to account for vertical surfaces, such as building walls, as significant contributors to runoff. Research by [29] revealed that walls and roofs collectively contribute to approximately 15% and 85% of total runoff, respectively, necessitating targeted interventions.

2.5. Limitations and Opportunities

While eco-drainage and zero runoff systems offer promising solutions, challenges remain. Low soil permeability, limited urban space, and the cost of implementing advanced systems are significant barriers. Future research should focus on optimizing these systems for cost-effectiveness and adaptability, particularly in high-density urban environments. Additionally, studies are needed to evaluate the long-term performance and maintenance requirements of eco-drainage systems under varying climatic conditions. By addressing these challenges, eco-drainage and zero runoff systems can be more effectively integrated into urban planning, contributing to sustainable and resilient cities.

3. METHODOLOGY

3.1. Study Area

The study was conducted in South Jakarta, focusing on a high-rise office building site located on Jl. Guru Mughni, Kuningan, Jakarta, which covers an area of 9,865 m². This location features two towers: Tower 1 (36 floors) and Tower 2 (46 floors), with a combined total floor area of 80,907.37 m². The study area lies within the Krukut watershed, a highly urbanized and densely populated region characterized by clay soil with low permeability, which poses challenges for rainwater management in Figure 1. The Krukut watershed's urban setting emphasizes the need for innovative water management strategies, such as the zero runoff concept.

To address these challenges, the eco-drainage system was designed to mitigate surface runoff and manage rainwater efficiently within the study area. Figure 2 provides a schematic representation of the planned eco-drainage system, which integrates multiple components:

- Infiltration Wells: Designed to increase groundwater recharge by allowing rainwater to percolate through the soil.
- Retention Ponds: Temporary storage areas for excess runoff, aiding in controlled water release during high rainfall events.
- Rainwater Reservoirs: Facilities for harvesting and storing rainwater for reuse in non-potable applications.
- Pump-Assisted Drainage Systems: Employed to discharge water efficiently during extreme rainfall, especially in areas with limited natural infiltration.

This system design aims to fulfill the zero runoff criteria by ensuring all rainwater within the site is absorbed, stored, or managed without contributing to surface runoff.

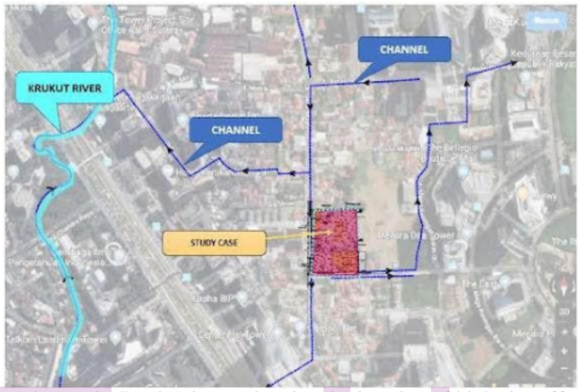


Figure 1. Map of the study area in South Jakarta, showing the location of high-rise office buildings within the Krukut watershed and nearby urban infrastructure

This Figure 1 illustrates the geographical location and boundaries of the study area, situated in South Jakarta within the Krukut watershed. The area encompasses a high-density urban environment with limited green spaces and features two high-rise office towers currently under development. The figure highlights the layout of the land, surrounding infrastructure, and its proximity to the Krukut River, emphasizing the challenges of implementing water management solutions in urbanized settings.

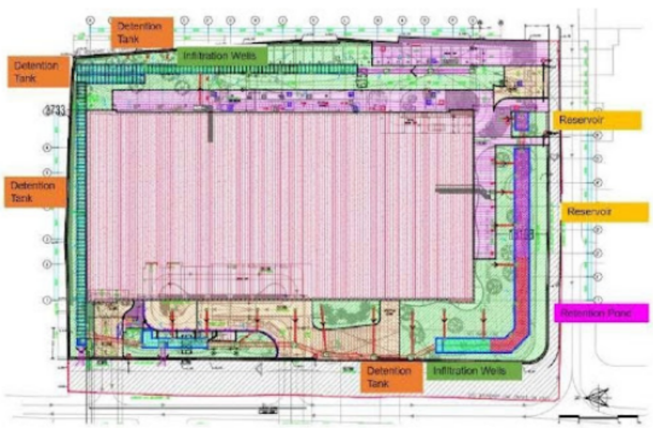


Figure 2. Ecodrainage System

Figure 2 depicts the eco-drainage system components planned for the study area, including infiltration wells, retention ponds, rainwater reservoirs, and pump-assisted drainage systems. It provides a schematic representation of how these elements are integrated to manage surface runoff and meet the zero runoff criteria. The system design addresses the limited permeability of the area's clay soil and emphasizes the role of innovative water management strategies in dense urban environments.

