



Identification of Blue Infrastructure for Sustainable Urban Development Strategy: A Case Study in the Yogyakarta Metropolitan Area

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Abstract

Urbanization in the Yogyakarta Metropolitan Area has intensified land conversion and hydrological degradation, underscoring the need for sustainable spatial strategies. This study identifies and analyses blue infrastructure as a nature-based solution to support ecological resilience and urban sustainability. Using a quantitative spatial approach, this research integrates secondary geospatial datasets and high-resolution satellite imagery to map natural and engineered blue elements. The spatial distribution was further examined using Average Nearest Neighbor (ANN) and Kernel Density Estimation (KDE) analyses to assess clustering patterns and concentration zones. The results reveal a total blue infrastructure area of 20,763.70 hectares, dominated by river systems (63.67%) and irrigation networks (34.55%). Spatially, blue infrastructures exhibit a clustered pattern concentrated in the northern and central parts of the metropolitan area, strongly influenced by geomorphological and watershed characteristics. Functionally, these systems contribute to achieving Sustainable Development Goals (SDGs) 6 and 11 by enhancing water-related ecosystem services, flood mitigation, and public open-space provision. The findings emphasize the strategic importance of integrating blue infrastructure into spatial planning instruments such as the RTRW and RDTR to strengthen Yogyakarta's resilience as a Sponge City. This integration is essential for realizing adaptive and sustainable urban development in Indonesia's rapidly growing metropolitan regions.

Keywords: Blue Infrastructure; Sustainable Development; Spatial Analysis; Yogyakarta Metropolitan Area

1. Introduction

Urbanization has accelerated population growth and increased human demands in urban areas. Statistics Indonesia (BPS, 2020) projects that by 2035, approximately 66.6% of Indonesia's population will reside in cities. Historical data from the World Bank (2024) indicate an average annual growth rate of 2.05% in Indonesia's urban population between 2021 and 2024. Urbanization is not merely a demographic shift but a multidimensional process encompassing demographic, social, economic, and spatial dynamics (Liu et al., 2014; Hadijah & Sadali, 2020). It fundamentally transforms land cover and urban spatial configuration, reshaping the physical form of cities (Nuissl & Siedentop, 2020). This transformation often leads to environmental challenges, including the degradation of natural ecosystem services (Lindley et al., 2018; Paudyal et al., 2019).

Yogyakarta Metropolitan Area exemplifies rapid urbanization, driven by accelerated economic growth in manufacturing, tourism, and information and communication technology sectors (BPS, 2024). While urbanization contributes to economic expansion, its spatial and ecological consequences remain significant. Large-scale infrastructure development has accelerated land conversion, leading to the sharp growth of built-up areas and the reduction of open spaces (Ni'mah & Lenon, 2017). Urban expansion also induces the loss of urban water bodies, reducing groundwater infiltration and exacerbating hydrological

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stress (Yao et al., 2015). These trends highlight the urgency of developing integrated, practical strategies for urban environmental management.

One of the promising approaches to addressing these challenges is the development of blue infrastructure within the framework of the blue-green infrastructure (BGI) concept, which aims to mitigate environmental degradation and the impacts of climate change. This concept emphasizes an integrated system combining “blue” elements (urban water systems such as rivers, ponds, and infiltration channels) with “green” elements (vegetation and green open spaces) in a multifunctional network (Boguniewicz-Zablocka & Łukasiewicz, 2025). According to Mell & Scott (2023), BGI utilizes both biotic urban elements and human-engineered structures to serve clear socio-economic and ecological functions. In essence, BGI comprises a collection of Nature-Based Solutions (NbS) that merge water and vegetation elements to enhance urban climate resilience. The New Urban Agenda (United Nations, 2017) underscores the importance of integrating ecosystem services into urban planning through blue-green infrastructure, emphasizing that strengthening natural systems can sustain ecosystem services and mitigate the impacts of climate change and natural hazards (Zamroni et al., 2025).

Blue infrastructure encompasses natural water bodies such as rivers, lakes, and wetlands, as well as artificial structures including canals, Reservoirs, drainage systems, retention ponds, and rainwater harvesting facilities (Haase, 2015; Iojă et al., 2021). These elements play a crucial role in maintaining urban ecosystem resilience and are fundamental to achieving sustainable development goals (Andersson, 2018). This is directly related to Sustainable Development Goals (SDGs) 6 and 11, which aim to provide sustainable water and to make cities and human settlements inclusive, safe, resilient, and sustainable. Accordingly, blue infrastructure holds great potential to support biodiversity and ecosystem services, including water cycle restoration, air cooling, water storage, flood prevention, water purification, vegetation growth, and overall human well-being (Plieninger et al., 2022).

