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Assessing Water Quality And Sustainability Of Alternative Surface Water Sources In An Urbanizing Indonesian Region

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Abstract: *Sustainable urban water management is increasingly challenged by rapid population growth, surface water degradation, and climate variability. This study provides an integrated assessment of surface water systems to evaluate their potential as sustainable urban water sources. Focusing on four primary rivers in Malang—Metro, Amprong, Brantas, and Bango—the research incorporates hydrological analysis and comprehensive water quality evaluations, using parameters such as Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), and turbidity. Pollution classification was performed using the Pollution Index (PI) and Storet Index, while Environmental Carrying Capacity (DDL) was used to assess future water sufficiency across districts. Results indicate that Amprong river has the highest annual water availability (17.9 million m³/year), whereas Metro river exhibits the best quality, with minimal treatment requirements. Bango river demonstrated severe pollution levels, rendering it suitable only for non-potable or backup uses. Spatial analysis revealed a mismatch between supply capacity and high-demand urban zones, indicating the need for strategic redistribution infrastructure. Additionally, climate projections suggest that by 2030, all districts will face heightened vulnerability to water stress. The findings offer a spatially explicit decision framework that integrates environmental quality, hydrological availability, and treatment needs for optimizing urban water supply. This research contributes to the advancement of ecological engineering strategies and supports policy development for climate-resilient and sustainable water management in rapidly urbanizing regions.*
Keywords: *Climate Resilience, Environmental Carrying Capacity, Pollution Index, Surface Water Assessment, Urban Water Sustainability*

1. INTRODUCTION

Rapid urban expansion, coupled with climate variability, continues to exert significant pressure on freshwater systems in developing regions (McDonald et al., 2011; Padowski & Gorelick, 2014). In urban areas, surface water sources such as rivers are increasingly essential for public water supply but are simultaneously exposed to intensified contamination from domestic, agricultural, and industrial activities (Fashae & Ayorinde, 2019; Adejuwon, 2025). These dual pressures necessitate integrated, data-driven assessments of water availability and quality to ensure sustainable resource planning and public health security. Globally, evidence has shown that unchecked land use changes often degrade river systems, leading to reduced water quality and altered hydrology (Olasoji et al., 2019; Berdenov et al., 2025). Meanwhile, climate models project increased frequency of extreme events, such as intense rainfall and prolonged droughts, which may exacerbate these vulnerabilities (Krueger et al., 2019; Zhang et al., 2024). In the face of these trends, urban centers must shift toward proactive planning strategies that incorporate environmental carrying capacity, pollution thresholds, and adaptive infrastructure (Halbe et al., 2021; Rathnayaka et al., 2016). This study aims to evaluate the surface water systems in a growing Indonesian city using an integrated approach. The objectives include: (1) quantifying annual river discharge; (2) assessing water quality using physicochemical parameters and pollution indices; (3) evaluating environmental carrying capacity across districts; and (4) determining climate-related vulnerabilities to support adaptive water management frameworks.

2. METHOD

Study Area

The study was conducted in a rapidly urbanizing city located within the Brantas River Basin in Malang, East Java, Indonesia. The region includes four key rivers—Metro, Amprong, Brantas, and Bango—which are being considered as potential sources for urban water supply due to the declining adequacy of spring-based systems. These rivers traverse both urban and peri-urban zones, making them susceptible to a range of pollution pressures.

Sampling and Laboratory Analysis

A mixed-methods approach was adopted, combining primary field data, laboratory analyses, hydrological records, and spatial mapping. Water samples were collected from multiple monitoring points across each river. Sampling was conducted during the dry season to capture baseline pollution levels under low flow conditions, which are considered representative of worst-case scenarios for water quality. Field sampling was conducted during the dry season to capture low-flow pollution concentrations, following guidelines from the APHA Standard Methods. Water samples were analyzed for temperature, pH, DO, BOD_5, COD, turbidity, TSS, and nitrate. Instruments were calibrated daily, and all procedures complied with QA/QC standards (Matovelle et al., 2024).

