RIPARIAN LANDSCAPE DESIGN CONCEPT FOR THE UPPER BRANTAS RIVER, BATU CITY, AS A WATER SENSITIVE URBAN DESIGN-BASED FLASH FLOOD MITIGATION STRATEGY

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Abstract
Flash floods are a hydrometeorological disaster whose frequency continues to increase in the upper watershed of the Brantas River, Batu City, driven by riparian vegetation degradation and extensive land-use conversion. This study aims to analyze the existing condition of the riparian landscape in the upper Brantas River, Bumiaji District, and to formulate a landscape design concept based on Water Sensitive Urban Design (WSUD) as a flash-flood mitigation strategy. A research-through-design method was applied, combined with a spatial approach using Geographic Information Systems (GIS) and purposive sampling of seven observation points across three zones: the Upper Area (A-1, A-2), the Middle Area (T-1, T-2), and the Lower Area (B-1, B-2, B-3). The results reveal a consistent degradation gradient from upstream to downstream, with riparian vegetation density decreasing from more than 80% in the Upper Area to less than 10% in the Lower Area, corresponding to increasing pressure from agricultural conversion and settlement encroachment on the river buffer zone. The resulting design concept integrates a three-layer vegetative buffer system, namely a Core Layer (0-10 m), a Filter Layer (10-20 m), and an Infiltration Layer (20-30 m from the riverbank), combined with green infrastructure elements such as retention ponds, biopores, and vegetative bank engineering using vetiver grass and bamboo. Intervention intensity is tailored to the degradation level of each point, ranging from minimal conservation in the Upper Area to intensive restoration in the Lower Area. The study confirms that the WSUD approach offers a relevant design framework for restoring the ecological function of riparian areas while sustainably reducing flash-flood risk in the upper Brantas watershed.

Keywords: riparian landscape; Water Sensitive Urban Design; flash flood mitigation; upper Brantas watershed

1. Introduction

Flash floods are among the hydrometeorological disasters whose frequency continues to rise across the globe as a result of climate change and the intensification of extreme rainfall (IPCC, 2021). In Indonesia, the National Disaster Management Authority (BNPB, 2025) recorded approximately 4,727 disaster events throughout 2025, with flooding as the most dominant category. Most of these events were triggered by a combination of high-intensity rainfall and reduced soil absorption capacity caused by deforestation, land-use change, and the loss of vegetation cover in water catchment areas.

This problem is also evident in the upper watershed of the Brantas River, Batu City, an area characterized by hilly topography, steep slopes, and annual rainfall of 2,000-2,500 mm, with approximately 85% concentrated during the rainy season (Pratama et al., 2023). Spanning approximately 320 km, the Brantas River plays a strategic role in the hydrological system of East Java, including downstream areas such as Malang Regency, Mojokerto, and Surabaya City (Kurniawan et al., 2018). The rapid growth of horticultural agriculture, tourism, and settlement in Batu City has pushed buildings and productive land into the river buffer zone that should function as an ecological buffer, reducing soil infiltration capacity and significantly increasing surface runoff.

Prior studies have examined flood-mitigation strategies through landscape and green-infrastructure approaches. Zevri and Asri (2019) demonstrated that retention ponds in watershed areas can reduce runoff while improving landscape quality. Egam (2018) emphasized the importance of Water Sensitive Urban Design (WSUD) elements such as bioswales, infiltration gardens, and riparian vegetation for increasing infiltration capacity in urban areas, while Rahmat and Djoeffan (2019) showed that integrated riparian management in the Cikapundung watershed reduced peak flood discharge and improved water quality. At the international scale, studies on the role of riparian vegetation in reducing flow velocity and sedimentation in mountainous watersheds (Journal of Hydrology, 2023), as well as the application of Nature-Based Solutions for urban flash-flood management in Southeast Asia (Water Resources Management, 2022), further reinforce the notion that vegetation-based green infrastructure is an effective and climate-adaptive mitigation strategy.

