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Policy and Strategy for Sustainable Water Management in Banjarmasin City

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Abstract Urbanization in Banjarmasin, South Kalimantan, has placed significant pressure on its water resources, leading to challenges in sustainable water management. The city, located in a deltaic area, faces frequent flooding and environmental degradation, especially in water quality and sanitation. This study looks at sustainable water management in Banjarmasin, focusing on clean water supply, wastewater handling, and the capacity of water resources. A mixed-methods approach was employed, integrating qualitative and quantitative techniques, including field surveys, GIS spatial analysis, system dynamics modeling, and policy analysis. The findings reveal that Banjarmasin excels in clean water sustainability, with a high sustainability index of 93.89 in Banjarmasin Timur, but struggles with wastewater management, which scored only 26.18. The city's reliance on external river sources, such as the Barito and Martapura Rivers, exacerbates its vulnerability, with the water availability ratio in 2023 being 0.35 in a closed-system scenario. Despite improvements in clean water services, wastewater infrastructure remains underdeveloped, with only 2.85% of the population receiving wastewater services. The study concludes that while clean water sustainability is commendable, integrated strategies for wastewater management and more resilient water systems are essential for long-term urban sustainability. Future work should focus on expanding wastewater infrastructure, optimizing water resource management, and promoting public awareness of water conservation.

Keywords Water Sustainability, Banjarmasin, Wastewater Management, Urbanization, Water Resources

1. Introduction

Urbanization represents a transformative force in contemporary global development, deeply reshaping demographic patterns, economic structures, and ecological balances. Today, more than half of the global population resides in urban areas, a figure projected to exceed 60% by 2030 [1]. Cities function as engines of economic growth and hubs of innovation, providing employment, education, and an improved quality of life [2]. However, these benefits come at an environmental cost. As Batalhao et al. [3] and Gioielli [4] note, the rapid pace of urbanization often outstrips infrastructure development and environmental management capacities. In Asian megacities like Tokyo, Delhi, and Shanghai, urban growth has triggered a multitude of challenges, including overcrowding, pollution, and water insecurity [5]. The cities have become concentrated zones of environmental and socioeconomic stress, where spatial expansion often results in ecological degradation [6]. Poor urban governance, especially in developing regions, intensifies the negative impacts of urbanization by failing to incorporate sustainable land and resource use policies. The unchecked growth of urban settlements also leads to the loss of agricultural land and the encroachment on ecologically sensitive areas, such as wetlands and riparian zones. Cities are thus described as both centers of economic prosperity and sources of social problems, including income inequality and environmental vulnerability [7]. The disproportionate consumption of natural resources and energy by urban populations exacerbates global environmental issues, including climate change, biodiversity loss, and freshwater depletion. In this context, the concept of sustainable urban development, with a strong ecological underpinning, is essential for ensuring the resilience and livability of cities in the long term [8]. As such, urban planners and policymakers must urgently consider environmental carrying capacity when planning for future urban growth [9].

Indonesia exemplifies the complexities of urbanization globally, where demographic pressures, infrastructure deficits, and ecological vulnerabilities coexist. Between 2010 and 2020, Indonesia experienced one of the fastest urban transitions in Southeast Asia, with major cities such as Jakarta, Surabaya, and Bandung facing exponential population growth [10]. According to projections by the Ministry of Public Works and Housing [11], urbanization in Indonesia is expected to reach 67% by 2035. This trend is particularly evident in provinces such as West Java, Banten, and the Special Region of Yogyakarta, which are anticipated to experience urbanization levels of over 80%. This growth, however, has not been met with sufficient environmental governance or infrastructure investment, leading to informal settlements, declining air and water quality, and increasing exposure to climate hazards [12]. Urban expansion in Indonesia is often characterized by land-use conflicts and the conversion of natural ecosystems into built environments without proper assessments of environmental capacity [13]. These dynamics have undermined efforts to achieve urban resilience, as cities struggle to cope with environmental degradation and social inequality simultaneously. Gutiérrez-Nava et al. [14] warned that cities unable to manage their ecological thresholds will suffer irreversible damage to both natural ecosystems and public health. In response, Indonesia has embraced the Sustainable Development Goals (SDGs) and the New Urban Agenda, committing to targets such as inclusive, safe, resilient, and sustainable [15]. However, the realization of these commitments requires localized implementation strategies rooted in environmental science. Concepts like environmental carrying capacity and environmental support capacity are pivotal in evaluating the limits of urban expansion. They serve as analytical tools to guide spatial planning, water resource management, and environmental impact assessment. Recent studies have emphasized the utility of such frameworks in urban sustainability assessments, especially when linked with geographic information systems (GIS) and spatial modeling [16]. By integrating these frameworks into urban development planning, cities can optimize land use, protect ecosystems, and enhance quality of life for present and future generations.

In this regard, Banjarmasin provides a pertinent case study to assess the sustainability of urban systems from a hydrological and ecological perspective. As the capital of South Kalimantan and one of the densest cities on the island of Borneo, Banjarmasin plays a critical role in the regional economy, while facing acute environmental challenges. The city occupies just 0.26% of the province's land area, yet its population density reached 6,798.28 inhabitants per km ^{2} in 2024 [17]. Situated within the Barito River delta, Banjarmasin is built on low-lying fluvial and alluvial terrain, making it highly susceptible to periodic flooding and land subsidence [18]. With much of the city's urban form sprawling into swampy and riverine areas, the natural hydrological systems are severely compromised. Data from the Environmental Quality Index from 2017 to 2023 indicate that Banjarmasin consistently scores low on water quality, with values improving from a “very poor” 10.27 in 2017 to a still “poor” 48.18 in 2023 [19], [20]. This trend reveals that water-related environmental pressures persist despite incremental improvements. Moreover, the water quality index contributes over 37% to the city's overall low IKLH score, underlining water as a major bottleneck to sustainability [21]. These challenges are compounded by increasing demand for water, inadequate wastewater treatment, and encroachments on water catchment areas. According to Saikia et al [22], cities with limited natural water resources and high population densities are particularly vulnerable to sustainability failure if integrated water management is not prioritized. Therefore, this study seeks to analyze Banjarmasin's urban sustainability by examining its environmental carrying and support capacity, specifically from the perspective of water. It aims to answer key questions regarding water resource conditions, spatial planning integration, and policy design. The novelty of this research lies in its effort to develop a context-specific, water-based urban sustainability model that can inform planning and policy in cities with similar ecological and socio-spatial constraints. Through this investigation, the study contributes both theoretically and practically to the broader discourse on sustainable urban development under environmental stress, offering actionable insights for achieving resilient and livable urban futures.

