Research Paper

Spatial Analysis of Water Infiltration Areas and Flood Risk in Yogyakarta City

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Abstract

Yogyakarta City faces environmental problems due to the reduction of water catchment areas resulting from urbanization and changes in land use. This reduction can disrupt the hydrological cycle, leading to groundwater depletion and an increased risk of flooding and inundation. Using a Geographic Information System (GIS) approach, this research will map the water catchment potential. The data analysed included soil type, rainfall, land slope, land use, and soil infiltration rate. Scoring and overlay methods were used to create a thematic map depicting the condition of water infiltration in Yogyakarta City. The results show that Yogyakarta City is dominated by regosol soil type (99.87%), residential land (61.08%), and slope <8% (45.16%). The highest infiltration zone is classified as "Very Large" (24.55%), while the lowest is "Very Small" (0.06%). Most areas have a "natural normal" condition (16.23%). Further analysis showed a relationship between infiltration ability and flood risk. This research is expected to serve as a basis for BPBD Yogyakarta City in formulating groundwater conservation and flood mitigation policies that support more adaptive decision-making in response to climate change and urban growth.

Keywords *infiltration, land use, water infiltration, spatial analysis, flood risk*

INTRODUCTION

Water is one of the most essential natural resources for human life. However, with the increasing population and rapid urban development, groundwater utilisation has become more intensive and continuous. Without proper management, this condition can lead to a decline in groundwater quantity and quality, ultimately resulting in adverse impacts on society, the economy, and the environment. One of the most pressing issues is the reduction of groundwater recharge areas, particularly in densely populated urban settings such as Yogyakarta City.

As one of the major cities in Indonesia, Yogyakarta faces serious challenges in water management. The conversion of green areas into built-up zones has diminished the soil's capacity to absorb water, thereby increasing surface runoff that can trigger local flooding during periods of high rainfall. This situation also affects the biophysical characteristics of the soil, including the reduction of organic matter and pore space, which directly decreases infiltration capacity. Recognising the critical role of recharge zones in sustaining groundwater availability, the government must establish and preserve recharge areas in accordance with Law No. 26 of 2007 on Spatial Planning. To support this effort, accurate spatial data on the distribution and condition of recharge zones in Yogyakarta is essential. This study aims to provide a scientific basis for policymaking, including the development of green infrastructure such as urban parks and infiltration wells, as well as the formulation of integrated and sustainable water management strategies. In this way, the quality of urban life can be improved while ensuring the sustainability of the city's ecosystem.

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LITERATURE REVIEW

A comprehensive understanding of groundwater recharge requires an examination of existing concepts and previous research. Surface water, which flows across the land to form ponds, lakes, and seas, is intrinsically linked to groundwater conditions (Simanjuntak et al., 2022). Continuous and intensive groundwater abstraction has been shown to affect its quantity and quality negatively (Hamzah et al., 2016). These findings underscore the importance of striking a balance between groundwater utilization and natural recharge processes to ensure long-term sustainability.

Several factors have been identified as key determinants of groundwater recharge. Malik (2023) highlighted soil and rock characteristics, rainfall, and slope gradients as critical variables, while Asdak (2010) defined recharge zones as areas where water infiltrates into the soil. This perspective is reinforced by Presidential Decree No. 32 of 1990, which outlines specific criteria for recharge areas, including high rainfall, permeable soil structures, and supportive geomorphological conditions. Land-use change, particularly in urban areas, further alters infiltration capacity by reducing organic matter and soil porosity, limiting water absorption (Nisa', 2017). Warsilan (2019) noted that the continuous decline in recharge capacity can lead to local flooding.

Advances in geospatial technology have provided powerful tools to analyse recharge potential across large areas. Geographic Information Systems (GIS) enable the integration and processing of diverse spatial datasets, allowing for more accurate mapping and analysis (Guvil et al., 2018; Prahasta, 2002). Building on this capability, Pandiangan et al. (2021) classified recharge potential into categories ranging from critical to good by considering parameters such as soil type, rainfall, land use, slope gradient, and infiltration rate. Guided by this framework, the present study applies scoring and overlay techniques to produce a detailed assessment of recharge potential in urban environments.