Nevertheless, most of these studies focus on lowland urban areas characterized by inundation-type flooding, or address technical, ecological, and managerial aspects separately. Research that integrates an analysis of existing riparian landscape conditions with the formulation of a site-specific design concept as a flash-flood mitigation strategy in steep-sloped upper watershed areas, particularly in the upper Brantas watershed of Batu City, remains relatively limited. The novelty of this study lies in formulating a three-layer, WSUD-based riparian landscape design concept developed on a site-specific basis for seven observation points with differing degradation levels, so that intervention intensity is tailored to actual field conditions rather than applied uniformly across the area.

Based on the foregoing, this study addresses two main questions: what is the existing condition of the riparian landscape in the upper Brantas watershed of Batu City, and how can a WSUD-based riparian landscape design concept be formulated as a flash-flood mitigation strategy. Accordingly, this study aims to analyze the existing riparian landscape condition of the upper Brantas River and to formulate a WSUD-based landscape design concept that can be replicated in other riparian areas with similar upper-watershed characteristics.

2. Research Method

This study was conducted in the riparian zone of the upper Brantas watershed, Bumiaji District, Batu City, East Java Province, which ecologically functions as the primary water-catchment area for the Brantas River hydrological system. A research-through-design approach was applied (Frayling, 1993), in which the design process itself serves as the method for generating knowledge and design solutions through systematic stages of analysis, synthesis, and evaluation.

Primary data were obtained through field observation, documentation of existing conditions, and identification of vegetation and water-flow conditions using the Avenza Maps application. Secondary data included the National Digital Elevation Model (DEMNAS), the Indonesian Topographic Map (RBI), land-use maps, and rainfall data. Field survey results were exported in Keyhole Markup Language (KML) format and converted into Shapefiles for integration into the ArcGIS 10.8 spatial database.

Observation points were determined using purposive sampling, considering the completeness of vegetation conditions, degradation level, zonal representativeness, and site accessibility and safety. A preliminary survey identified 14 candidate points across an elevation range of 964-1,351 m above sea level, which were subsequently screened into seven final observation points distributed across three zones-the Upper Area (A-1, A-2), the Middle Area (T-1, T-2), and the Lower Area (B-1, B-2, B-3)-extending from the Coban Talun area downstream.

Data analysis employed two complementary approaches. First, descriptive-qualitative analysis was used to identify field-level issues such as vegetation degradation, erosion potential, and river buffer conditions at each observation point. Second, GIS-based spatial analysis was carried out through map overlay of elevation, slope (referring to the classification of the Ministry of Agriculture Decree No. 837/Kpts/Um/11/1980), land use, rainfall, river networks, and river buffer zones to identify spatial vulnerability patterns related to flash flooding. The results of both analyses were verified through ground checks and then synthesized into zoning directives, which were translated into a WSUD-based landscape design concept, as illustrated in Figure 1.

Figure 1. Spatial Analysis Procedure in Formulating the Design Concept
Source: Author's analysis (2026)

The main instruments and materials used included spatial data-processing software (ArcGIS 10.8, Google Earth), a GPS-based field survey application (Avenza Maps), a digital camera for documentation, and supporting visualization software (AutoCAD and Canva) for developing site plans and design recommendations at each observation point.

3. Results and Discussion

3.1 General Condition and Spatial Characteristics of the Study Area

The study area is located around Coban Talun, Tulungrejo Village, Bumiaji District, at an elevation of 900-1,200 m above sea level, with topography dominated by hills and the slopes of Mount Arjuno and Mount Welirang. Bumiaji District covers a total area of 11,825.27 ha, with Tulungrejo Village as the largest village (51.90%) and the main location of the study. The land-cover pattern of the area (Figure 2) shows a dominance of non-agricultural forest in the northern part, which gradually shifts to open fields, mixed gardens, and settlements toward the south, in line with the elevation gradient and increasing land-use pressure downstream.