2. Material and Methods

2.1. Study Area

This research is conducted in Banjarmasin, a prominent urban center in South Kalimantan Province. Formerly designated as the provincial capital before the administrative shift to Banjarbaru, Banjarmasin remains one of the largest cities on the island of Borneo. Geographically, the city lies between 3 ° 16' 46" and 3 ° 22' 54" South Latitude, and 114 ° 31' 40" to 114 ° 39' 55" East Longitude. It is situated at an average altitude of approximately 0.16 meters below sea level, characterized by low-lying, flat, and swampy terrain. This topography results in frequent flooding, particularly during high tides, which inundate most areas of the city. Banjarmasin's strategic location—acting as a gateway to Borneo and intersected by the Trans Kalimantan highway has played a crucial role in driving its urban growth and development. The specific location of the study area is illustrated in Figure 1.

This study originates from the global commitment to implement sustainable development goals (SDGs), ratified by the Government of Indonesia through various national strategies and frameworks. One of the main derivations of the SDG framework is the concept of sustainable cities [23]. A sustainable city must be supported by a resilient environment, with water playing a crucial role as one of its core pillars. The deterioration of water quality in Banjarmasin over recent years, indicated by a declining Water Quality Index classified as 'very poor,' reflects the limited capacity of the city's water resources to support sustainable urban development. Furthermore, spatial planning is essential in determining how a city can grow while maintaining environmental viability. In a complex, multi-sectoral, and multidisciplinary urban system, sustainable development requires an integrative approach to spatial planning and the assessment of environmental carrying and support capacity, especially concerning water systems. This research is designed to analyze sustainability through four integrated lenses: (1) water sustainability status (evaluated using RAPFISH, a multidisciplinary technique for assessing sustainability across ecological, social, and economic dimensions), (2) environmental carrying and support capacity (GIS and system dynamics), (3) spatial planning assessment (policy analysis), and (4) policy and strategy design (AHP) [24].

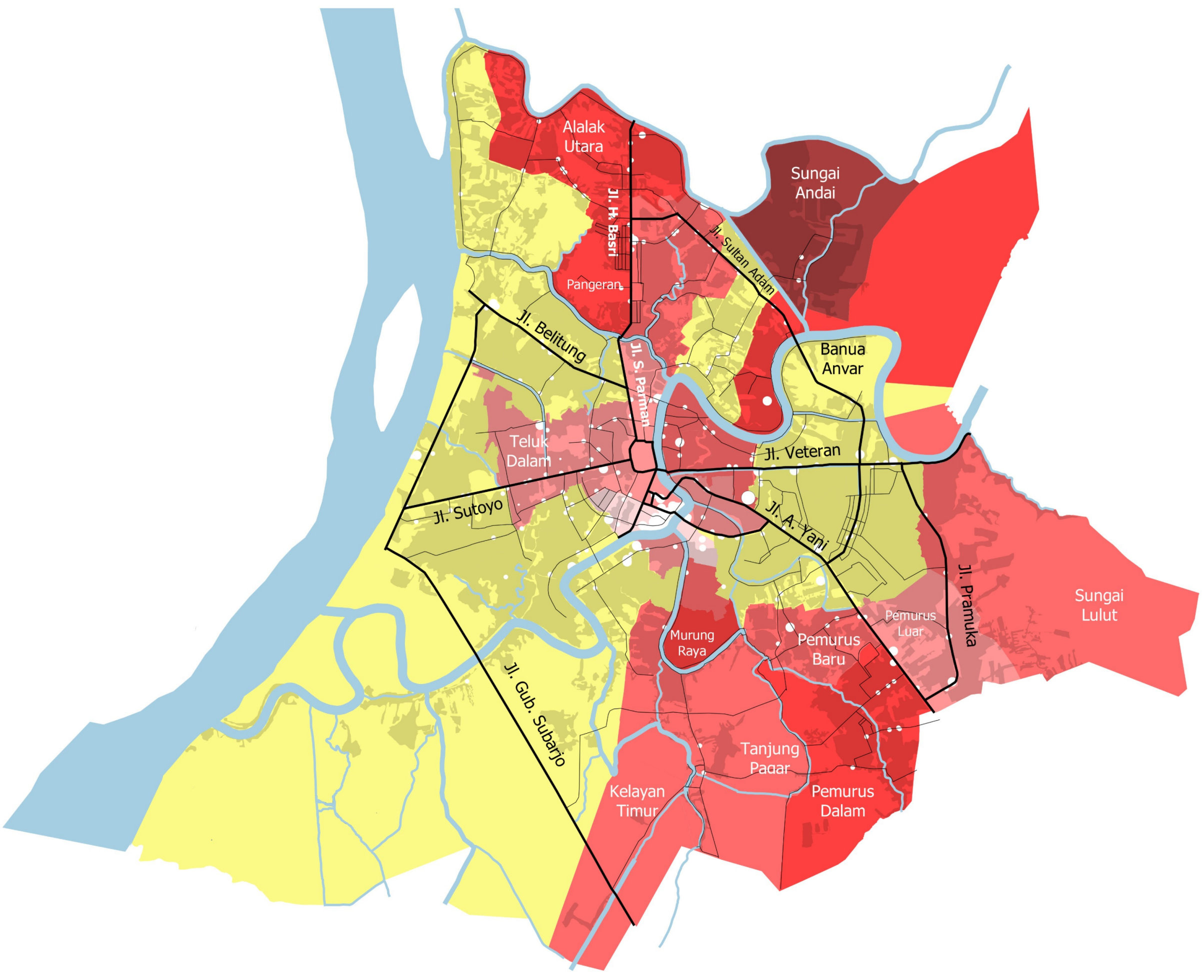

Figure 1. Map Area of Interest in Banjarmasin City

2.2. Research Approach

This research adopts a mixed-methods approach that integrates both qualitative and quantitative techniques to examine complex and multi-scalar issues of urban sustainability. As noted by L. Penserini [25], Mixtures of Contaminants of Emerging Concern (CECs) in drinking water pose health risks, and the QCRAMIX method offers a more accurate evaluation by accounting for uncertainties in exposure and hazard assessment. In this context, the research focuses on sustainable urban water management in Banjarmasin, with specific reference to Sustainable Development Goal (SDG) 6, which emphasizes universal access to clean water and sanitation.