RESEARCH METHOD

The study was conducted in Yogyakarta City, the capital of the Special Region of Yogyakarta Province, with a total area of approximately 32.5 km^2. Astronomically, Yogyakarta City is located between 110°24′19″ and 110°28′53″ East longitude and between 7°15′24″ and 7°49′26″ South latitude, with an average elevation of 114 m above sea level. In general, Yogyakarta City is a relatively flat area, with an even profile from west to east and a slope of approximately 1 degree from north to south. Yogyakarta City is traversed by three main rivers: the Gajah Wong River in the east, the Code River, which flows through the central part of the city, and the Winongo River in the west. Administratively, the city lies in the centre of the Special Region of Yogyakarta and is bounded by Sleman Regency to the north, Bantul and Sleman Regencies to the east, Bantul Regency to the south, and Bantul and Sleman Regencies to the west.

This study refers to the Minister of Forestry Regulation of the Republic of Indonesia No. 32 of 2009, which outlines the procedures for preparing technical plans for forest and land rehabilitation in watersheds. The regulation specifies four parameters for assessing recharge areas: rainfall, slope gradient, land use, and soil type. Accordingly, data for these parameters were obtained from official regional and national agencies. Rainfall data for 2019 to 2024 were acquired from the Climatology Station of the Special Region of Yogyakarta. Elevation and slope data for 2024 were derived from DEMNAS, the National Digital Elevation Model distributed by the Geospatial Information Agency. Land use and soil type maps for 2018 were sourced from the National Land Agency ATR BPN and the Office of Land Affairs and Spatial Planning of the Special Region of Yogyakarta, respectively. The 2022 flood risk map was included for qualitative spatial comparison with the mapped recharge areas.