Empirical evidence highlights the potential benefits of integrating blue infrastructure in urban design. Van Oorschot et al. (2024) demonstrated that combining conventional (grey) infrastructure with nature-based interventions—such as rain gardens, permeable pavements, and retention tanks—could increase urban green space by 5%, enhance flood resilience, lower urban temperatures, and reduce pollutant loads. Similarly, Lumuan et al. (2017) found that applying blue-green elements, including absorbing parks and roof gardens, in the Universitas Gadjah Mada campus area reduced surface runoff to only 8.14% during the rainy season. Beyond hydrological benefits, blue-green spaces also create more livable and ecologically productive urban landscapes.

Despite these benefits, the implementation of BGI in Indonesia remains limited due to practical and knowledge constraints. Hamel and Tan (2022) observed that BGI adoption across Southeast Asia remains low, with insufficient empirical data to address urban flooding and water pollution effectively. Within the Yogyakarta Metropolitan Area urban context, scholarly attention to blue infrastructure remains scarce, underscoring the need for research on its identification and adaptive strategies. Therefore, this study aims to identify existing urban blue infrastructure and formulate adaptive, sustainable strategies for its implementation. The findings are expected to contribute to spatial planning and disaster mitigation policies while strengthening urban resilience against climate change and environmental degradation.

2. Data and Methods

2.1 Study Area

The Yogyakarta Metropolitan Area (*Kawasan Perkotaan Yogyakarta*, KPY) is designated as a *National Activity Center (Pusat Kegiatan Nasional, PKN)* in accordance with Regional Regulation of the Special Region of Yogyakarta No 5/2019 regarding the Regional Spatial Plan (RTRW) for 2019–2039. Administratively, KPY encompasses all *kemantren* (districts) within Yogyakarta City, six *kapanewon* (districts) namely Depok, Gamping, Godean, Ngaglik, Ngemplak, and Mlati in Sleman Regency, and three *kapanewon* in Bantul Regency, namely Banguntapan, Kasihan, and Sewon (Daerah Istimewa Yogyakarta, 2019). The spatial extent of KPY is illustrated in Figure 1. The designation of KPY as a National Activity Center underscores its strategic role as a hub for economic, service, educational, and tourism activities, requiring an integrated and sustainable approach to environmental governance (Firmansyah et al., 2024). Demographically, KPY exhibits rapid population growth, which drives the increasing demand for residential land and supporting infrastructure (Sadali, 2018). However, this physical expansion has triggered extensive land conversion, particularly from agricultural and groundwater recharge areas into built-up zones (Tulus & Ramadan, 2021). Such transformations have reduced soil infiltration capacity and groundwater recharge, thereby increasing the potential for urban flooding during periods of intense rainfall (Wijayanti et al., 2020).

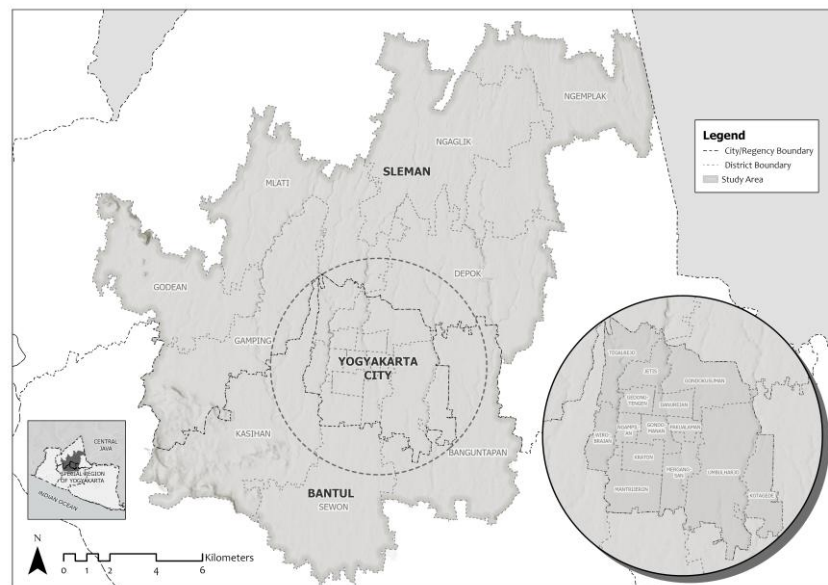


Figure 1. The Map of Yogyakarta Metropolitan Area
(Source: Authors' analysis, 2025)

2.2 Blue Infrastructure Identification

This study employed a quantitative research approach that integrates secondary data analysis with digital observation through spatial mapping. Geospatial secondary data served as the primary foundation, complemented by digital observation using imagery sourced from Google Satellite to map and detect blue infrastructure features not represented in the secondary datasets. This approach follows the concept of *spatial data integration* proposed by De Smith et al. (2018), which emphasizes the importance of compiling multiple data sources to enhance spatial representation accuracy. Visual interpretation was conducted based on established image interpretation elements, representing a classical method in remote sensing (Lillesand et al., 2015). This visual interpretation approach enabled the identification of both natural and man-made blue infrastructure features through spectral and morphological characteristics observable in high-resolution imagery.