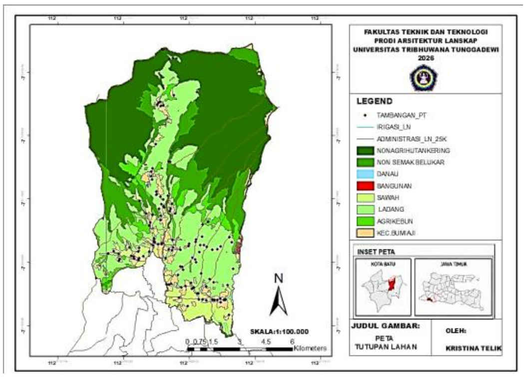

Figure 2. Land Cover Map of Bumiaji District, Batu City

Source: Author's analysis based on RBI Map and image interpretation (2026)

Rainfall and soil-type characteristics show an inverse pattern from upstream to downstream. The Upper Area receives the highest rainfall (3,250 mm/year) with Andosol soils that have high infiltration capacity as long as vegetation cover is maintained, yet become highly erosion-prone once vegetation is lost. The Middle Area receives 2,250-2,750 mm/year of rainfall with Latosol soils of moderate infiltration capacity, while the Lower Area receives the lowest rainfall (1,750 mm/year) but has young Regosol soils with low infiltration capacity, causing surface runoff to occur very rapidly (Table 1). This combination indicates that flash-flood risk is not determined solely by local rainfall volume, but by the accumulation of runoff from upstream areas concentrated toward the downstream area with the lowest infiltration capacity.

Table 1. Rainfall and Soil-Type Characteristics by Study-Area Zone

Zone	Rainfall (mm/year)	Soil Type	Infiltration Capacity	Flood Vulnerability
Upper (A-1, A-2)	3,250	Andosol	High (if vegetated)	High if vegetation lost
Middle (T-1, T-2)	2,250-2,750	Latosol	Moderate	Moderate-High
Lower (B-1, B-2, B-3)	1,750	Regosol	Low	Very High

Source: DEMNAS data analysis and field survey (2026)

3.2 Existing Condition of the Riparian Landscape at Seven Observation Points

Observations at the seven points reveal a consistent degradation gradient from the Upper Area toward the Lower Area. Point A-1, the most upstream point, shows the best condition, with vegetation density exceeding 80% and a relatively intact multi-strata structure, although small-scale bank erosion and surrounding agricultural pressure were beginning to be observed. Point A-2, located within the Coban Talun waterfall tourism area, reveals an ecological paradox: formally managed tourism activity is accompanied by active bank erosion and an exposed riverbank caused by vehicle-washing activities, indicating that tourism management has not yet been integrated with river buffer protection.

In the Middle Area, point T-1 shows dominance of invasive vegetation (Tithonia sp.) replacing native riparian vegetation, while point T-2 shows agricultural land encroaching directly to the riverbank without an adequate buffer zone. The turbid, brownish water quality at both points directly indicates a high sediment load from unfiltered agricultural runoff. The most critical conditions were found in the Lower Area: point B-2 experiences massive bank erosion with vertical cut faces, while point B-3 has lost its river buffer function entirely due to multi-story residential buildings standing directly on the riverbank and upper slope, accompanied by the worst water quality recorded across the entire study area (Table 2).

Table 2. Recapitulation of Degradation Level and Intervention Priority at the Seven Observation Points

Point	Location	Zone	Degradation Level	Intervention Priority
A-1	Above Coban Talun	Upper	Low-Moderate	Conservation
A-2	Around Coban Talun	Upper	Moderate-High	Rehabilitation
T-1	Riparian zone past Coban Talun	Middle	Moderate-High	Rehabilitation
T-2	Agricultural & settlement riparian	Middle	High	Restoration
B-1	Buffer near settlement	Lower	High	Intensive Restoration
B-2	Active eroding bank	Lower	Very High	Vegetative Bank Engineering
B-3	Near tributary confluence	Lower	Very High	Integrated Restoration & Enforcement

Source: Field observation and assessment (2026)

In terms of vegetation, riparian cover density declines sharply from more than 80% at point A-1 to less than 10% at points B-2 and B-3, with an intact multi-strata structure (tall trees, shrubs, and ground cover) found only in the Upper Area. In the Middle Area, the loss of the tall-tree stratum is replaced by low-canopy invasive vegetation, substantially reducing the ability to dissipate rainfall energy and stabilize the bank. Water quality follows a similar pattern: clear water at A-1 becomes turbid and brownish at T-1 and T-2, and severely turbid with indications of organic pollution at B-2 and B-3, corresponding to increasing sediment and domestic waste inputs that enter the river directly, unfiltered by buffer vegetation.