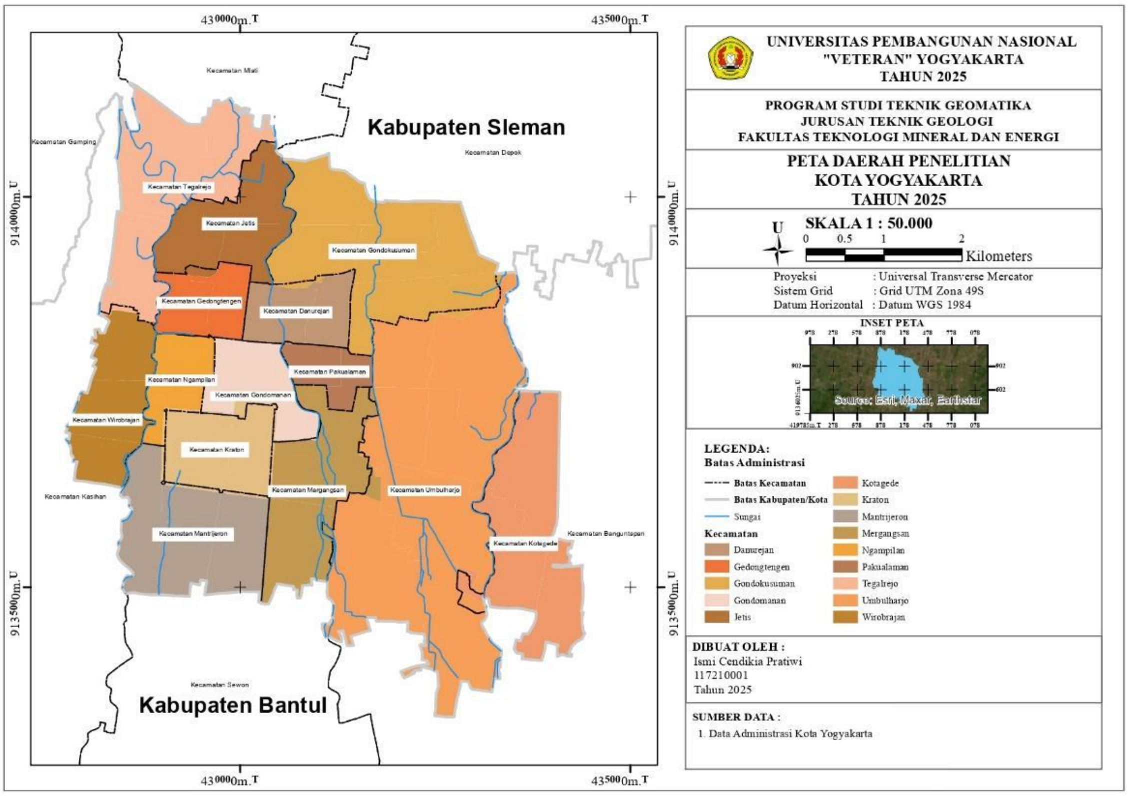


Figure 1. Study Location

The method applied is a scoring and overlay approach implemented in ArcGIS 10.4. The main stages are: literature review, data collection, creation of thematic maps for each parameter, data processing, and data analysis. The literature review provides a theoretical and methodological background relevant to the study. Data collection includes datasets on rainfall, slope gradient, land use, and soil type. Subsequent processing steps include generating a soil type map, producing an infiltration map from rainfall data using the isohyet method, interpolating with the Inverse Distance Weighted technique, and deriving a slope map from DEMNAS. The three resulting layers are scored and overlaid for a natural infiltration map. Next, the natural infiltration result and the land use layer are scored and overlaid to derive the condition of recharge areas. Finally, a visual comparison analysis is conducted between the recharge area map and the flood risk map. Weights and scores for the recharge area parameters follow Ministerial Regulation P.32/MENHUTII/2009 on Procedures for Preparing Technical Plans for Forest and Land Rehabilitation in Watersheds. The parameter weights are listed in the table below.

Table 1. Parameter Criteria and Weights for Recharge Potential Water

Parameter	Weight
Soil type	5
Rainfall	4
Land use	3
Slope gradient	2

The classification of recharge area conditions uses a scoring and weighting method by summing the products of scores and weights for each parameter, as expressed in Equation (1.1) below (Hastono, 2012).

$$Total\ Score = Kb\ x\ Kp + Pb\ x\ Pp + Sb\ x\ Sp + Lb\ x\ LP$$

Notes:
KB = Score for soil type
Lb = Score for slope gradient
Kp = Weight for soil type
Lp = Weight for slope gradient
Sb = Score for land use
Pb = Score for rainfall
Sp = Weight for land use
Pp = Weight for rainfall

Class intervals for infiltration capacity are determined using the Sturges formula according to the desired number of classes. The Sturges interval formula is (Hendriana, 2013) :

$$Ki = (Xt - Xr)K$$

Notes:
Ki = Class interval
Xt = Maximum value of the total scores
Xr = Minimum value of the total scores
k = Number of recharge condition classes