The spatial data used in this study consisted primarily of vector data obtained from multiple geospatial platforms, including the *Sleman Regency Geoportal*, *Yogyakarta City Geoportal*, *Geospatial Information Agency (BIG) Geoportal*, and *OpenStreetMap*, as summarized in Table 1.

Table 1. List of Research Data.

No	Type	Source
1	Water springs distribution map	Geospatial Portal of the Government of Sleman Regency, digital observation
2	Reservoirs distribution map	Geospatial Portal of the Government of Sleman Regency, OpenStreetMap, digital observation
3	Blue-Green Multi-functional Open Spaces map	Geospatial Portal of the Government of Sleman Regency, OpenStreetMap, digital observation
4	Map of river network	Geospatial Portal of the Indonesian Geospatial Information Agency
5	Map of irrigation and drainage network	Geospatial Portal of the Indonesian Geospatial Information Agency
6	Administrative boundary map	Geospatial Portal of the Indonesian Geospatial Information Agency

Source: Authors' analysis, 2025

Blue infrastructure in the Yogyakarta Metropolitan Area was identified using vector-based spatial analysis to improve both the accuracy and completeness of mapped components. Temporal validation and data updating were conducted through high-resolution satellite imagery interpretation and on-screen digitization to ensure spatial integrity. Sample points derived from digital observation were used for spatial verification to confirm positional accuracy. The spatial distribution of blue infrastructure elements was subsequently quantified by calculating the proportional area of each component relative to the total study area. Because the river and irrigation/drainage networks were available as line features, their areas were derived by buffering each line into a polygon before area calculation.

In this study, *blue infrastructure* refers to all water bodies and water management systems within an area that are designed to support environmental, social, and economic sustainability. It encompasses both natural and artificial water features, which, in urban contexts, are commonly integrated with green infrastructure (Iojă et al., 2021; Valente de Macedo et al., 2021). Blue infrastructure emphasizes the utilization of natural hydrological landscapes in urban areas to capture surface runoff and provide water

resources through the restoration of natural water cycles. Table 2 presents the types of blue infrastructure typically found in urban environments.

Table 2. Main Types of Blue Infrastructure in Urban Areas.

No	Type	Definition
1	Natural blue elements	Natural or semi-natural surface water features that function as flow paths or Reservoirs within the urban landscape.
2	Natural and engineered drainage systems	Urban drainage systems that combine natural elements (such as rivers) with built structures (such as canals, pipes, or irrigation channels) designed to convey surface runoff.
3	Engineered stormwater control systems	Man-made or engineered structures designed to manage urban stormwater, including vegetated filtration systems (bioretention areas) and small retention ponds that temporarily store rainwater.
4	Blue-green multifunctional open spaces	Areas with a high concentration of blue and green elements that serve as public gathering spaces while performing multifunctional roles in flood management and water quality improvement.

Source: Hamel & Tan, 2022; Nazarpour et al., 2023; Suni et al., 2023

The identifiable blue infrastructure types within the Yogyakarta Metropolitan Area, as observed through satellite imagery, include several key categories, as summarized in Table 3.

Table 3. Typical Blue Infrastructure Found in Urban Areas.

No	Type	Definition
1	Springs	Natural discharge points where groundwater flows to the surface, forming continuous or seasonal flows that sustain surface water systems.
2	Rivers	Flowing water bodies of varying sizes and morphologies, characterized by dynamic channel forms and continuous movement of water across the landscape.
3	Irrigation and Drainage Channels	Open channels designed to infiltrate water into the ground, direct it to ponds, or convey it to primary drainage systems and rivers.
4	Bioretention Ponds	Dammed, vegetated basins engineered to capture and treat stormwater through filtration, infiltration, and biological processes.
5	Ponds	Natural or artificial standing water bodies that store water permanently or seasonally, serving ecological and hydrological functions.
6	Reservoirs	Large man-made water storage structures formed by damming rivers or runoff channels, functioning for water supply, flood control, or irrigation.
7	Riverside Parks	Green open spaces located along riverbanks that provide recreational opportunities while supporting flood mitigation and riparian ecosystem protection.
8	Urban Riparian Forest	Vegetated areas dominated by trees and shrubs along urban waterways that stabilize riverbanks, filter runoff, and enhance urban biodiversity.