3.2. Method

The steps of the research carried out were as follows:

1. **Hydrological Analysis:** Collecting rainfall data for 10 years (2000-2022) from Kemayoran Rain Station.
2. **Soil Data:** Collecting soil permeability data and groundwater elevation measurements.

3. **Design Rainfall Analysis:** Analysis of the design rainfall by return period using Normal, Gumbel, Log Normal, and Log Pearson Type III methods. The resulting design rainfall must comply with the requirements of the:
   - Skewness coefficient (C_s),
   - Variation coefficient (C_v), and
   - Kurtosis coefficient (C_k).

   After performing the frequency analysis calculations, the next step involves conducting goodness-of-fit tests using the Chi-square and Smirnov-Kolmogorov tests. These tests determine whether the selected distribution type is appropriate for the given data [22, 30].

4. **Hydrological Model Setup:**
   - The Soil Conservation Service (SCS) method was used to calculate direct runoff. The model incorporated curve numbers (CN) derived from landuse and soil characteristics.
   - HEC-HMS (Hydrologic Engineering Center's Hydrologic Modeling System) software was employed to simulate the hydrological response of the site to various rainfall events [23, 31].

5. **Rainfall Analysis for Zero Runoff System:** Based on the Standard of Indonesia (SNI-03-2453-2002) and Ministerial Regulation of Public Works And Public Housing No. 11/prt/m/2014.
   - **Catchment Area Calculation:** The catchment area included both the building's surface (roof and ground) and its vertical surfaces (walls).
   - **Simulation Scenarios:** Several simulation scenarios were developed to evaluate the effectiveness of the rainwater management system:
     – Scenario 1: Initial conditions (empty retention systems), assessing zero runoff compliance.
     – Scenario 2: Conditions after previous rainfall events, assessing the system's capacity under zero delta runoff.
     – Scenario 3: Inclusion of runoff from building walls in addition to surface runoff.
     – Scenario 4: Varied outlet types were considered, including normal outlets, orifice systems, and pump-assisted drainage, to assess their effectiveness in controlling runoff.

6. **Performance Metrics:**
   - The effectiveness of the rainwater management system was evaluated based on its ability to meet zero runoff criteria. This was measured by the percentage of runoff volume that could be managed on-site without exceeding the design discharge limits.
   - **Key performance indicators included:**
     – Volume of rainwater managed (m^3).
     – Peak discharge rates (m^3/s).
     – Effectiveness of detention and infiltration systems (%).

4. RESULT AND DISCUSSION

4.1. Hydrology Analysis

The calculation of rainfall distribution uses four methods for each station, namely the Normal, Log-Normal, Log-Pearson Type III, and Gumbel distribution methods. The results were obtained using the chi-square and Smirnov Kolmogorov tests. A summary of the design rainfall analysis is in Table 2. The distribution to be used must comply with the requirements of the skewness coefficient (C_s), variation coefficient (C_v), and kurtosis coefficient (C_k) according to Table 3.

Table 2. Rainfall and Return Period Recapitulation (200-2023)

No.	R_t (Year)	Gumbel	Normal	Log-Normal	Log-Pearson III
1	2	137.13	146.30	135.21	132.62
2	5	200.85	197.60	189.43	188.27
3	10	243.04	224.48	226.03	228.60
4	25	296.36	250.64	268.43	283.66
5	50	335.90	271.51	307.90	327.75
6	100	375.16	288.62	344.53	374.31
7	200	414.27	303.89	380.90	423.88
8	500	465.88	322.21	429.65	494.73
9	1000	504.88	335.04	467.44	553.28

Table 2 presents the rainfall data calculated for various return periods (R_t) using four different probability distribution methods: **Gumbel**, **Normal**, **Log-Normal**, and **Log-Pearson Type III**. These distributions are widely used in hydrology to analyze extreme rainfall events and design flood discharges.

Table 3. Chi Square Test Recapitulation

Probability Distribution	Chi Square (%)	Smirnov-Kolmogorov (%)	Average (%)	Rank
Gumbel	53%	39%	46.0%	3
Normal	37%	61%	49.0%	4
Log-Normal	32%	38%	34.6%	2
Log-Pearson III	32%	33%	32.4%	1

Rainfall was based on the recurrence period of the results of four methods, namely the Normal, Log-Normal, Log-Pearson Type III, and Gumbel distribution methods. Testing was carried out using the Chi-square and Smirnov-Kolmogorov tests. The Chi-square test can compare two or more groups of categorized data, while the Smirnov-Kolmogorov test is used to test the goodness of fit between the sample distribution and other distributions and to compare a series of data on the sample against the normal distribution of a series of values with the same mean and standard deviation. The flood plan was calculated using the Log Pearson III Method, based on the analysis results presented in Table 2.