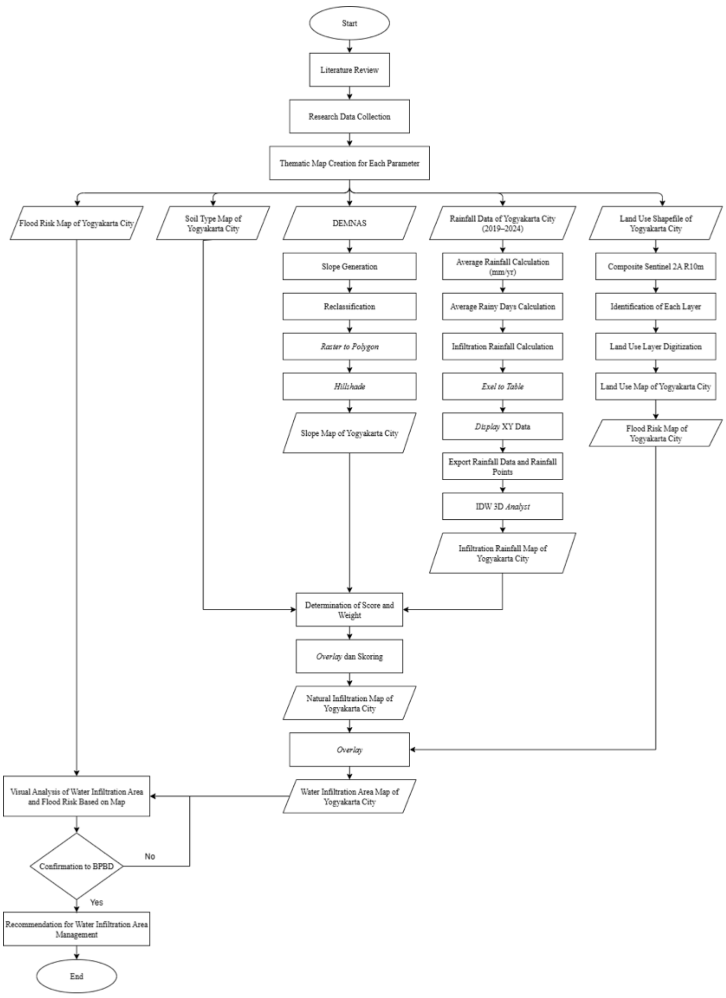


Figure 2. Research Workflow

FINDINGS AND DISCUSSION

Soil Type

Based on mapping results, soil type is an essential factor in delineating recharge areas because it partly determines how readily water can infiltrate into subsurface layers. Using a 1:50,000 scale soil map for Yogyakarta City, two soil types were identified: regosol and kambisol. These soil types are distributed across the study area. Kambisol is symbolised in the map by a cream colour and occupies a small portion of Yogyakarta City, covering 4.06 ha or 0.128 per cent of the municipal area. A brown colour symbolises Regosol and covers most of the city, with an area of 3,274.64 ha or 99.872 per cent of the municipal area.

Table 2. Soil Type Classification for Yogyakarta City

Zone	Soil type	Area (Ha)	Percentage
1	Regosol	3.274,64	99,872%
2	Kambisol	4.06	0,128%
Total		3.278,70	100,00%

Slope Gradient

Slope mapping at a 1:50,000 scale classifies slopes in Yogyakarta City into five categories according to Minister of Forestry Regulation No. 32 of 2009. The five categories are less than 8 per cent, 8 to 15 per cent, 15 to 25 per cent, 25 to 40 per cent, and greater than 40 per cent. Most of Yogyakarta City is relatively flat. The distribution by category is as follows. Flat slopes, defined as less than 8 per cent and shown in dark green, cover 1,480.75 ha or 45.16 per cent of the study area. Gentle slopes, 8 to 15 per cent and shown in light green, cover 1,210.43 ha or 36.90 per cent. Undulating slopes, 15 to 25 per cent and shown in yellow, cover 454.142 ha or 13.84 per cent. Steep slopes, 25 to 40 per cent shown in orange, are primarily concentrated along river corridors and cover 117.549 ha or 3.58 per cent. Very steep slopes, greater than 40 per cent and shown in red, occupy 16.988 ha or 0.52 per cent. Overall, flat and gentle slopes dominate the city while steep and very steep areas are limited, primarily near river channels.

Table 3. Slope Classification for Yogyakarta City

Zone	Slope Category	Area (Ha)	Percentage (%)
1	< 8%	1,480.75	45.16%
2	8% – 15%	1,210.43	36.90%
3	15% – 25%	454.14	13.84%
4	25% – 40%	117.55	3.58%
5	> 40%	16.99	0.52%
Total	—	3,279.86	100.00%

Average Infiltration Rainfall (RD)