Source: Mell & Scott, 2023; Agustine et al., 2023; Hamel & Tan, 2022

Spatial analysis was subsequently applied to examine the connectivity, distribution, and density of aquatic elements within the urban system. Following the identification phase, nearest neighbor and kernel density analyses were employed to provide empirical evidence on the spatial integration between blue infrastructure systems and other urban components.

2.3 Average Nearest Neighbor

To further examine the spatial organization of blue infrastructure within the Yogyakarta Metropolitan Area, the Average Nearest Neighbor (ANN) method was applied. This analysis, a core component of spatial statistics, is used to assess randomness or pattern in the spatial distribution of points by comparing the observed mean distance between each feature and its nearest neighbor to that expected from a statistically random distribution (Sillero, 2021). The analysis of blue infrastructure distribution, based on data derived from this investigation, aims to determine whether the spatial pattern tends toward a clustered, random, or uniform configuration (Riadhi et al., 2020).

The ANN statistic operates by measuring the distance between each blue infrastructure feature centroid and that of its nearest neighboring feature, then averaging all nearest-neighbor distances to obtain a single summary value (Valgunadi et al., 2023). This method assumes a homogeneous level of accessibility across the study area and that all objects exert equal spatial influence. The resulting ANN

index ranges from 0 to 2.15, where values between 0 and 0.7 indicate a clustered pattern, 0.71 to 1.4 represent a random pattern, and 1.41 to 2.15 signify a uniform or regular spatial pattern (Szmyt, 2014).

2.4 Kernel Density Estimation (KDE)

To obtain a comprehensive understanding of the spatial distribution of blue infrastructure, Kernel Density Estimation (KDE) analysis was employed. This method assesses the extent to which nearby points contribute to the local density, using a statistical approach to estimate the probability density function of a random variable based on observed data (Jiang et al., 2020). KDE is particularly useful for visually illustrating spatial distribution patterns in the form of density maps or heatmaps, allowing a clearer depiction of spatial intensity and concentration (Le et al., 2022).

Conceptually, KDE operates by placing a kernel function over each data point and smoothing the point distribution to produce a continuous density surface. This surface represents the magnitude and spatial spread of blue infrastructure across the Yogyakarta Metropolitan Area, both in terms of overall distribution and specific types. The resulting density maps are visualized as heatmaps, where color gradients indicate intensity levels or density values. These visual representations provide valuable insights into concentration zones and spatial trends of blue infrastructure, thereby enhancing the analytical depth and interpretive clarity of this study.

3. Results and Discussion

3.1 Characteristics of Blue Infrastructure in the Yogyakarta Metropolitan Area

To establish a foundational understanding of the role and spatial distribution of water-related elements in Yogyakarta's urban spatial structure, this analysis examines the characteristics of blue infrastructure based on the area and proportion of each component. The development of blue infrastructure is a crucial approach to ensuring sustainable urban growth; thus, its identification serves as an essential step in planning, regulating, and evaluating urban development processes. Based on the results of the identification, the total area of blue infrastructure within the Yogyakarta Metropolitan Area reaches 20,763.70 hectares.

Table 4. Area and Percentage of Blue Infrastructure Types in Yogyakarta Metropolitan Area.

No	Type	Area (hectares)	Percentage (%)
1	Springs	284.49	1.37
2	Rivers	13,220.55	63.67
3	Irrigation and Drainage Channels	7,172.91	34.55
4	Bioretention Ponds	1.20	0.01
5	Ponds	7.88	0.04
6	Reservoirs	14.84	0.07
7	Riverside Parks	43.96	0.21
8	Urban Riparian Forest	17.87	0.09
Total		20,763.70	100

Source: Authors' analysis, 2025

As presented in Table 4, the distribution of blue infrastructure exhibits a strong dominance of two primary types: rivers (13,220.55 ha or 63.67%) and irrigation & drainage systems (7,172.91 ha or 34.55%). Together, these two components account for 98.22% of the total blue infrastructure area, indicating that almost all spatial representations of blue infrastructure in the metropolitan area consist of hydrological and waterway networks. In contrast, minor components such as springs, bioretention ponds, ponds, reservoirs, riverside multifunctional parks, and urban riparian forests collectively occupy only 370.24 ha (approximately 1.78%). Quantitatively, the river category covers nearly twice the area of the second-largest category (irrigation & drainages) and approximately 35 times the combined area of minor blue infrastructure types across Yogyakarta.