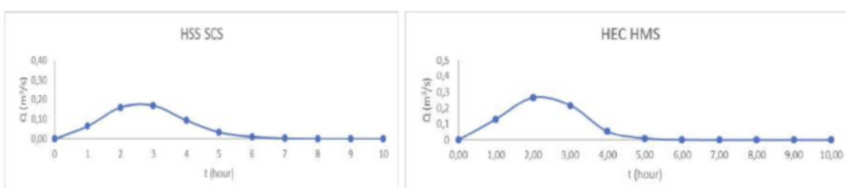


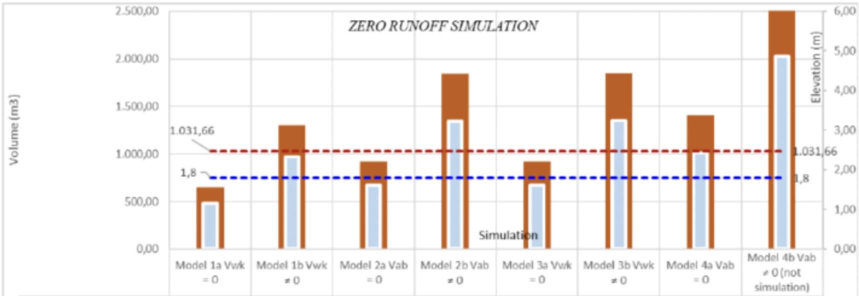
Figure 3. Hydrograph SCS and HMS Models

Based on the analysis results presented in Figure 3, the design flood discharge that is close to existing conditions, namely at a 25-year return period using the HEC HMS method, has a peak discharge of 2,46 m3/s.

4.2. Zero Runoff Analysis

Zero Runoff, namely rainwater that falls on the building plot, is calculated as part of the mandatory rainwater management status, which must be attempted to prevent overflowing out of the building plot. The catchment area used in the zero runoff concept is in accordance with the plot planning area and the area of the building walls, in accordance with the Standard of Indonesia (SNI—8153-2015) Plumbing Systems in Buildings. Based on these regulations, the criteria used in the zero runoff analysis consist of rainfall, catchment area, runoff coefficient, and outlet type. The calculation of the planned flood discharge at the outlet is based on two criteria; each criterion has 2 analyses of the outlet design. Criteria 1 consists of surface runoff, and Criteria

2 consists of surface runoff and building walls. Analysis of each criterion is based on percentile volume and flood contribution volume.



	Model 1a Vwk = 0	Model 1b Vwk ≠ 0	Model 2a Vab = 0	Model 2b Vab ≠ 0	Model 3a Vwk = 0	Model 3b Vwk ≠ 0	Model 4a Vab = 0	Model 4b Vab ≠ 0 (not simulation)
Water Required	650,10	1.300,17	919,60	1.839,15	922,92	1.845,80	1.411,54	2823,074029
Elevation Required	1,16	2,33	1,61	3,23	1,62	3,24	2,43	4,86
Water Availability	1.031,66	1.031,66	1.031,66	1.031,66	1.031,66	1.031,66	1.031,66	1.031,66
Elevation Normal (m)	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8

Figure 4. Simulation zero runoff condition

Based on the simulation results, the models that meet the zero runoff concept are model 1A, model 2A, and model 3A. All three models had an initial condition of 0 (no high-rise buildings had been built), whereas, at that time, it was still a green open space area with a majority of lush green trees. The flow of water/drainage load from the upstream that enters the high-rise building area is channeled to the outlet through the existing drainage with a square cross-sectional shape of concrete masonry. The planned flood discharge at the outlet was obtained at 2.46 m3/sec.

Eco-drainage management, with a simulation of a rainwater management system at various rainfall intensities, is needed to fulfill the concept of zero runoff with an eco-drainage system. Based on the conditions of the research area, the eco drainage management used each has a function in rainwater management to anticipate surface runoff, including:

- **Infiltration Wells:** Infiltration wells play a crucial role in managing 60-70% of the total runoff during moderate rainfall, demonstrating their effectiveness. However, during extreme events (eg, a 10-year storm), the infiltration capacity is exceeded, necessitating the use of retention ponds and pumps. The limited effectiveness due to low soil permeability at the site (especially clay) is a challenge highlighted in previous research [32, 26].