The infiltration rainfall map was produced using the isohyet method and interpolated with the inverse distance weighted technique in ArcGIS 10.4. This interpolation approach assumes that the influence of an observation on an estimated location decreases with distance from that location. Rainfall records from four observation stations distributed across Yogyakarta City were combined with five years of rainfall data. The spatial distribution map indicates that rainfall is relatively uniform across the city. Each observation station represents the surrounding areas that do not have their own stations. The resulting infiltration rainfall map was classified into three categories by annual infiltration rainfall intensity. Low intensity is indicated by light blue and corresponds to annual infiltration rainfall less than 2,500 mm per year. Moderately low intensity is indicated by medium light blue and corresponds to annual infiltration rainfall between 2,500 and 3,500 mm per year. Moderate intensity is indicated by dark blue and corresponds to annual infiltration rainfall between 3,500 and 4,000 mm per year.

Table 4. Infiltration Rainfall Classification for Yogyakarta City

Zone	Infiltration Rainfall (mm/year)	Area (Ha)	Percentage (%)
1	< 2500	469.95	14.32%
2	2500 – 3500	490.33	14.95%
3	3500 – 4000	2,319.39	70.73%
Total	—	3,279.67	100.00%

Natural Infiltration

The natural infiltration map for Yogyakarta City was classified into five categories: tiny, small, moderate, large, and large. The spatial extent and score ranges for each category are shown below. The tiny category covers 2.026 ha with a total score range of 27 to 31, representing 0.06 per cent of the municipal area. The small category covers 92.873 ha with a total score range of 31 to 35 and represents 2.84 per cent. The moderate category covers 478.052 ha with a total score range of 35 to 39, representing 14.60 per cent. The large category covers 803.863 ha with a total score range of 39 to 43, representing 24.55 per cent. The huge category covers 1,897.866 ha with a total score range of 43 to 47, representing 57.96 per cent of the mapped area.

Table 5. Natural Infiltration Classification for Yogyakarta City

Infiltration category	Total score range	Area (Ha)	Percentage
Very small	27 – 31	2.026	0.06%
Small	31 – 35	92.873	2.84%
Moderate	35 – 39	478.052	14.60%
Large	39 – 43	803.863	24.55%
Very large	43 – 47	1897.866	57.96%
Total		3.274,680	100.00%

Land Use

Land use mapping at a 1:50,000 scale classified Yogyakarta City into five categories: built-up land, residential area, plantations, rice fields, and shrubland. As a densely populated urban area, most of the city is dominated by residential use. Built-up land is shown in orange and is distributed across the municipality, covering 1,111.01 ha or 33.92 per cent of the area. Residential use is shown in yellow and is the largest class, covering 2,002.46 ha or 61.08 percent. Plantations, shown in dark green, constitute the smallest land use class with 3.93 ha or 0.12 percent. Rice fields, shown in green, occupy 36.72 ha or 1.12 percent. Shrubland, shown in light green, covers 117.42 ha or 3.57 percent.

Table 6. Land Use Classification for Yogyakarta City

Zone	Land Use	Area (Ha)	Percentage (%)
1	Built-up land	1,111.01	33.92%
2	Residential	2,002.46	61.08%
3	Plantation	3.93	0.12%
4	Rice fields	36.72	1.12%
5	Shrubland	117.42	3.57%