Water Quality Assessment

The following physicochemical parameters were measured: pH, temperature, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), turbidity, and nitrates. In-situ measurements (e.g., pH, temperature, DO) were conducted using handheld instruments. BOD_5 and COD were analyzed in accordance with APHA Standard Methods (5210B and 5220D, respectively). Turbidity and Total Suspended Solids (TSS) were measured using the nephelometric method and filtration, respectively. Nitrate concentrations were determined via spectrophotometry.

Pollution Classification

Water pollution levels were quantified using the Pollution Index (PI) and Storet Index. PI was calculated by comparing measured concentrations to permissible limits under Indonesian standards (PP No. 22/2021, Class II). Storet Index was employed to categorize deviations from ideal water quality thresholds, facilitating classification into "good," "lightly polluted," "moderately polluted," or "heavily polluted" segments. Pollution severity was evaluated using the Pollution Index (PI) and Storet Index, both widely adopted for surface water quality classification (Olasoji et al., 2019; Mukonza & Chiang, 2023). PI values were computed using Class II standards as baseline thresholds (PP No. 22/2021).

Hydrological Analysis

To assess water availability, historical discharge data were obtained from the Indonesian Meteorological, Climatological, and Geophysical Agency (BMKG) and relevant public works authorities. Dependable discharge volumes (Q_{80}) were calculated using the Basic Month Method. Historical flow records were analyzed to determine dependable discharge (Q_{80}) for each river using the Basic Month Method. Water availability (in MCM/year) was calculated using the equation:

$V=Q\times t\times 86{,}400$ (m³/day), where Q is average daily discharge (m³/s), and t is time in days (Gacu et al., 2025).

Environmental Carrying Capacity

The Environmental Carrying Capacity Index (Daya Dukung Lingkungan, DDL) was used to evaluate the balance between water supply and projected demand. to assess sustainability thresholds for each administrative district (Halbe et al., 2021; Berdenov et al., 2025). Classifications included: Safe (DDL > 2.0), Conditionally Safe (1.0–2.0), and Unsafe (DDL < 1.0). Environmental Carrying Capacity (DDL) was calculated using the formula:

DDL = Total Supply / Total Demand

Climate Vulnerability Assessment

Projected climate data for 2011–2030 were obtained from General Circulation Models (GCMs) and used to simulate future changes in temperature, rainfall, and evapotranspiration. These parameters informed estimates of climate-induced variability in river discharge and water availability. Key variables modeled included changes in rainfall intensity, temperature, and evapotranspiration (Krueger et al., 2019; Zhang et al., 2024).

Statistical and Spatial Analysis

Descriptive statistics (mean, standard deviation) were used to summarize water quality results. One-way ANOVA and Tukey's HSD tests were performed to identify significant differences between river segments. Pearson correlation was used to explore relationships between variables (e.g., BOD and DO). Geographic Information Systems (GIS) were employed to visualize spatial distributions of pollution intensity, water availability, and DDL status across districts. One-way ANOVA and Pearson correlation were used to identify relationships between quality indicators and between river segments. GIS was employed to visualize pollution gradients and DDL maps across districts (Masud et al., 2025; Wai et al., 2022).

3. RESULT AND DISCUSSIONS

Surface Water Availability

Analysis of dependable discharge (Q_{80}) revealed significant variation in water availability across river systems. Amprong river provided the highest annual volume, estimated at 17.9 million cubic meters (MCM), constituting approximately 60.4% of the total volume across the study area. Metro and Bango river followed with 5.9 MCM each. Despite their lower yield, these rivers still hold strategic importance for localized water service provision during peak demand periods. Spatial analysis of Environmental Carrying Capacity (DDL) projected for 2042 showed that districts such as Kedungkandang (DDL = 2.7) and Sukun (DDL = 2.3) are within the "Safe" category, whereas Klojen (1.4), Blimbing (1.6), and Lowokwaru (1.7) are "Conditionally Safe." These findings suggest that while the total volume is sufficient, its geographic distribution does not align with high-demand zones, highlighting the need for strategic redistribution. River Amprong had the highest dependable discharge (17.9 MCM/year), making up 60.4% of total flow. Metro and Bango rivers each contributed 5.9 MCM/year. These disparities align with trends in other mid-sized cities where upstream catchments vary greatly in capacity (Padowski & Gorelick, 2014; Kumar, 2021). Environmental Carrying Capacity analysis showed Kedungkandang (DDL = 2.7) and Sukun (DDL = 2.3) were categorized as "Safe." In contrast, Klojen, Blimbing, and Lowokwaru had DDL values below 2.0, reflecting constrained capacity (Halbe et al., 2021).