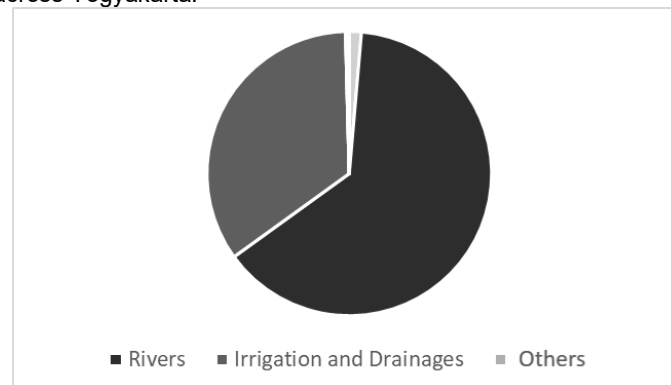


Figure 2. Area distribution of Blue Infrastructure
(Source: Authors' analysis, 2025)

As shown in Figure 2, the area distribution of blue infrastructure reflects Yogyakarta's position within two major watersheds, Progo and Opak-Oya, where river corridors and irrigation canals form the backbone of the city's blue infrastructure. This condition aligns with previous studies (Kusnanto et al., 2017) highlighting the multifunctional role of urban rivers in supporting ecological restoration and socio-economic activities. The peri-urban zones remain shaped by extensive irrigation systems for agriculture and flood control, sustaining their spatial dominance. In contrast, smaller engineered and fragmented features, such as bioretention ponds and riparian parks, represent recent urban interventions. Overall, blue infrastructure management in Yogyakarta remains largely dependent on linear water networks and watershed connectivity.

3.2 Spatial Distributions of Blue Infrastructure in the Yogyakarta Metropolitan Area

The spatial distribution of blue infrastructure across the Yogyakarta Metropolitan Area shows a concentration pattern influenced by administrative and geomorphological factors. Of the 23 sub-districts, those located in Sleman Regency account for the largest share (68%), followed by Bantul Regency (24%) and the City of Yogyakarta (8%). The widest areas are found in Ngaglik (3,297.61 ha) and Ngemplak (2,932.52 ha), while the smallest are in Kraton (15.12 ha) and Pakualaman (20.19 ha). Among all districts, Mlati exhibits the greatest diversity and number of blue infrastructure features, dominated by rivers, irrigation channels, ponds, and small reservoirs distributed mainly along the northern and central zones.

The dominance of hydrological elements corresponds to Yogyakarta's geomorphic position on the southern slopes of Mount Merapi, where abundant springs and upstream rivers shape the urban hydrological network. Natural blue infrastructures such as rivers and springs show a linear pattern concentrated in the north, along the springs belt which is consistent with the upper catchments of the Progo and Opak–Oya river basins. The distribution of springs also follows the varied geological formations, including the Sentolo Hills, Godean Hills, and other volcanic landforms, which create multiple natural discharge points in the south and southwest.

Artificial blue infrastructures, such as bioretention ponds, reservoirs, and riverside parks, display a linear alignment along major rivers, particularly Code, Gajahwong, and Bedog Rivers. These river corridors form the central concentration of engineered water-based facilities in the metropolitan area. Although their total area remains limited ($\approx 0.42\%$), these infrastructures play an increasingly strategic role in flood mitigation, ecological restoration, and the creation of multifunctional public spaces within Yogyakarta's urban core.