Anthropogenic pressure on the buffer zone also shows a consistent gradient. In the Upper Area, pressure mainly stems from tourism and agricultural activity, though the buffer boundary is generally still discernible. In the Middle Area, part of the buffer has been converted to horticultural land with no vegetative corridor. The most extreme condition is found in the Lower Area, particularly point B-3, where pressure now takes the form of permanent multi-story residential buildings, livestock pens, and piles of domestic waste standing directly within the zone that, under Government Regulation No. 38 of 2011, should be protected as a river buffer.

Overall, these findings are consistent with BNPB (2025) and Mongabay Indonesia (2021), which attribute the Batu City flash floods to the cumulative impact of ecosystem degradation in the upper Brantas watershed. The upstream-to-downstream degradation gradient observed in the field reinforces the urgency of a site-specific riparian landscape design, since the varying intensity of damage at each point requires correspondingly differentiated intervention strategies rather than a uniform approach across the entire area.

3.3 WSUD-Based Riparian Landscape Design Concept

The formulated design concept aims to restore the ecological function of the riparian area as a hydrological buffer, reduce flash-flood risk through green infrastructure, and create ecological and social sustainability by integrating conservation, ecotourism, and community empowerment functions. The design is grounded in four principles: ecological (prioritizing ecosystem recovery), contextual (tailored to local environmental and socio-cultural conditions), differentiated intervention (varying intensity per zone according to damage level), and participatory (involving the local community).

At the core of this concept is a three-layer vegetative buffer system applied consistently along the river buffer zone across a total width of 30 meters from the riverbank (Figures 3 and 4). The Core Layer (0-10 m) is planted with deep-rooted, massive vegetation such as vetiver grass (Chrysopogon zizanioides), green bamboo (Schizostachyum brachycladum), and banyan (Ficus benjamina) for bank stabilization and direct protection of the riverbank from flood flow. The Filter Layer (10-20 m) is planted with shrubs such as Calliandra calothyrsus, fragrant pandan, and ramie to filter sediment and pollutants from agricultural and settlement runoff before it reaches the river. The Infiltration Layer (20-30 m) integrates ground-cover plants and economically valuable agroforestry species such as jackfruit and breadfruit, which increase water infiltration while providing economic incentives for farmers to maintain the buffer zone.

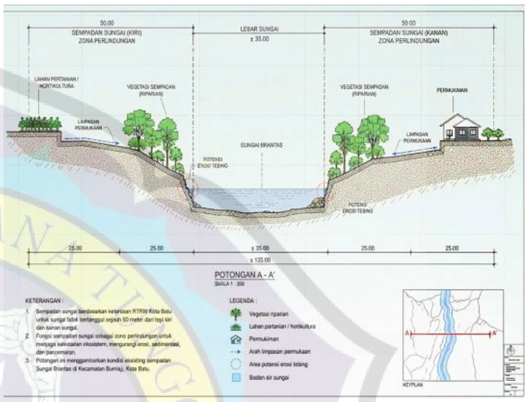

Figure 3. Cross-Section Concept of the Brantas River Buffer and Riparian Protection Zone
Source: Author's analysis (2026)

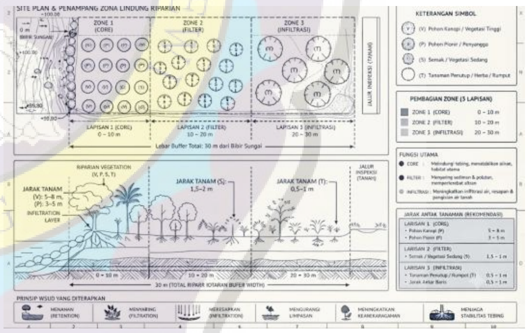

Figure 4. Three-Layer Zoning Concept (Core, Filter, Infiltration) of the Riparian Buffer
Source: Author's analysis (2026)

The intensity of applying this three-layer concept is tailored to the degradation level of each zone (Table 3). The Upper Zone applies minimal intervention in the form of conservation and periodic monitoring, integrated with a permeable boardwalk and an ecological interpretation shelter at point A-2 so that Coban Talun's ecotourism activities remain aligned with conservation functions. The Middle Zone applies selective rehabilitation through invasive-vegetation control and the addition of infiltration paths on terraced agricultural land. The Lower Zone, as the highest priority, applies intensive restoration and revegetation combined with vegetative bank engineering and, at points with active landslides such as B-2, a temporary retaining wall to provide protection before the vegetation root system is fully established.