Total	—	3,278.54	100.00%

Recharge Area Condition

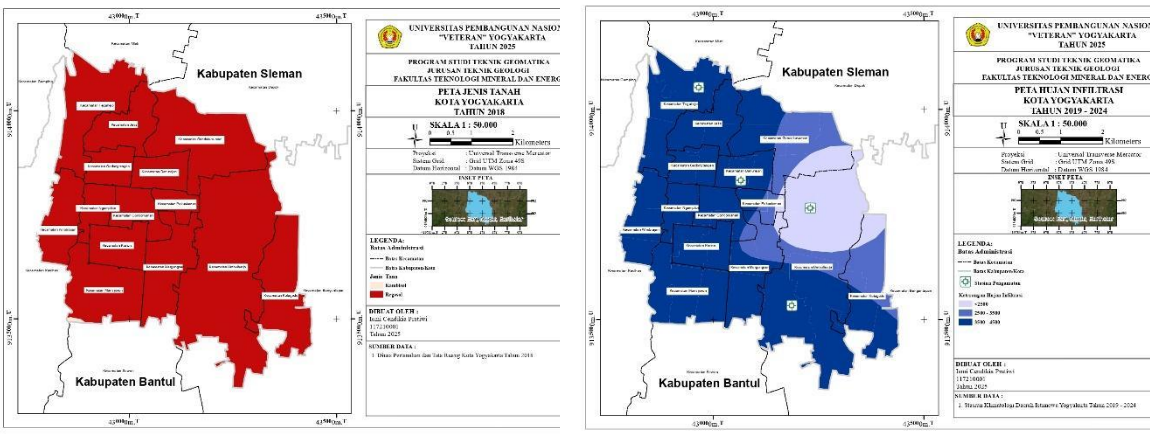
The recharge area condition map produced six conditions: good, naturally normal, beginning to be critical, moderately critical, critical, and very critical. Areas classified as good have scores greater than 53 and cover 59.602 ha or 1.82 percent of Yogyakarta City. The naturally regular class, with scores between 48 and 52, covers 1,722.754 ha or 52.65 percent. Areas identified as beginning to be critical, with scores between 43 and 47, cover 912.151 ha or 27.87 percent. Moderately critical areas, with scores between 38 and 42, cover 531.186 ha or 16.32 percent. Critical areas, with scores between 33 and 37, total 46.117 ha or 1.41 percent. The critical class, with scores less than 32, covers 0.489 ha or 0.01 percent.

Table 7. Recharge Area Condition Classification for Yogyakarta City

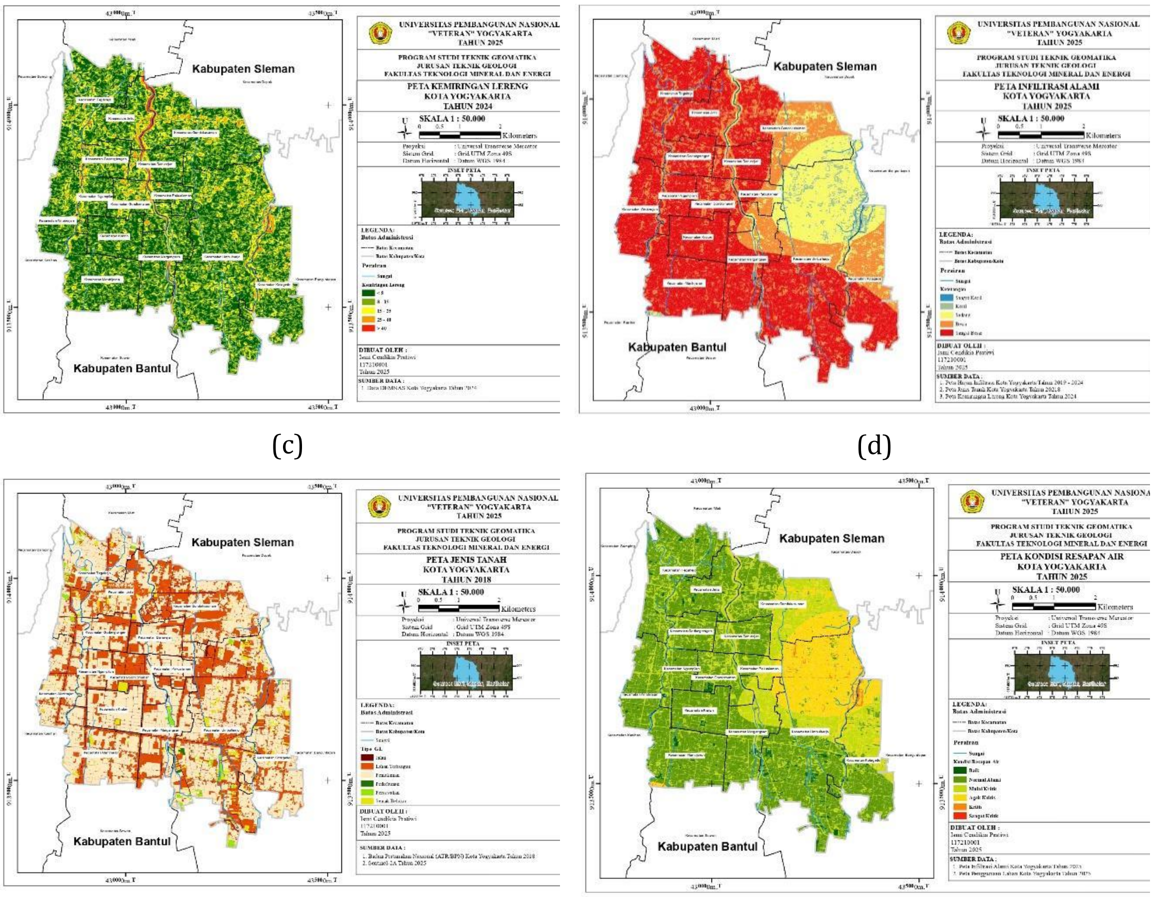
Recharge Potential Class	Total Score Range	Area (Ha)	Percentage
Good	>53	59.602	1.82%
Naturally normal	48 – 52	1722.754	52.65%
Beginning to be critical	43 – 47	912.151	27.87%
Moderately critical	38 – 42	531.186	16.32%
Critical	33 – 37	46.117	1.41%
Very critical	<32	0.489	0.01%
Total		3272.299	100%