A quantitative approach with a descriptive design is employed to assess the environmental carrying capacity of water resources and to identify the gaps between urban water demand and resource availability. Primary data will be collected through field surveys, in-depth interviews, and direct observations of water-related infrastructure to evaluate the current state of urban water systems and their capacity to meet the needs of a growing population. Additionally, secondary data such as government reports will be analyzed to provide a broader understanding of the water management framework in the city.

Surveys and questionnaires will be administered to local residents to assess access to clean water and sanitation services. Meanwhile, interviews with policymakers, water management officials, and other stakeholders will offer insights into the challenges faced and strategies implemented in Banjarmasin's water governance. Field observations will focus on the physical condition of water distribution networks, treatment facilities, and other infrastructure to assess the real-world effectiveness of existing policies and initiatives. The data collected will be analyzed using descriptive statistics to summarize the current conditions and qualitative analysis to identify emerging themes and critical issues from stakeholder perspectives.

Furthermore, an environmental carrying capacity model will be applied to evaluate the balance between water supply and the increasing demand across different sectors in the city. The findings are expected to inform policy recommendations aimed at improving urban water management practices, supporting sustainable access to water, and advancing the achievement of SDG 6 in Banjarmasin. The research framework adopted in this study is illustrated in Figure 2.

The study begins with secondary data collection from official publications, statistics, environmental reports, and planning documents. These quantitative data are supplemented with qualitative insights gathered through expert interviews and stakeholder analysis. In the analytical phase, data are processed using various tools: Rapfish for sustainability assessment; system dynamics modeling (Vensim) for dynamic simulations of water carrying and support capacity; Geographic Information Systems (GIS) for spatial mapping of ecosystem services; and Analytical Hierarchy Process (AHP) using Expert Choice software for policy prioritization. The integration of these methods allows triangulation and strengthens the validity of the research findings.

2.3. Research Location and Period

Banjarmasin's location as the gateway to Kalimantan and a node along the Trans-Kalimantan corridor makes it both strategic and ecologically sensitive. This research was carried out over a 24-month period, beginning with the official approval of the dissertation proposal. The study covers multiple sites across the six administrative districts (kecamatan) of Banjarmasin, selected based on demographic density, spatial distribution, and their representation of water management challenges.

2.4. Research Phases

2.4.1. Water Sustainability Status Assessment

The first phase of the research focuses on analyzing the sustainability status of Banjarmasin from a water perspective. This phase follows the indicators established in SNI ISO 37120:2018, which evaluates cities' sustainability through clean water and sanitation indicators. Using secondary data collected from relevant local institutions such as BPS, DLH, and PDAM, the analysis applies the Multidimensional Scaling (MDS) technique using Rapfish software. Key indicators include the percentage of residents served with clean water, compliance with drinking water standards, and the rate of water service interruptions. Each indicator is scored based on peer-reviewed expert judgment and converted into sustainability indices. The outcomes are visualized in ordination plots and kite diagrams, with interpretations categorizing the city's water sustainability status as either sustainable (index $\geq$50%) or unsustainable (index <50%).

2.4.2. Environmental Carrying and Support Capacity

In the second phase, the study examines the carrying and supporting capacity of the water system, which involves evaluating the balance between water supply and demand, as well as the city's ability to absorb pollution loads. Two methodologies are employed: spatial analysis using GIS and system dynamics modeling. Spatial analysis is conducted using ecosystem service mapping, incorporating land cover, ecoregion, and native vegetation data to produce maps that categorize regions by their capacity to provide water and absorb pollutants. Concurrently, system dynamics simulations are executed in Vensim software to quantify thresholds and detect capacity exceedance in water provision and wastewater absorption. This phase culminates in a diagnostic of areas under stress, providing essential input for planning and regulation.

