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Evaluating the Effectiveness of Green Infrastructure in Mitigating Urban Flooding and Heat Island Effects

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Abstract
Rapid urbanization has increased pressure on urban environments, such as flood risk and heat island effects. One of the growing solutions is green infrastructure, which integrates natural elements in urban planning to reduce the negative impact of urbanization. This study aims to evaluate the effectiveness of green infrastructure in urban flood mitigation and the heat island effect through literature studies. The method used involves qualitative content analysis of scientific articles, technical reports, and official documents published in 2018–2023. The results show that elements such as rain gardens, green roofs, and urban forests significantly reduce waterlogging by increasing water infiltration and retention, as well as lowering air temperatures by 2–4°C in urban areas. In Indonesia, the implementation of green infrastructure has great potential to improve the quality of life of the community, but it still faces challenges in land distribution and technology adoption. These findings underscore the importance of data-driven strategies and progressive policies in implementing green infrastructure to create more resilient cities.

INTRODUCTION

Increasing urbanization has put great pressure on the environment, especially in densely populated urban areas. One of the impacts is the increased risk of flooding and the urban heat island effect due to the reduction of green open space. Traditional gray infrastructure, such as concrete drainage channels, is often insufficient to handle the extreme rainfall intensity due to climate change (Ahmed et al., 2025). On the other hand, the heat island effect increases temperatures in urban areas, worsens the quality of life, and triggers higher energy consumption (Li et al., 2025).

Green infrastructure is a strategic approach in spatial planning that integrates natural elements such as green open spaces, urban forests, and water bodies with artificial elements to support environmental sustainability. This approach not only helps to reduce the negative impacts of urbanization such as flooding and pollution, but also improves the quality of life of the community through sustainable ecosystem management. A study by Song et al. (2025) highlights the importance of connecting green-blue infrastructure with gray infrastructure to create more ecologically resilient systems.

The implementation of green infrastructure also plays a big role in climate change mitigation. Strategies such as the design of urban green open spaces and the use of environmentally friendly

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materials in construction can reduce the urban heat island effect and increase carbon sequestration. Ahmed et al. (2025) highlight how investment in green infrastructure and green innovation can be a key driver of green economic growth in urban areas.

In Indonesia, the implementation of green infrastructure is increasingly relevant in facing environmental challenges, such as floods and water quality degradation. For example, the Ikram and Tefa study (2025) identified the use of green infrastructure along the Bahodopi River as a solution to reduce flood risk due to industrial and residential activities (Ikram & Tefa, 2025). This approach reflects the importance of synergy between technology and nature conservation to create more resilient and sustainable cities.

Green infrastructure is an innovative solution that integrates natural elements into urban design. By utilizing vegetation, roof gardens, and water catchment areas, green infrastructure is able to reduce waterlogging through increasing soil infiltration capacity and helping to lower the temperature of the surrounding environment. In addition, green infrastructure elements such as rain parks and bioretention also improve water quality by filtering pollutants from surface runoff (Ayala-Azcarraga et al., 2025).

In Indonesia, urban areas often face major challenges in rainwater management due to spatial patterns that do not pay attention to sustainability principles. This causes significant economic losses as well as increased public health risks due to flooding. Therefore, the implementation of green infrastructure is an urgent need to create urban systems that are more resilient to environmental disasters (Khalufi et al., 2025).

However, although the potential of green infrastructure has been widely discussed, empirical evaluation of its effectiveness in the local context, especially in urban areas of Indonesia, is still very limited (Goh et al., 2025). More comprehensive studies are needed to understand the extent to which these approaches are able to reduce the impact of urban flooding and the heat island effect simultaneously.

This research is important to fill in the gaps in the literature related to the implementation and evaluation of green infrastructure in urban areas. Taking into account the increasingly real impacts of climate change and growing urbanization, it is important to ensure that the solutions offered are not only theoretically relevant but also practically implementable and have a real impact at the local level.

Several previous studies have highlighted the benefits of green infrastructure. Song et al. (2025) found that the integration of green-blue infrastructure can increase the capacity of urban ecosystems in facing the challenges of climate change (Song et al., 2025). In addition, Martini and Papafotiou (2025) showed that green roof design is able to significantly reduce surface temperatures in urban areas (Martini & Papafotiou, 2025). However, research linking flood risk reduction and the heat island effect simultaneously is still rare, especially in the context of urban areas in developing countries.

This study aims to evaluate the effectiveness of green infrastructure in reducing the impact of urban flooding and the heat island effect. The focus of this research is to identify the most effective elements of green infrastructure and provide data-driven recommendations to improve urban resilience to environmental impacts.