Analysis of Recharge Potential of Water

The 2025 recharge area map for Yogyakarta City reveals marked differences between subdistricts. Some subdistricts, such as Tegalrejo, Jetis, Mantrijeron, and Kotagede, retain good infiltration capacity due to the availability of open space and existing vegetation. In contrast, central and eastern subdistricts, including Danurejan, Pakualaman, Gondokusuman, and parts of Umbulharjo, have experienced a significant decline in infiltration capacity due to rapid development and the loss of open areas. These spatial patterns highlight the need for more prudent spatial planning to preserve and restore recharge area functions to reduce surface runoff and lower flood risk.



(a) (b)



(c) (d)

(e) (f)

Figure 3. Maps: (a) soil type, (b) infiltration rainfall, (c) slope gradient, (d) natural infiltration, (e) land use, (f) recharge potential for Yogyakarta City

Confirmation with BPBD

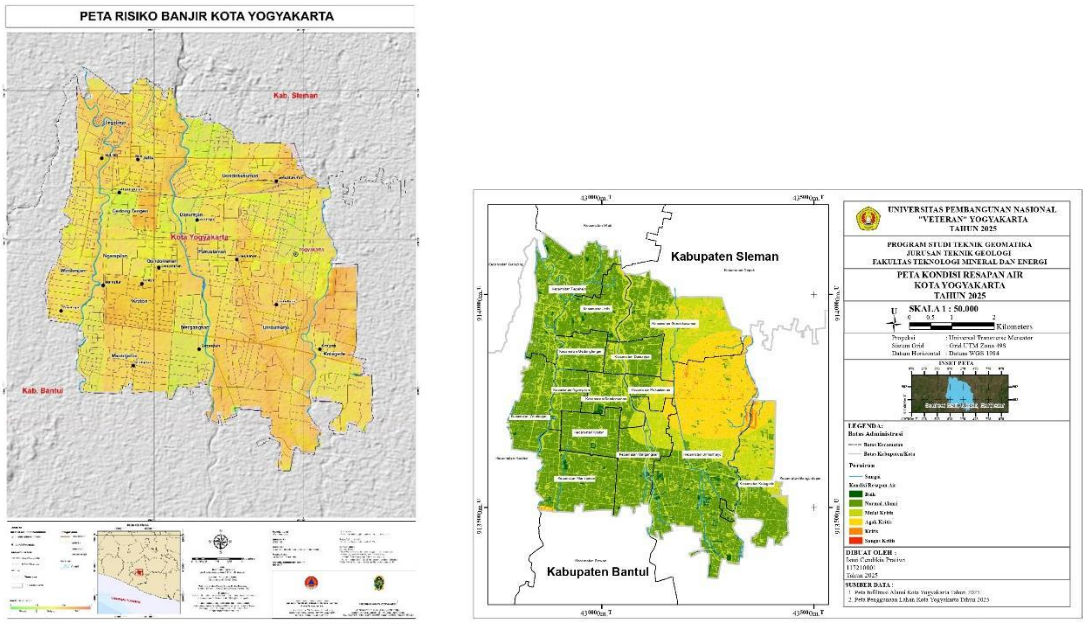
An interview with representatives from BPBD, the Regional Disaster Management Agency of Yogyakarta City, revealed that BPBD does not currently maintain up-to-date, specific spatial data on recharge areas or flood risk for every part of the city. BPBD has not previously conducted a study specifically to identify and map recharge areas. The BPBD representative indicated that the methodology used in this research aligns with the requirements set by the relevant ministry. However, BPBD operational standards focus primarily on recording flood incidents and managing response efforts rather than on the specific management of recharge areas.