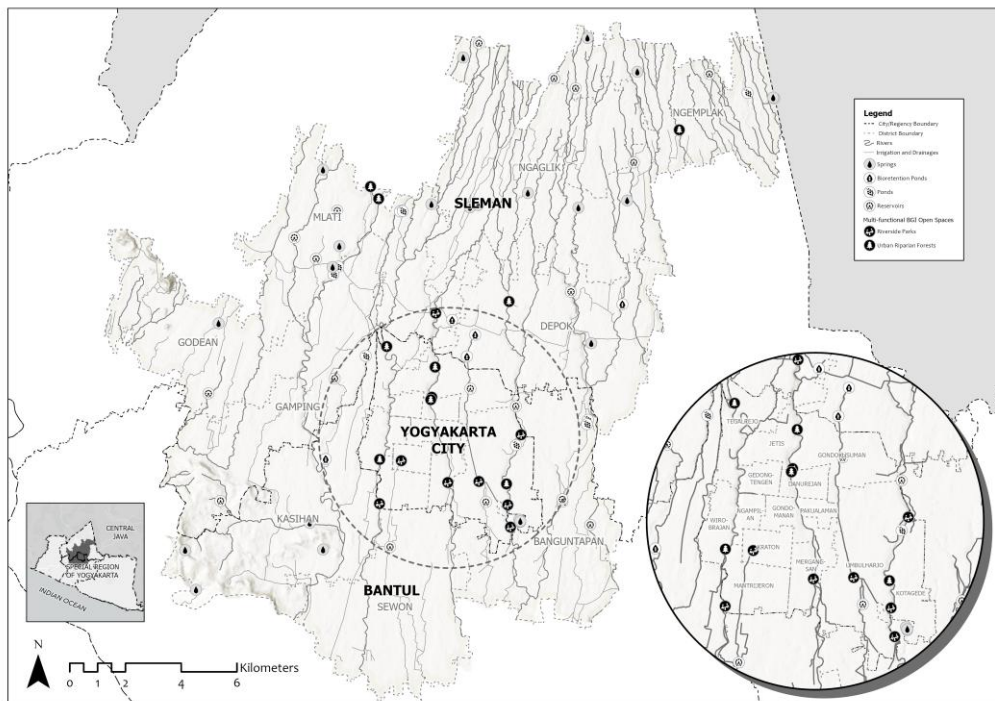


Figure 3. The Map of Blue Infrastructure Distribution in Yogyakarta Metropolitan Area
(Source: Authors' analysis, 2025)

The spatial distribution of blue infrastructure in the Yogyakarta Metropolitan Area, as illustrated in Figure 3, exhibits a clustered pattern aligned with the city's hydrological networks. The Average Nearest Neighbor analysis indicates an Observed Mean Distance of 282.30 m and an Expected Mean Distance of 459.18 m, producing a Nearest Neighbor Index (NNI) of 0.615 from 657 feature points. The negative z-score (-18.89) confirms that the distribution is significantly clustered rather than random. This clustering pattern corresponds to the dominance of river and irrigation corridors, suggesting that water-based systems form the structural backbone of urban hydrology in Yogyakarta.

The Kernel Density Estimation (KDE) supports this finding, revealing several high-density clusters in the northern subdistricts of Ngaglik and Ngemplak, as well as Depok, where multiple tributaries originate from the lower slopes of Mount Merapi. Additional moderate concentrations are identified around the borders of Mlati, Gamping, Kasihan, and Tegalrejo, coinciding with the convergence of major waterways such as Selokan Mataram and Kali Winongo. These areas represent critical intersections between natural river systems and engineered channels, forming nodes of high hydrological interaction.

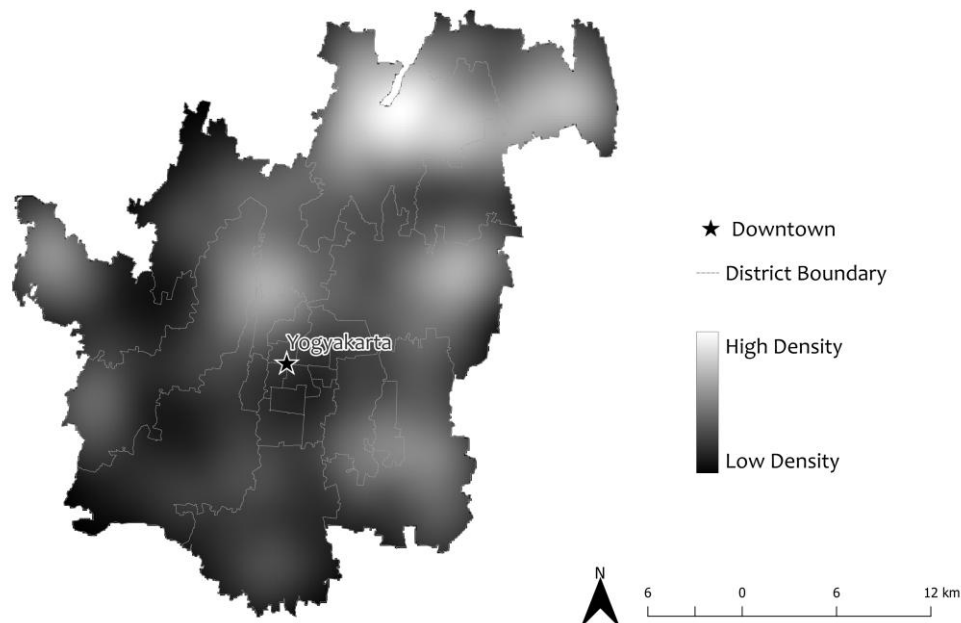


Figure 4. Kernel Density Estimation Results for the Whole Blue Infrastructure Objects in Yogyakarta Metropolitan Area (Source: Authors' analysis, 2025)

Natural blue infrastructure such as rivers and springs shows a linear, geomorphologically influenced pattern that mirrors Yogyakarta's topography. In contrast, engineered components like irrigation canals, drainage systems, ponds, and bioretention basins exhibit localized clustering adjacent to these natural corridors. As shown by the Kernel Density Estimation results in Figure 4, high densities of irrigation and drainage infrastructure are found in Ngemplak, Ngaglik, Godean, Depok, and Banguntapan, aligning with agricultural and peri-urban zones where water management remains essential. Meanwhile, smaller engineered features, such as ponds, bioretention areas, and urban riparian forests, form compact clusters around riverbanks in the northern and central areas, reflecting limited but deliberate urban water design interventions.