- **Infiltration Ponds:** Retention ponds are effective in most rainfall scenarios, successfully accommodating excess runoff that cannot be absorbed by infiltration wells. This system, when combined with a pump system during high-intensity storms, allows for controlled water release. These findings align with the study by [28], which demonstrated the efficiency of detention systems in urban stormwater management.

- **Pumping System:** The pumping system is a crucial addition to ensure the zero delta runoff criterion is met during extreme rainfall events. Pumps effectively discharge excess water that cannot be handled by the natural drainage system, preventing flooding at the site. Similar results have been observed in high-rise construction where space for infiltration is limited.

In addition, the contribution of vertical surfaces (building walls) to the total runoff is quite significant. The system initially met the zero runoff criterion in simulations where runoff from walls was not considered. However, after including runoff generated by walls, the total runoff increased by an average of 10-15%, especially during heavy rainfall events. These results are consistent with the findings, which showed that vertical surfaces in high-rise buildings can contribute significantly to the total runoff. Roof vs. Wall Contribution: Simulations showed that roofs contributed about 85% of the total runoff, while walls contributed 15%. This additional runoff increases the load on the infiltration wells and detention systems, reducing their effectiveness in extreme scenarios.

5. MANAGERIAL IMPLICATIONS

Urban planners and policymakers should prioritize implementing the zero runoff concept in high-density urban areas by integrating eco-drainage systems such as infiltration wells, retention ponds, and rainwater reservoirs. These systems can effectively mitigate urban flood risks and support sustainable water management. Developers should design high-rise buildings with rainwater management strategies that address both horizontal (roofs) and vertical (walls) runoff contributions. Additionally, establishing regulatory frameworks and offering financial incentives, such as subsidies or tax benefits, can encourage the adoption of such systems in new developments.

Municipal governments must create a robust monitoring and maintenance framework to ensure the long-term performance of eco-drainage infrastructure under changing climatic conditions. Scaling these strategies to other urban areas with similar challenges can further enhance urban resilience. By embedding zero runoff approaches into broader climate adaptation and urban development plans, cities can better manage hydrological risks while promoting sustainable and livable urban environments.

6. CONCLUSION

The study evaluated the application of the zero runoff concept in high-rise office building areas within the Krukut watershed, focusing on managing surface runoff and rainwater contributions from building walls. By simulating the peak flood discharge for a 25-year return period, the research compared pre and post-construction conditions to assess the effectiveness of various water management systems. **The findings** demonstrated that models 1A, 2A, and 3A successfully met the zero runoff criteria, achieving complete on-site management of rainwater. Pre-construction conditions, characterized by dense vegetation and open green spaces, played a significant role in mitigating surface runoff. However, the transition to urbanized land use introduced challenges in managing drainage loads effectively.

Key insights from the simulation emphasize the critical role of integrating eco-drainage systems, such as infiltration wells, retention ponds, and pump-assisted drainage, in urban water management. These systems proved capable of handling peak runoff volumes under normal and extreme rainfall scenarios. However, the study also underlined that achieving zero runoff is more complex in highly urbanized settings with low soil permeability, such as the clay-dominated soil in the study area. Challenges like limited space for infiltration infrastructure and increased vertical runoff from high-rise buildings necessitate innovative approaches to ensure sustainable water management.

In conclusion, **this research provides** valuable insight into the implementation of the zero runoff concept in dense urban environments. It reinforces the importance of eco-drainage strategies in mitigating urban flood risks and highlights the need for more studies addressing long-term performance, cost-effectiveness, and adaptability of these systems to climate variability. Policymakers and urban planners are encouraged to incorporate these strategies into urban development projects to achieve sustainable and resilient water management solutions for rapidly growing cities like Jakarta. **Future work** should explore optimizing these systems for broader applications, particularly in regions facing similar urbanization and hydrological challenges.

7. DECLARATIONS

7.1. About Authors

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7.2. Author Contributions

Conceptualization: AC; Methodology: AC, EK and AR; Software: EK dan AR; Validation: AR; Formal Analysis: AC, EK, and DP; Investigation: AC, EK, and AR; Resources: DP; Data Curation: DP;

Writing Original Draft Preparation: AC and AR; Writing Review and Editing: AC, EK, and AR; Visualization: DP; All authors, AC, EK, AR and DP, have read and agreed to the published version of the manuscript.

7.3. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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7.5. Declaration of Conflicting Interest

The authors declare that they have no conflicts of interest, known competing financial interests, or personal relationships that could have influenced the work reported in this paper.

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