Tabel 1. Surface water availability

River	Volume (MCM/year)	Share (%)
Amprong	17.9	60.4
Metro	5.9	19.8
Bango	5.9	19.8

Water Quality and Pollution

Metro River displayed the most favorable water quality (BOD = 5.3 mg/L; PI = 2.95), while Amprong had slightly higher BOD but remained within Class II standards (Adejuwon, A. A., 2025). River Brantas recorded higher COD and BOD levels, indicating organic pollution consistent with upstream urban inputs. River Bango showed critical pollution levels, with BOD reaching 17.65 mg/L and turbidity exceeding 160 NTU—consistent with heavily degraded rivers in industrial zones (Berdenov et al., 2025; Iqbal et al., 2023). Storet Index classifications reinforced these findings: Metro and Amprong were "lightly polluted," while Bango was "moderately polluted." This aligns with previous assessments of rivers in urbanizing cities under land use pressure (Fashae & Ayorinde, 2019; Olasoji et al., 2019).

Table 2. Water quality parameters

River	BOD (mg/L)	COD (mg/L)	DO (mg/L)	Turbidity (NTU)
Brantas	8.55	24.2	5.95	11.3
Metro	5.3	15	4.8	15
Bango	15.5	23.6	4	93
Amprong	3	9.6	6.8	8

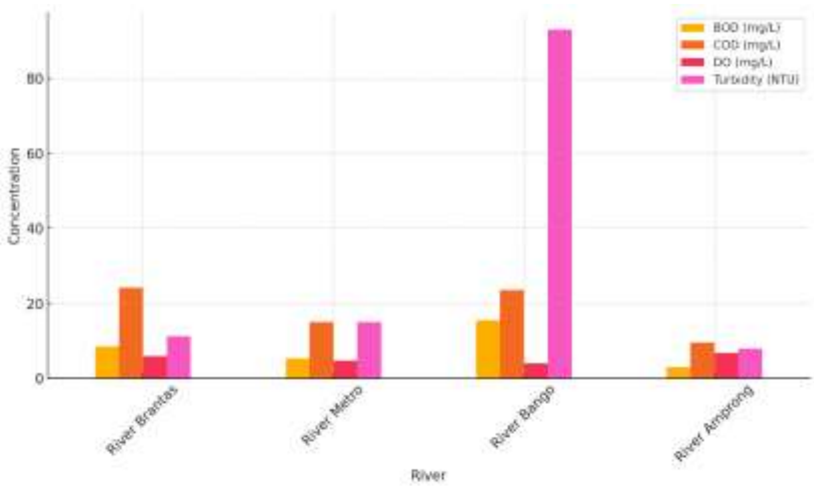

Figure 1. comparison of key water quality parameters across rivers

Table 3. Pollution index and storet

River	Pollution Index (PI)	Storet Index
Brantas	2.45	-1
Metro	2.95	-1
Bango	2	-4
Amprong	2.55	-1

Source Suitability Ranking

A comparative radar chart of all four rivers assessed them across five dimensions: availability, water quality, treatment need, pollution risk, and overall suitability. The radar chart comparing the five performance dimensions ranked Metro highest in overall suitability, followed by Amprong, Brantas, and Bango. Metro river ranked highest overall due to its favorable quality and minimal treatment requirements. Amprong river, with the highest availability but moderate quality, is best suited for industrial or blended supply. Brantas offers redundancy potential but requires standard treatment. Bango, due to intensive treatment needs and low quality, is more appropriate for backup or non-potable applications. These findings validate the use of multi-criteria decision frameworks for urban water supply selection (Rathnayaka et al., 2016; Arora et al., 2016).