The geological context of Yogyakarta further reinforces this pattern. The city lies between the volcanic plains of Mount Merapi in the north and the karstic formations of the Sentolo and Godean Hills in the west and southwest. These landscapes generate diverse hydrological characteristics that give rise to numerous springs, small reservoirs, and underground water flows. The volcanic sediments of Merapi create permeable layers that store groundwater, while the limestone hills regulate discharge and contribute to the surface flow network. Consequently, the combination of volcanic and sedimentary formations supports a spatially rich hydrological environment that sustains both natural and engineered blue infrastructure.

Overall, the clustering of blue infrastructure across Yogyakarta, as shown by the Kernel Density Estimation results for each infrastructure type in Figure 5, reflects a spatial synthesis between natural landscape processes and urban planning practices. The dominance of water-based linear networks demonstrates the city's continued reliance on ecological systems for managing water flow, mitigating flood risk, and maintaining urban resilience. These findings underscore the importance of preserving hydrological connectivity as an integral part of sustainable urban development in Yogyakarta.

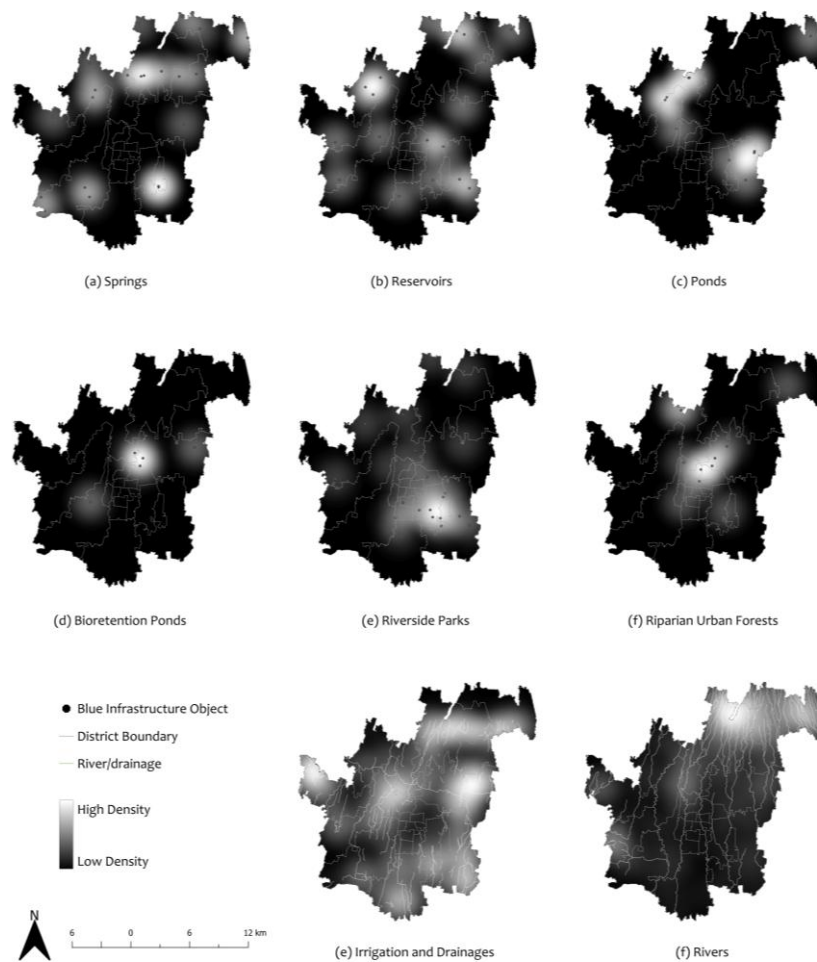


Figure 5. Kernel Density Estimation Results for Each Blue Infrastructure Type in Yogyakarta Metropolitan Area (Source: Authors' analysis, 2025)

3.3 The Potential of Blue Infrastructure for Sustainable Development

Blue infrastructure in the Yogyakarta Metropolitan Area holds vital importance for achieving Sustainable Development Goals (SDGs), particularly Goal 6 (Clean Water and Sanitation) and Goal 11 (Sustainable Cities and Communities). Specifically, it contributes to Indicator 6.6.1: Change in the extent of water-related ecosystems over time, emphasizing the role of blue infrastructure in conserving inland water-related ecosystems. This aligns with the role of the Yogyakarta Metropolitan Area as part of the *Sponge City* initiative, which aims to reduce surface runoff through enhanced infiltration, stormwater storage, and ecosystem protection (Ariyanti et al., 2025).