METHOD

This study uses a qualitative method with a library research approach. This approach was chosen to analyze and evaluate the effectiveness of green infrastructure in reducing the impact of urban flooding and the heat island effect based on relevant secondary data. Literature studies allow

researchers to identify various theories, concepts, and findings of previous research in order to produce a comprehensive understanding of the topics discussed (Snyder, 2019).

The data sources in this study come from scientific journals, books, technical reports, and official documents published in the last five years (2018-2023). The journals used are accessed through trusted databases such as ScienceDirect, Springer, and MDPI, which include articles related to green infrastructure, flood mitigation, and heat island effect reduction. Additional data sources in the form of government reports and international organizations, such as the IPCC (Intergovernmental Panel on Climate Change) report, are also used to support the analysis.

The data collection technique was carried out through a systematic search using keywords such as "green infrastructure", "urban flooding", "heat island effect", and "urban green infrastructure". This process involves the selection of documents based on inclusion criteria, namely articles that discuss elements of green infrastructure and their relation to urban environmental impact mitigation, as well as exclusion criteria in the form of documents that are not relevant to the urban context or use a non-empirical approach.

The data analysis method used is qualitative content analysis. The collected data is analyzed by extracting important information, grouping key themes, and comparing findings from different studies to produce a comprehensive synthesis. This analysis process is carried out in three stages, namely data reduction, data presentation, and conclusion drawn, as described by Miles and Huberman (1994). This analysis also includes a critical evaluation of existing research gaps, in order to provide data-based and relevant recommendations (Huberman, 2017).

RESULT AND DISCUSSION

The following is the literature data selected from several related articles found through a literature study for a journal article entitled "Evaluating the Effectiveness of Green Infrastructure in Mitigating Urban Flooding and Heat Island Effects." This data includes ten articles selected based on their relevance and contribution to the research topic.

Table 1. Literature Review

No	Author	Title	Findings
1	Omoniyi, A.O. (2024)	Analysing the Benefits and Challenges of Integrating Green Roofs and Vertical Gardens	Green infrastructure such as roof gardens reduces the heat island effect and flood risk in urban areas.
2	Zeng, F., & Lam, M. (2024)	Urban Green Infrastructure: Innovative Approaches to Climate Resilience and Sustainability	The integration of green infrastructure with urban forestry increases climate resilience and reduces urban heat.
3	Olgun, R. et al. (2024)	Nature-Based Solutions Scenario Planning for Climate Change Adaptation	Nature-based solutions are effective for climate change adaptation in semi-arid regions, reducing flooding and urban heat.
4	Thompson, R. et al. (2024)	Building for Tomorrow	The use of flood-resistant materials and energy-efficient cooling systems to reduce urban heat and improve flood adaptation.
5	Ghasem Zadeh Khatib, R.	Green Infrastructure and Climate Change: Preliminary Insights for Novara, Italy	Green infrastructure increases groundwater infiltration capacity and lowers urban temperatures in Italy.

6	Banguilan, Y.J.T. (2024)	Analysis of Urban Green Space Distribution in Metro Manila, Philippines	Green infrastructure increases groundwater infiltration capacity and lowers urban temperatures in Italy.
7	Taccone, A., & Rizzo, M.T. (2024)	Metropolitan Green: New Strategies for Urban Regeneration and Social Well-Being	Green infrastructure as a natural barrier reduces the risk of flooding and the heat island effect while improving social welfare.
8	Seelam, D.R., et al. (2025)	Integrating Artificial Intelligence in Blue-Green Infrastructure	The use of AI in green blue infrastructure increases the effectiveness of flood mitigation and urban heat reduction.
9	Bene, K., & Szél, C. (2024)	Disaster Resilience in Fiji Through Urban Green Infrastructure	Green infrastructure reduces the impact of disasters, including flooding and urban heat, with a locally-based approach.
10	Bene, K., & Szél, C. (2024)	Enhancing Stormwater Management in Érd, Hungary	Nature-based green infrastructure solutions are effective for water runoff management and surface temperature reduction in urban areas.

This literature study aims to evaluate the effectiveness of green infrastructure in reducing the impact of urban flooding and the heat island effect. Selection results from various articles show that green infrastructure plays a significant role in improving urban resilience to climate change, with various interesting findings obtained from recent research.

An article by Omoniyi (2024) explores the benefits and challenges of implementing green roofs and vertical gardens in urban infrastructure. The findings show that these elements of green infrastructure not only improve the aesthetics of urban environments but also significantly reduce surface temperatures and flood risk through increased rainwater infiltration. This research provides important insights into how the combination of green elements with modern architectural design can provide practical solutions to the challenges of urbanization (Omoniyi, 2024).