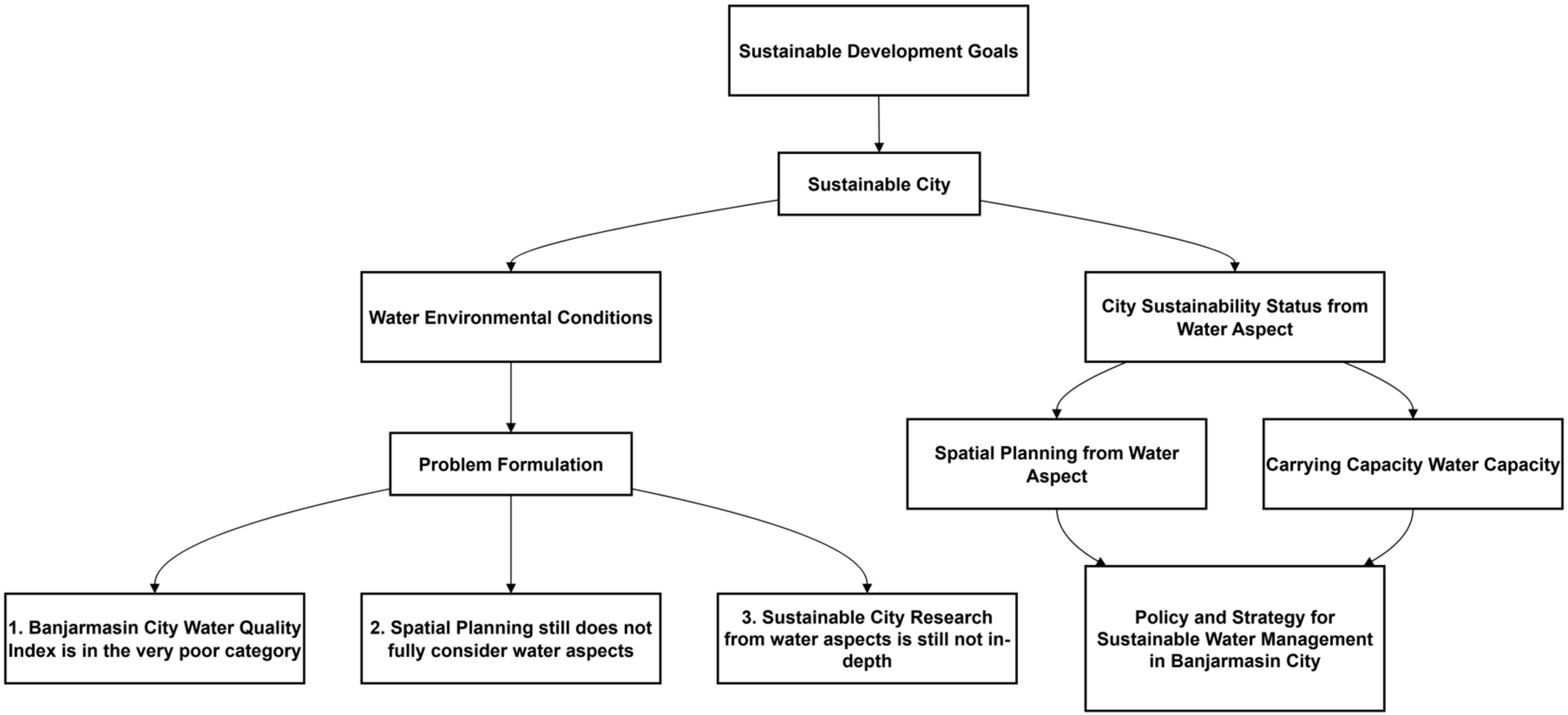

Figure 2. Research Framework

2.4.3. Spatial Planning Assessment

The study investigates how existing urban spatial plans align with the principles of sustainable water management. This analysis draws from formal spatial planning documents including RTRW (Rencana Tata Ruang Wilayah) and RDTR (Rencana Detail Tata Ruang), assessed through descriptive and policy integration analyses. Indicators reviewed include the planning objectives, strategies, and spatial structuring of the urban water system. The results are categorized based on whether current planning frameworks support or hinder sustainable water governance, providing insights into the coherence between environmental goals and legal-planning instruments.

2.4.4. Policy and Strategy Design for Sustainable Water Management

The final phase of the study formulates a policy and strategy framework for sustainable water management in Banjarmasin. It begins with the identification of key stakeholders and experts using purposive and snowball sampling, followed by in-depth interviews and questionnaires. These data are analyzed using Analytical Hierarchy Process (AHP), which prioritizes critical factors influencing sustainable water governance. AHP is conducted with the support of Expert Choice software, which calculates consistency ratios and ranks policy alternatives. Final outputs include recommended strategies and actionable policies for managing clean water provision, domestic and non-domestic wastewater systems, tailored to the specific urban context of Banjarmasin.

3. Results and Discussion

In the effort to develop and implement Banjarmasin as a sustainable city, a set of indicators must be achieved, as outlined in SNI ISO 37120:2018 concerning sustainable urban development and communities—indicators for city services and quality of life. These indicators serve as guidelines for the local government and residents of Banjarmasin to take strategic actions or formulate policies aimed at realizing urban sustainability. The sustainable city indicators that have been achieved by Banjarmasin, particularly in the areas of clean water and wastewater, are presented in Table 1.

Table 1. Indicators for Cleanwater and Wastewater

Aspect		Indicator	Subdistrict					Banjarmasin City
			West Banjarmasin	Central Banjarmasin	East Banjarmasin	South Banjarmasin	North Banjarmasin	
Cleanwater	1	Percentage of urban population with access to clean water services	86.90	82.50	96.87	92.20	95.65	91.87
	2	Percentage of population with sustainable access to improved water sources	98.82	98.82	98.82	98.82	98.82	98.82
	3	Total domestic water consumption per capita (L/person/day)	109.97	111.59	137.63	120.10	140.95	125.01
	4	Compliance rate with clean water quality standards	94.65	97.78	94.65	97.62	98.80	96.70
	5	Total water consumption per capita	118.87	163.07	169.54	128.38	160.69	146.12
	6	Average service disruption time per household (hours/day)	2.5	2.5	2.5	2.5	2.5	2.5
	7	Percentage of non-revenue water	28.87	28.87	28.87	28.87	28.87	28.87
Wastewater	1	Percentage of population receiving wastewater services	0.21	4.74	0.84	3.49	4.78	2.85
	2	Percentage of wastewater treated through centralized systems	0.69	0.89	0.32	0.85	1.04	0.76
	3	Percentage of population with access to improved sanitation	1.29	6.39	2.73	6.21	5.64	4.49
	4	Compliance rate with wastewater treatment standards	85.71	57.14	92.31	62.50	83.33	75.93

3.1. Status of Clean Water Sustainability

The clean water dimension is a key indicator in assessing the sustainability of Banjarmasin City, as outlined in SNI ISO 37120:2018. Based on Rapfish analysis using five of the seven core indicators for clean water, all districts in Banjarmasin demonstrate high levels of sustainability. The results are shown in Table 2.

Table 2. Indicators for Cleanwater

Region	Score
Banjarmasin City	93.89
West Banjarmasin	92.73
Central Banjarmasin	92.73
East Banjarmasin	93.89
North Banjarmasin	93.89
South Banjarmasin	92.73

The city itself, along with Banjarmasin Timur and Banjarmasin Utara Districts, scored 93.89 in the sustainability index, while the other three districts Banjarmasin Barat, Tengah, and Selatan each scored 92.73. All scores are well above the minimum sustainability threshold of 50, indicating that the clean water aspect in Banjarmasin is highly sustainable. Several factors contribute to these high achievements, including the clean water service coverage, which reaches 91.87% of the city's total population, access to improved water sources at 98.82%, and compliance with clean water quality standards at 96.70% (see Table 1). Additionally, domestic water consumption per capita stands at 125.01 liters/person/day. Although this is below the national standard of 170 liters/person/day, the abundance of river water throughout the city enables adequate fulfillment of daily water needs. Clean water services are mainly provided by the regional utility company, PT. Air Minum Bandarmasih, which also serves parts of Banjar Regency. The city's strong reliance on piped water distribution reflects the success in equitable water service delivery.