In addition, blue infrastructure supports Indicator 11.7.1: Proportion of urban open space for public use, which is a key measure of urban sustainability. For instance, the current share of Green Open Space (RTH) in Yogyakarta City is only 18.6% of its total area, which is significantly below the 30% minimum threshold mandated by Law No 26/2007 on Spatial Planning (Achmad et al., 2024). Addressing this gap requires innovative approaches to expand multifunctional open spaces that integrate ecological and social benefits. Blue infrastructure offers such potential by merging water-based elements with urban green systems, thus creating hybrid ecological spaces that support both human and environmental well-being.

Urban blue infrastructure, which comprises rivers, canals, retention ponds, and other water features, serves as a nature-based solution (NbS) for climate adaptation, hydrological management, and ecosystem restoration. Empirical studies have demonstrated its capacity to strengthen ecosystem services such as water regulation, flood mitigation, and biodiversity enhancement (Pinto et al., 2023). Similarly, Siehr *et al.* (2022) highlight that integrating natural water systems into urban spatial planning enhances hydrological circulation and ecological corridor resilience to natural hazards. Beyond the ecological dimension, blue infrastructure also promotes social and economic co-benefits, including spaces for recreation, social interaction, and improved urban livability (Zhao et al., 2023). Moreover, Andersson et al. (2019) note that blue-green infrastructure collectively stimulates local economies and generates new employment opportunities in ecosystem service and recreation sectors. Table 5 lists various types of blue infrastructure in the Yogyakarta Metropolitan Area along with their roles in sustainable development.

Table 5. The Role of Blue Infrastructure on Sustainable Development Aspects in the Yogyakarta Metropolitan Area.

No	Type	Sustainability Aspects
1	Springs	Environment, Social
2	Rivers	Environment
3	Irrigation and Drainage Channels	Environment, Economics
4	Bioretention Ponds	Environment, Social
5	Ponds	Economics, Social
6	Reservoirs	Environment, Social
7	Riverside Parks	Economics, Social
8	Urban Riparian Forest	Economics, Social

Source: Authors' analysis, 2025

In relation to Target 6.6 which states “by 2030, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes” (Dickens et al., 2017), this study shows that natural blue elements remain abundant in Yogyakarta's urban landscape, predominantly in the form of rivers and tributaries. However, ongoing urban expansion and land-use conversion pose significant threats to these systems, potentially leading to decreased infiltration, water pollution, and ecological degradation. Therefore, ensuring the long-term sustainability and quality of blue infrastructure requires explicit regulatory integration within spatial planning instruments such as the Regional Spatial Plan (*Rencana Tata Ruang Wilayah*, RTRW) and Detailed Spatial Plan (*Rencana Detail Tata Ruang*, RDTR). The institutional protection and optimization of blue-green infrastructure within these plans are essential to achieving SDG targets and securing Yogyakarta's urban ecological resilience.

4. Conclusion

The Yogyakarta Metropolitan Area faces increasing environmental pressures driven by rapid urban development and the dominance of built-up land, making blue infrastructure an essential nature-based solution for sustainable urban growth. With a total area of 20,763.70 ha, which is dominated by river systems that comprise 63.67%, blue infrastructure serves as a vital ecological and socio-spatial asset. It supports biodiversity, sustains natural hydrological cycles, mitigates disasters, and provides social and economic benefits while enhancing climate resilience and Yogyakarta's role as Sponge City. However, the ongoing pace of urbanization and land conversion threatens the integrity of these ecosystems, underscoring the urgent need for proactive protection, restoration, and integration of blue infrastructure within spatial planning instruments such as RTRW and RDTR. Embedding this approach within policy and planning frameworks aligns with SDG 6 and SDG 11, ensuring the preservation of water-related ecosystems and equitable access to urban open spaces. Ultimately, recognizing and managing blue infrastructure as a central element in ecological, hydrological, and socio-spatial systems will enable Yogyakarta to pursue urban development that is both adaptive and sustainable without compromising its natural foundations.

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6. Conflict of Interest Statement

The authors declare that they have no conflict of interest regarding the research, authorship, or publication of this manuscript.

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