BPBD recommended overlaying the study results with the official flood risk map maintained by the city for validation. The agency validates its flood risk maps through a combination of spatial data analysis and field verification, particularly during the preparation of area risk assessments and in the context of establishing Disaster Resilient Villages, locally known as Kampung Tangguh Bencana. BPBD also provided practical recommendations, such as community outreach, to encourage the construction of infiltration wells and biopores to enhance rainfall infiltration.

BPBD emphasised optimising watershed functions and maintaining riverbank recharge zones to reduce flood and landslide risk. For areas with low recharge capacity but moderate flood risk, BPBD suggested specific mitigation measures to minimise overflow impacts. As additional input, the agency recommended further identification and assessment of artificial recharge management in eastern Yogyakarta, given the low infiltration values and the rapid decline in groundwater levels associated with land use change.

BPBD further advised integrating spatial data with socioeconomic information and cross-checking the results with groundwater level data from previous studies to obtain a more comprehensive understanding. These steps would strengthen the scientific basis for targeted policy and management interventions.

Visual Comparison of Recharge Areas and Flood Risk



(a) (b)

Figure 4. Maps: (a) Flood Risk for Yogyakarta City, 2022; (b) Recharge Potential Water for Yogyakarta City, 2025

CONCLUSIONS

Yogyakarta City exhibits physical characteristics that strongly influence its infiltration capacity. Using the Inverse Distance Weighted method, analysis of infiltration rainfall produced three classification zones, with maximum values reaching 3,820 mm per year and minimum values of 1,429 mm per year. Spatially, the municipality is dominated by residential land use, which covers approximately 61.08% of the total area, or 1,826.54 hectares. Regosol is the predominant soil type, occupying the entire city at 99.87 percent. The city's topography is mainly flat, with slopes less than 8 percent, which generally supports infiltration into the subsurface.

Mapping of natural infiltration reveals substantial heterogeneity. Areas with extensive infiltration potential account for 24.55% of the mapped area, while zones with very small infiltration potential represent 0.06%. The naturally normal category generally dominates the recharge condition. However, the percentage reported here differs from that in an earlier table in the manuscript; please confirm which value should be used in the final text.

Spatial analysis indicates that the western and southern parts of the city retain a relatively high recharge potential and therefore warrant protection as groundwater conservation zones. Central and eastern areas have experienced degradation in infiltration capacity due to intensive urban development. However, selected locations within these zones remain suitable for improvement through more prudent spatial planning and targeted interventions.

A correlation between recharge conditions and flood risk is evident in the results. Areas with low infiltration capacity, such as Kotagede, display higher flood potential, while districts with good recharge capacity, such as Tegalrejo, are comparatively less prone to flooding. These findings confirm that the capacity of soil and land cover to absorb rainfall is a key determinant of flood vulnerability and should be prioritized in disaster mitigation planning and urban environmental management.

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