Water losses can be attributed to several factors, including pipe leakages caused by aging distribution networks or external disturbances such as construction activities and soil shifts; illegal connections in the form of unauthorized use or unregistered tapping, which result in unrecorded consumption; inaccuracies in customer water meters due to malfunction or poor calibration, leading to discrepancies between distributed and recorded volumes; technical issues in the distribution system, such as excessively high or low pressure, which reduce efficiency and increase the risk of leakage; and losses occurring during the treatment process due to evaporation, runoff, or internal usage within the treatment facilities. Beyond these technical factors and service coverage, the average water service disruption of 2.5 hours per household per day also influences the sustainability index. Although this level of disruption is relatively high, particularly during peak hours, overall water service remains reliable. Non-Revenue Water (NRW) is recorded at 28.87%, which is still within the nationally acceptable efficiency limit, though further improvement is recommended for operational efficiency. The NRW data for Banjarmasin City are presented in Figure 3.

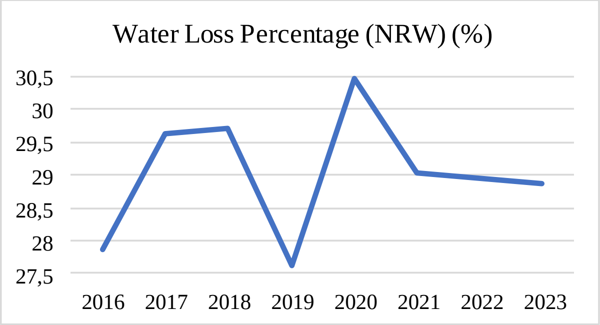

Figure 3. NRW Data in Banjarmasin City

With consistent achievements across all districts and the critical role of the regional water utility, Banjarmasin's clean water sustainability demonstrates strong performance. However, optimizing water consumption and improving distribution efficiency remain key priorities for medium and long-term planning.

3.2. Status of Wastewater Sustainability

The analysis of the wastewater dimension in Banjarmasin shows a stark contrast to that of clean water. Based on Rapfish assessments of four core indicators, all districts in the city score below 50% indicating that the wastewater aspect is still categorized as less or even unsustainable. The results are shown in Table 3.

Table 3. Indicators for Wastewater

Region	Score
Banjarmasin City	26.18
West Banjarmasin	28.64
Central Banjarmasin	21.27
East Banjarmasin	31.10
North Banjarmasin	28.64
South Banjarmasin	23.72

Banjarmasin Timur scores the highest at 31.10, while Banjarmasin Tengah records the lowest at 21.27. The citywide score stands at only 26.18. This low level of sustainability is caused by several factors. First, the coverage of wastewater services is extremely low, with only 2.85% of the city's population receiving such services. Second, only 0.76% of domestic wastewater is treated through centralized systems, meaning that most household waste is discharged untreated. Third, only 4.49% of the population has access to improved sanitation, a figure that is far below national standards and SDG targets. Lastly, while the compliance rate for wastewater treatment reaches 75.93%, it has not significantly lifted the overall sustainability score due to the limited service coverage.

Another major issue is the low public willingness to connect to or construct domestic wastewater treatment systems. Many residents remain unaware of the environmental and health benefits of proper wastewater management. Additionally, open defecation (OD) behavior is still prevalent, with a rate of 4.9% among the population. Existing infrastructure, such as wastewater treatment plants (WWTPs), is significantly underutilized, with an idle capacity of 84.5%. This situation is further exacerbated by the public's limited ability to pay for service connections and their lack of perceived value in wastewater services. These conditions reflect a significant gap between the government's commitment to mainstream sustainable development already integrated into policy, planning, and regulatory frameworks at all levels and the community's willingness to participate, particularly in wastewater management. As evidenced in Banjarmasin, while the clean water dimension is categorized as sustainable, the wastewater dimension remains unsustainable, highlighting the disparity in public and governmental attention to these two essential aspects of urban sustainability.

This analysis highlights a substantial gap that the Banjarmasin City Government must address in expanding wastewater services. Key strategies should include public education on the importance of sanitation, financial incentives for low-income households to connect to centralized systems, and better utilization of existing WWTP capacity.

3.3. Comparison of Clean Water and Wastewater Dimensions

From a combined analysis perspective, there is a significant disparity between the sustainability performance of the clean water and wastewater dimensions in Banjarmasin. The average sustainability index for clean water exceeds 93, meaning all districts are categorized as "good (sustainable)." In contrast, the average index for wastewater stands at only 26.18, with all areas falling into the "poor" or "unsustainable" categories. This gap indicates that urban water infrastructure development in Banjarmasin has not been holistic.

The strong focus on clean water infrastructure is understandable, as it addresses an immediate and essential need. However, the lack of parallel investment in sanitation and wastewater management has resulted in significant environmental consequences, including heavy pollution of the city's surface water bodies. The river systems in Banjarmasin are notably impacted by untreated domestic wastewater.

Visual comparisons of the sustainability indices reveal sharp contrasts across all districts. For instance, Banjarmasin Timur, which scored 93.89 for clean water, only managed 31.10 for wastewater. Banjarmasin Tengah, while recording 92.73 for clean water, scored the lowest at 21.27 in wastewater sustainability. These results suggest that advancements in clean water access have not translated into improvements in sanitation infrastructure. The results are shown in Figure 4.

Therefore, an integrated policy approach is needed in managing urban water systems. The Banjarmasin City Government must align clean water improvements with enhanced wastewater management in long-term urban planning. This alignment is also essential to fully achieve Sustainable Development Goal (SDG) 6, which aims to ensure the availability and sustainable management of water and sanitation for all.

1. Water Carrying Capacity of Banjarmasin

Water carrying capacity refers to the environmental ability of a region to support human water needs based on available resources. In Banjarmasin, this capacity has been analyzed using two complementary approaches: the ecosystem service model and dynamic system modeling. Both provide different insights into the city's hydrological sustainability.

Using the ecosystem service approach, spatial data analysis indicates that the majority of Banjarmasin's territory has a limited capacity to supply water. Specifically, 51.65% of the area falls under the “low” provisioning category, and 38.79% under “moderate.” Only 9.45% of the total area is categorized as “very high.” This distribution shows that natural conditions such as limited vegetation, heavy urban development, and the lack of open space, restrict the ecosystem's ability to regulate, retain, and release clean water. Urbanized areas often lack the infiltration capacity needed for effective groundwater recharge, reducing their support for sustainable water supply.