Zeng and Lam (2024) present an innovative approach to climate resilience through the integration of urban forestry and green infrastructure. The study notes that cities that use urban forestry strategies simultaneously with blue-green infrastructure show increased efficiency in flood management and a decrease in the heat island effect. This article underscores the importance of adopting a holistic approach in urban design to maximize ecological benefits (Zeng & Lam, 2024).

Olgun et al. (2024) evaluated nature-based solutions for adaptation to climate change in semi-arid regions. This study identifies that scenario-based planning for green infrastructure in semi-arid areas is very effective in reducing flooding and maintaining air temperature. This study also shows that the implementation of this scenario can increase local community awareness of the importance of environmental conservation (Olgun et al., 2024).

In another article, Thompson et al. (2024) highlight the use of flood-resistant materials and energy-saving technologies to support climate change mitigation. This approach focuses not only on green infrastructure but also on energy efficiency as a complementary component. This research is relevant because it integrates sustainable design with modern technology to create a more adaptive urban environment (Thompson et al., 2024).

Ghasem Zadeh Khatib (2024) conducted a case study in the city of Novara, Italy, to evaluate the influence of green infrastructure on environmental impact mitigation. The study found that green elements such as urban parks and water catchment areas increase soil infiltration capacity, reduce waterlogging, and contribute to a decrease in surface temperature. This study offers insights into how

experiences in developed countries can be adapted to the context of developing countries (Ghasem Zadeh Khatib, 2024).

Research in the Southeast Asian region also provides rich insights. Banguilan (2024) explores the distribution of urban green space in Metro Manila, Philippines. This article reveals that the uneven distribution of green space has an effect on the ineffectiveness of green infrastructure in reducing flooding and urban temperatures. This study emphasizes the importance of equitable spatial planning to ensure that ecological benefits can be felt by all levels of society (Banguilan, 2024).

The study by Taccone and Rizzo (2024) expands the discussion to the social welfare aspects of green infrastructure. This article highlights the role of green infrastructure as a natural barrier against urban flooding and heat, while improving people's quality of life through increased access to green open spaces. These findings show how the integration of social aspects in environmental planning can strengthen public acceptance of environmental programs (Taccone & Rizzo, 2024).

In addition, Seelam et al. (2025) provide a unique perspective on the utilization of artificial intelligence (AI) in green-blue infrastructure. This article highlights how AI technology can improve the effectiveness of flood management and urban heat reduction through better data analysis and accurate predictions. This research provides a future overview of how technology can support nature-based solutions in climate change mitigation (Seelam et al., 2025).

In Fiji, Alam et al. (2024) investigated how green infrastructure can reduce the risk of disasters such as floods and extreme heat. The local-based approach applied in this study shows positive results, especially in involving local communities to support the sustainability of green infrastructure programs (Alam et al., 2024).

Finally, Bene and Szél (2024) evaluated stormwater runoff management in Érd, Hungary, by utilizing nature-based solutions. Their findings suggest that green infrastructure is not only effective in reducing water runoff but also contributing to reduced surface temperatures and increased biodiversity (Szél et al., 2024).

From the entire article, it is clear that green infrastructure not only provides ecological solutions but also has a positive impact on social and economic aspects. However, challenges in equitable distribution, technology adoption, and sustainable management remain key issues that require further attention. This research makes an important contribution to the development of data-driven strategies in supporting sustainable urban planning.

Discussion

The Effectiveness of Green Infrastructure in Reducing Urban Flooding

Green infrastructure has proven to be an effective solution to overcome the problem of urban flooding. The solution uses a natural approach that utilizes soil absorption and infiltration as well as surface water management. One of the prominent ways in rainwater management is through the use of rain gardens, which are able to absorb up to 90% of the daily rainfall. This ability helps reduce surface water runoff, which is usually the main cause of inundation and flooding in urban areas. In addition, permeable pavements are also an important element in green infrastructure. This pavement is able to reduce surface water runoff by up to 70% compared to conventional pavements, thereby significantly reducing pressure on the city's drainage system. Furthermore, bioswales, which are designed to facilitate the infiltration of rainwater into the soil to a depth of 1–3 meters, are very effective in reducing runoff in flood-prone locations.

Not only that, green infrastructure also plays an important role in water absorption and retention. Green open spaces such as city parks have the ability to store up to 20–30% more rainwater compared to paved areas. Thus, green open spaces can help reduce the load on urban drainage systems. Green areas on roofs also make a significant contribution to water retention, with the ability

to store up to 50% of rainwater that falls on it. This directly reduces the volume of water runoff towards the sewer.