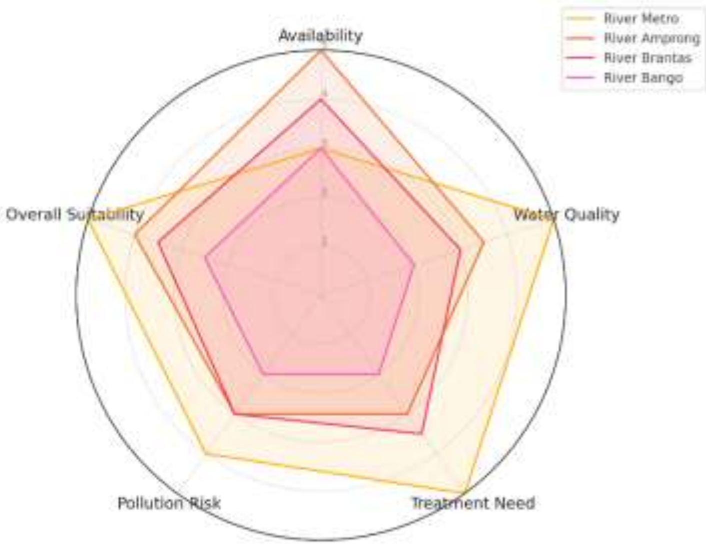

Figure 2. Comparative suitability of river sources

Climate Risk Implications

Climate projections indicated a 1.0°C temperature increase and more intense rainfall events (60–100 mm/day) by 2030. Projections from GCM-based simulations indicate a 1.0°C rise in temperature and increasing frequency of extreme rainfall events (60–100 mm/day) by 2030. Climate-induced stress is expected to disproportionately affect districts such as Blimbing and Kedungkandang. These trends coincide with a projected 140% increase in urban water demand by 2042, widening the gap between supply and demand if mitigation strategies are not implemented. Blimbing and Kedungkandang were identified as high-risk zones. These trends mirror projections across the Asian subcontinent, where water systems are increasingly impacted by compounded environmental pressures (Krueger et al., 2019; Zhang et al., 2024). Policy RelevanceThe study supports prioritizing Metro and Amprong for primary supply, while Brantas and Bango require advanced treatment or non-potable reallocation. Long-term planning should integrate decentralized systems, and risk-based infrastructure investments (Masud et al., 2025; Wai et al., 2022; Gacu et al., 2025). The results support the need for an integrated, adaptive approach to urban water resource management. Specifically, planners should prioritize Metro for direct potable use, allocate Amprong for high-volume, moderate-quality needs. Maintain Brantas as a supplementary reserve and invest in advanced treatment for Bango or repurpose it for non-potable uses. Climate-resilient infrastructure, real-time water quality monitoring, and decentralized treatment systems should be central to future planning.

4. CONCLUSION

This study provides a comprehensive assessment of surface water systems with respect to their availability, quality, and strategic suitability for sustainable urban water supply planning. Through hydrological analysis and pollution indexing, four major river sources—River Metro, River Amprong, River Brantas, and River Bango—were evaluated to determine their viability as raw water inputs in an increasingly urbanized and climate-stressed context. Findings highlight River Amprong as the most abundant source, contributing over 60% of the total surface water volume, making it well-suited for industrial or blended urban supply applications. River Metro emerged as the most viable for potable use due to its favorable water quality and minimal treatment requirements. In contrast, River Brantas, though moderately polluted, can serve as a reliable supplementary source with conventional treatment technologies. River Bango, characterized by high turbidity and organic pollution, was deemed suitable only for non-potable or backup use due to its intensive treatment demands. Pollution Index (PI) and Storet Index classifications reinforced spatial disparities in water quality, underscoring the need for localized pollution control and remediation strategies. Moreover, environmental carrying capacity analysis revealed mismatches between high-demand districts and water availability, necessitating infrastructure redistribution and decentralized supply approaches. Climate vulnerability projections further emphasize the urgency of adaptive and resilient water management planning. In response, this study proposes a spatially informed decision-making framework integrating environmental capacity, water quality, and infrastructural feasibility. The results offer actionable insights for utility managers, urban planners, and policymakers seeking to enhance water security and public health outcomes in rapidly urbanizing regions.

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