In addition to ecosystem-based analysis, a dynamic system model was employed to assess both the supply and demand of water in Banjarmasin. This model considers rainfall input (between 1,750 mm and 2,750 mm/year) and population projections from both BPS and the Civil Registry Office. Under a closed system scenario, where water availability relies solely on local rainfall, the city experiences a consistent water deficit. For instance, in 2023, the ratio between availability and demand was only 0.35 (using BPS population data), far below the threshold for sufficiency. This ratio declines further in future projections.

However, in an open system scenario that includes inflows from the Barito, Martapura, and Alalak Rivers, water availability meets or even exceeds demand. The 2023 open system ratio stood at 0.55, which is still below ideal but significantly better than the closed system result. This dependency on external water sources highlights a critical vulnerability in Banjarmasin's hydrological balance.

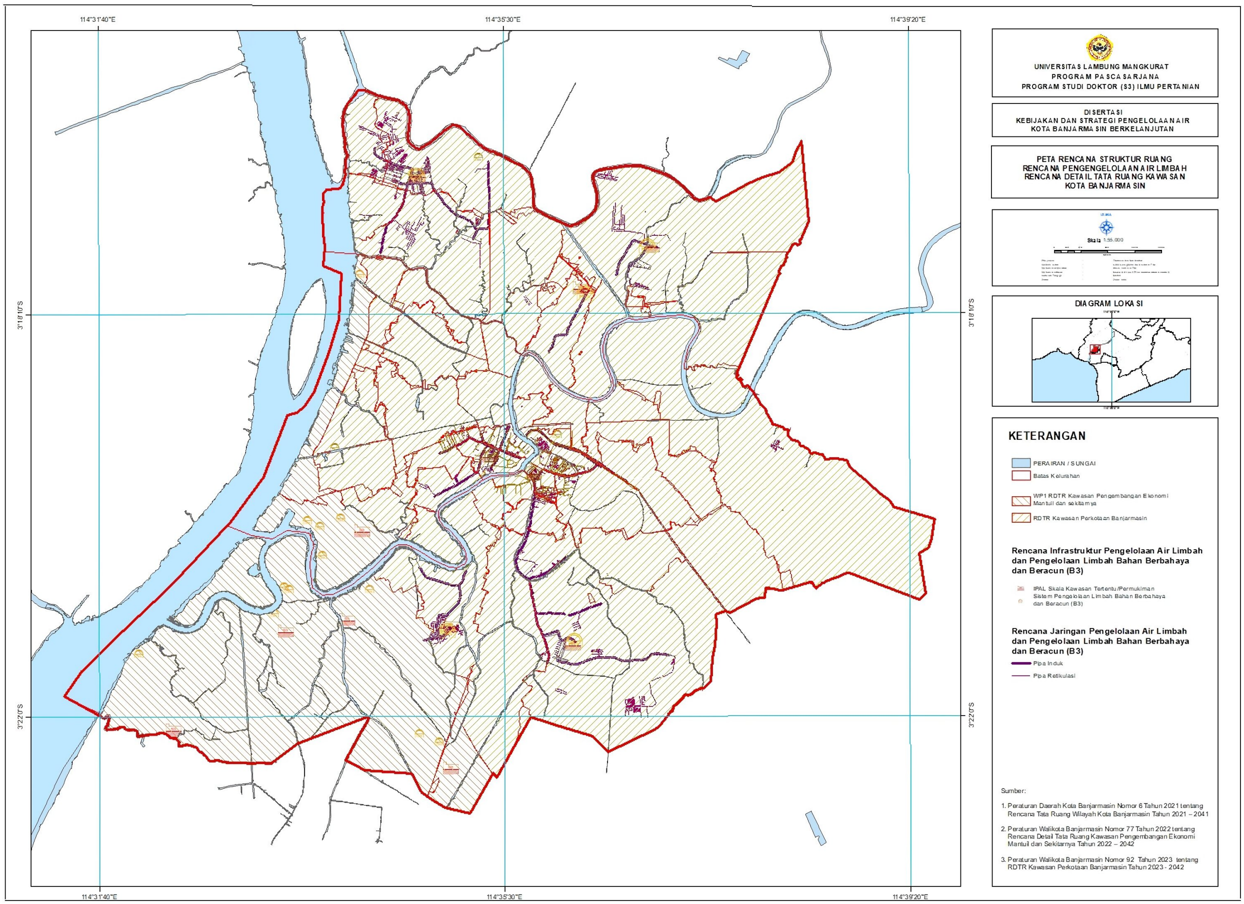

Figure 4. Spatial Analysis Cleanwater and Wastewater Sustainability

Thus, the city's carrying capacity is heavily influenced by land use patterns, rainfall variability, and reliance on surrounding river basins. While water availability appears sufficient under certain assumptions, the true picture reveals that local supply alone is inadequate. These insights suggest that without continued access to external water sources, Banjarmasin would face significant challenges in meeting its future water demands, especially under scenarios of rapid urbanization and population growth.

2. Water Assimilative Capacity of Banjarmasin

The water assimilative capacity of Banjarmasin has been evaluated using two complementary methodologies: ecosystem purification services and dynamic system modeling of pollutant load assimilation. Both analyses converge on one key conclusion—the city's rivers are under intense pressure from pollution, and their natural ability to cleanse themselves is highly constrained.

Ecosystem-based assessment reveals that 90.15% of Banjarmasin's land area offers "very low" capacity to purify wastewater. Only 7.01% falls under the "moderate" category, with no areas recorded as having "high" or "very high" purification capacity. This reflects a heavily urbanized landscape with limited vegetative cover and natural infiltration zones. Vegetated areas, such as forests and wetlands, are vital for filtering pollutants, absorbing excess nutrients, and maintaining ecological resilience. However, in Banjarmasin, dense construction and impervious surfaces inhibit these functions, allowing contaminants to accumulate in the hydrological system.

Dynamic modeling of river pollution loads offers a more granular view. Seven critical water quality parameters were analyzed: Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), total phosphate, fecal coliform, cyanide, chlorine, and detergents. These were evaluated across six rivers: Barito, Martapura, Alalak, Kuin, Pemurus, and Pekapuran. Results vary by river and pollutant, with smaller rivers generally exhibiting poorer performance.