In addition, green infrastructure provides a flexible solution to extreme flood risks due to high rainfall intensity affected by climate change. Nature-based solutions allow cities to be more adaptive in dealing with these conditions. The results of the simulation model show that cities with green areas covering 30% of their total area can experience a decrease in flood frequency by up to 25% compared to cities that do not implement green interventions. Thus, green infrastructure is one of the effective and sustainable strategies in facing the challenges of urban flooding.

The Effectiveness of Green Infrastructure in Reducing the Heat Island Effect

The urban heat island effect is a phenomenon that occurs due to the dominance of paved surfaces and the lack of vegetation cover, which causes the air temperature in cities to be higher than in the surrounding areas. Green infrastructure is an important solution in reducing air temperature through various effective mechanisms. One way is by reducing surface temperatures through the presence of urban vegetation. Large trees have the ability to lower the surface temperature by 2–4°C at a radius of 50–100 meters, mainly through the process of evapotranspiration and the resulting shadow. In addition, green roofs also contribute significantly by reducing the surface temperature of the roof by up to 40% compared to conventional roofs. Green roofs not only cool the surface, but also lower the ambient air temperature by 1–2°C, which has a direct impact on thermal comfort in urban areas.

In addition, green infrastructure plays an important role in improving albedo and evapotranspiration. Green surfaces have a higher albedo compared to asphalt, so more solar energy is reflected and reduces heat accumulation on the surface. Trees and other vegetation also increase evapotranspiration, a process that absorbs latent heat from the atmosphere and naturally helps to cool the surrounding air. In this way, green infrastructure contributes to creating a cooler and more comfortable urban environment.

On a city scale, GIS-based analysis shows that areas with at least 30% green cover have an average temperature 1.5°C lower compared to areas with less than 10% green cover. This confirms that the existence of vegetation and green areas has a significant impact on lowering urban air temperatures, while helping to reduce the heat island effect which is one of the major challenges in dense and rapidly growing urban areas. Green infrastructure, with its various effective elements, is a sustainable solution to create a healthier and more resilient urban environment to climate change.

The Most Effective Green Infrastructure Elements

1. Urban Parks and Urban Forests:

   Urban parks play a significant role in absorbing rainwater, reducing air temperature, and improving air quality. Urban forests have a greater contribution to carbon sequestration and the reduction of the heat island effect.
2. Green Roofs:

   In addition to lowering the surface temperature, green roofs increase thermal insulation in buildings, thereby reducing energy requirements for cooling.
3. Green Walls:

   Effective in cooling the surface of building walls and improving air quality through pollutant absorption.
4. Porous Pavement:

   Overcoming inundation in areas with limited space, especially on sidewalks and environmental roads.

Data-Driven Recommendations to Improve Urban Resilience

Based on the analysis of the effectiveness of green infrastructure, here are strategic recommendations to improve urban resilience:

1. Green Area Improvement:
   a. Cities need to set a green cover target of at least 30% of the total urban area to significantly reduce the impact of flooding and the heat island effect.
   b. Integrating vertical gardens and green roofs in commercial and residential buildings to improve land efficiency.
2. Strengthening Policies and Regulations:
   a. Adopt green zoning regulations that integrate green infrastructure in new development, such as the use of porous pavement in public areas.
   b. Provide fiscal incentives to developers and building owners who implement green solutions.
3. Monitoring and Evaluation:
   a. Applying GIS- and IoT-based technologies to monitor the effectiveness of green infrastructure in real-time, such as rainwater absorption, surface temperature, and air quality.
   b. Conduct periodic environmental audits to measure the impact of green programs on urban resilience indicators.
4. Education and Community Engagement:

   Involve the community in the management of city parks, tree planting, and maintenance of green infrastructure. This education is important to increase awareness of the importance of environmental impact mitigation.

CONCLUSION

The study shows that green infrastructure, through elements such as rain gardens, green roofs, porous pavements, and urban forests, is an effective solution in reducing the risk of urban flooding and the heat island effect. This infrastructure is not only able to manage rainwater runoff but also create a cooler environment, improve air quality, and improve people's welfare. In Indonesia, the implementation of green infrastructure faces challenges in the uneven distribution of green space and technology integration, but it has great potential if implemented with adequate policy support.

To increase the effectiveness of green infrastructure, it is necessary to strengthen green zoning policies by setting a minimum target for green cover in urban areas. The government can provide incentives to developers who adopt green elements in their projects. In addition, it is necessary to apply technology-based monitoring such as GIS to measure the environmental impact of green infrastructure in real-time. Education and community involvement in the planning and maintenance of green elements are also essential for sustainability. With these measures, it is hoped that green infrastructure can become an integral part of a sustainable city management strategy.

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