The Barito River demonstrates moderate assimilative capacity for COD (ratio 1.26) and cyanide (10), but fails for BOD and fecal coliform. The Martapura River exceeds safe thresholds for almost all parameters, except phosphate. The Alalak River shows acceptable levels for phosphate (5.47) and detergent (11.94), but performs poorly for coliform and BOD. The Kuin and Pekapuran Rivers are severely overburdened, with extremely high coliform counts (up to 100,500 MPN/100 mL) and a negative capacity for COD. The Pemurus River also reveals failing scores for fecal coliform, phosphate, and cyanide. The results of these findings are illustrated in Figure 5.

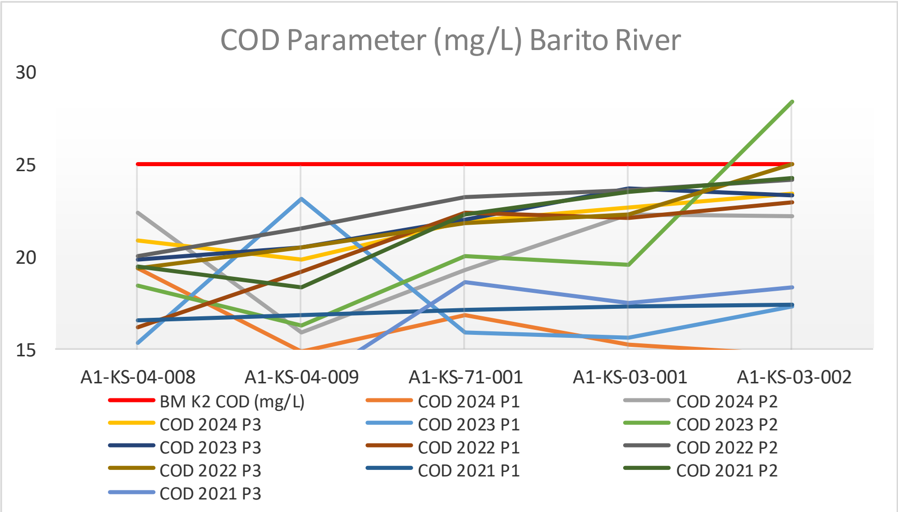

Figure 5. Results of COD parameter monitoring of the Barito River

Overall, assimilative capacity is weakest in smaller rivers with low flow volumes, where pollutants are less diluted. Parameters like fecal coliform are particularly problematic, driven by inadequate sanitation infrastructure and widespread open defecation. These factors result in untreated domestic waste entering waterways directly, causing rapid degradation of water quality. The city's rivers, once central to daily life, now struggle to support their ecological and functional roles due to overwhelming pollution loads.

3. Causes and Context of Water Pollution

The causes behind Banjarmasin's deteriorating water quality and limited assimilative capacity are deeply rooted in its urban structure and sanitation infrastructure. High population density, widespread informal settlements, inadequate waste treatment facilities, and poor sanitation practices all contribute to rising pollution levels.

According to the 2024 data, only 4.49% of the city's population has access to improved sanitation facilities. In contrast, 90.6% rely on substandard facilities such as unimproved latrines or cubluks, while 4.9% of residents practice open defecation. These practices directly introduce fecal waste into the urban environment, particularly into rivers. The high fecal coliform counts observed across all monitored rivers (especially in the Pekapuran and Pemurus Rivers) are a direct consequence of these conditions.

Land use is another major contributing factor. As a densely built-up city with minimal green cover, Banjarmasin lacks sufficient permeable surfaces for natural water infiltration and purification. The loss of vegetative areas due to construction, especially near waterways, has further reduced the ecological buffer zones that once helped filter pollutants before they reached rivers.

Population growth and increasing water demand exacerbate these issues. With limited space for expanding sanitation infrastructure and a growing urban footprint, waste output is surpassing the capacity of both natural and engineered systems. Compounding this is the limited coverage of centralized wastewater treatment systems. As of 2024, only 2.85% of residents are served by formal wastewater collection and treatment systems, leaving the majority of domestic effluent untreated.

Moreover, the city's hydrological reliance on external water sources conceals underlying vulnerabilities. While river inflows temporarily meet demand, they do not address the local capacity to manage and treat wastewater. Without sufficient intervention, river degradation will continue, further stressing public health, water security, and ecosystem resilience. The water pollution context in Banjarmasin reflects a critical intersection of infrastructural gaps, environmental neglect, and social behavior that must be urgently addressed through multi-dimensional strategies.

4. Water Availability, Ecosystem Services, and Dynamic Modeling in Banjarmasin

The analysis of water availability in Banjarmasin reveals a significant challenge in meeting the increasing demand for water from its growing population. The city's total water supply, derived primarily from rainfall and river sources such as Sungai Barito, Sungai Martapura, and Sungai Alalak, remains constant at approximately 3.47 billion cubic meters per year between 2023 and 2030. However, the demand for water is rising steadily, with estimates from the BPS (Central Statistics Agency) predicting a demand of 178.02 million cubic meters per year by 2030, and Disdukcapil's population estimates projecting a slightly higher demand of 178.5 million cubic meters per year. This shows a water deficit when the water availability is compared to the demand, especially under a closed system model where only local water sources are considered. However, in an open system model, additional water supply from surrounding rivers helps mitigate the issue. Table 4 summarizes the water availability and demand projections for Banjarmasin from 2023 to 2030.

Table 4. Water Availability and Water Needs of Banjarmasin City (m3/year)

Year	Water Availability			Water Requirements		Ratio				
	Minimum Rainfall + River	Maximum rainfall (2750)	Minimum rainfall (1750)	BPS population	Population of Civil Registration Office	+ River / BPS Pend	CH Max, P-BPS	CH Min, P-BPS	CH Max, P-Dinas dukcapil	CH Min, P-Dinas dukcapil
2023	3.470.840.000	96.185.000	61.208.600	174.525.000	174.748.000	198.874	0.551	0.351	0.550	0.350
2024	3.470.840.000	96.185.000	61.208.600	175.345.000	175.205.000	197.944	0.549	0.349	0.549	0.349
2025	3.470.840.000	96.185.000	61.208.600	176.175.000	175.665.000	197.011	0.546	0.347	0.548	0.348
2026	3.470.840.000	96.185.000	61.208.600	177.016.000	176.129.000	196.075	0.543	0.346	0.546	0.348
2027	3.470.840.000	96.185.000	61.208.600	177.868.000	176.595.000	195.136	0.541	0.344	0.545	0.347
2028	3.470.840.000	96.185.000	61.208.600	178.730.000	177.065.000	194.195	0.538	0.342	0.543	0.346
2029	3.470.840.000	96.185.000	61.208.600	179.603.000	177.539.000	193.250	0.536	0.341	0.542	0.345
2030	3.470.840.000	96.185.000	61.208.600	180.488.000	178.015.000	192.303	0.533	0.339	0.540	0.344

Table 4 presents the relationship between water availability and water demand in Banjarmasin during the period 2023–2030. The analysis shows that while total water availability remains constant at 3.47 billion m^3 per year, the growing population steadily increases the demand for water. In 2023, the water availability–demand ratio ranged between 0.35 under the minimum rainfall scenario and 0.55 under the maximum rainfall scenario, suggesting that the city's water resources are sufficient in aggregate but already vulnerable under dry conditions. Over the following years, the ratio demonstrates a declining trend, falling to 0.533 in 2030 under the maximum rainfall scenario and to 0.339 under the minimum rainfall scenario. Although the differences between BPS and Civil Registration data are relatively small, both datasets confirm this consistent downward trend. These findings imply that, despite current adequacy in total water availability, the city will face increasing pressure on its water resources, and the sustainability of water management will become more uncertain, particularly in years of low rainfall.

The ecosystem service approach for assessing water provision capacity shows that most of Banjarmasin's regions are categorized in the low (51.65%) and moderate (38.79%) classes, with only a small fraction in the high (9.45%) and very high (0.09%) categories. This classification reflects the city's limited natural capacity to supply water, largely due to urbanization, which reduces the area available for natural water retention and purification. These results indicate that most of the city's water supply comes from external sources such as rivers, rather than from local, natural sources. The low capacity of ecosystem services in terms of water provision is exacerbated by the presence of impervious surfaces like roads and buildings, which prevent water infiltration and storage. Additionally, water purification capacity in Banjarmasin is critically low, with 90.15% of the area falling into the very low category, showing the difficulty in filtering pollutants naturally, particularly in densely urbanized areas.

Using a dynamic system model to assess water quality and pollution levels provides deeper insights into Banjarmasin's ability to manage water resources. Parameters such as Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), fecal coliform, and suspended solids were assessed in various rivers. The model showed that the river systems such as the Sungai Barito, Sungai Martapura, and Sungai Alalak had higher water purification capacity due to their larger size and higher debit (flow), which helps dilute pollutants. On the other hand, smaller rivers like Sungai Pemurus and Sungai Pekapuran showed significant challenges in dealing with pollutants, as indicated by negative BOD values (indicating poor oxygen levels) and high levels of fecal coliform, a direct indicator of pollution from human waste. The ratio of water purification capacity is crucial in determining whether the river can handle pollutants effectively. For example, the BOD ratio for Sungai Barito is 0.66, which suggests that the river's ability to handle organic pollution is moderate, while Sungai Pemurus showed a lower BOD ratio of 0.32, indicating a much higher pollution load than it can manage. This further underscores the urgency for enhanced wastewater management and water purification technologies in the city to ensure sustainable water quality for both domestic and ecological needs. The results are shown in Figure 6.

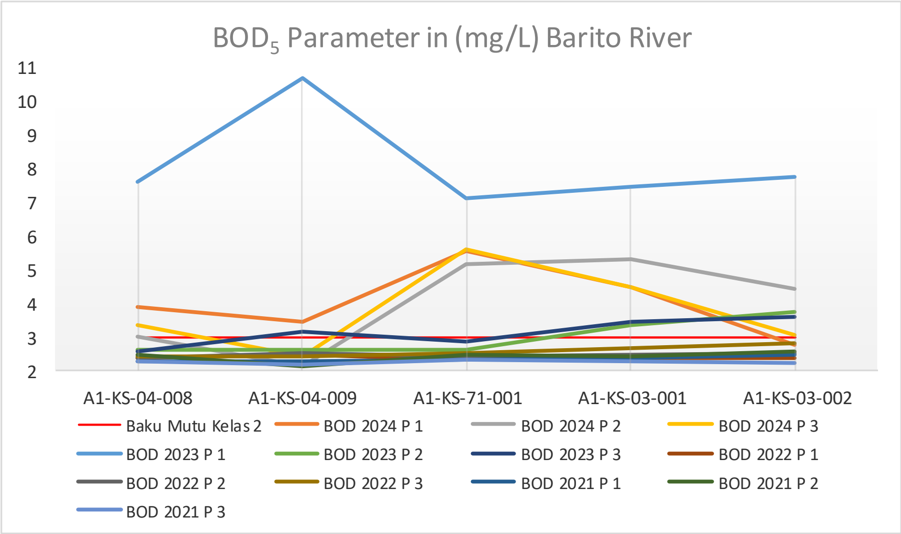

Figure 6. BOD Parameter Water in Banjarmasin

4. Conclusions

This study concludes that Banjarmasin demonstrates commendable achievements in clean water sustainability, with high service coverage, reliable supply, and compliance with quality standards; however, wastewater management remains critically underdeveloped, with extremely limited service coverage, underutilized infrastructure, and persistent open defecation practices contributing to severe river pollution. The city's strong reliance on external river sources for water availability underscores its vulnerability, particularly under conditions of rapid population growth and rainfall variability. These findings highlight the urgent need for integrated strategies that not only strengthen clean water systems but also prioritize wastewater management, river pollution control, and community behavioral change. For future work, research should focus on developing advanced wastewater treatment technologies suited to densely populated riverine cities, integrating climate change scenarios and land-use dynamics into water carrying capacity models, and designing participatory governance frameworks that enhance public willingness to adopt sustainable sanitation practices. Such approaches will provide a more resilient and holistic pathway toward achieving Sustainable Development Goal 6 and ensuring long-term water security for Banjarmasin.

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