Table 3. Riparian Zoning and WSUD-Based Intervention Strategy

Zone	Location	Main Strategy	Key Design Elements
Upper	A-1, A-2	Conservation & Limited Ecotourism	Periodic monitoring, permeable boardwalk, ecological interpretation shelter
Middle	T-1, T-2	Selective Rehabilitation	Invasive vegetation control, infiltration paths on terraced land
Lower	B-1, B-2, B-3	Intensive Restoration	Vegetative bank engineering (vetiver, bamboo), temporary retaining wall, buffer-zone enforcement

Source: Synthesis of the design concept (2026)

Beyond the three-layer system, the design concept also integrates additional green-infrastructure elements at points with high visitor pressure or surface runoff. At point A-2, for instance, a 4x5 m rain garden planted with fragrant pandan is proposed within the tourist parking area, connected to a 15 m vegetated channel that slowly conveys overflow into the Core Layer, along with 15-20 biopore points along the tourist path to restore infiltration in soil compacted by visitor traffic. Hard elements such as a wooden boardwalk are designed to be elevated and contour-following so as not to obstruct surface flow or the infiltration area beneath it, while also directing visitor movement away from ecologically sensitive zones.

At the most critical point, B-2, a retaining wall is considered as a complementary structural element based on three criteria: the criticality of erosion on an actively sliding bank, the presence of directly affected assets such as settlements or irrigation channels, and limited rooting space caused by an overly steep slope. This hard structure is positioned as temporary protection, while deep-rooted vegetation such as vetiver remains the long-term permanent solution, gradually assuming the structural function once its root system is fully established-consistent with the WSUD principle of minimizing hard infrastructure.

3.4 Linking the Findings to WSUD Theory

The WSUD approach applied in this study aligns with Wong's (2006) definition of a planning framework that integrates water-cycle management into the design of the built environment to minimize the impact of land development on aquatic ecosystems. The WSUD principles proposed by Fletcher et al. (2015)-protecting natural hydrological elements, protecting surface-water quality, integrating stormwater management into the landscape, minimizing hard infrastructure, and adding social-aesthetic value-served as a direct reference in determining the proportion of soft and hard elements at each design point.

The selection of vetiver grass as the vegetative bank-engineering element is supported by Hamidifar, Keshavarzi, and Truong (2018), who found that vetiver roots penetrating soil to a depth of 3-5 m provide more sustainable structural reinforcement than conventional civil structures. The multi-strata vegetation approach aligns with López-Barrera et al. (2022), who found that riparian vegetation diverse in both species and structure provides more comprehensive ecosystem services than monocultures. Meanwhile, the green-infrastructure connectivity principle proposed by Ahern (2007) reinforces the argument that a three-layer system applied consistently along the river corridor achieves far greater mitigation effectiveness than partial, unconnected interventions. These findings confirm that ecosystem-recovery-based mitigation strategies, as emphasized by UNDRR (2022) within the Eco-DRR framework, represent a cost-effective and sustainable approach for steep-sloped upper watershed riparian areas such as the upper Brantas River.

From a landscape-ecology perspective, the three-layer division applied in this study can also be understood through the patch-corridor-matrix framework proposed by Forman and Godron (1986), in which the riparian vegetation corridor connects the remaining ecosystem patches along the watershed, while the surrounding agricultural and settlement land functions as the matrix that determines the area's ecological connectivity. Strengthening the riparian corridor through the three-layer system is expected to enhance this connectivity while slowing the flow of water toward the main river channel. This is consistent with Naiman et al. (2005), who argue that riparian zones are among the most productive yet most vulnerable ecotones, making the restoration of their function through landscape design a key factor in the success of nature-based flash-flood mitigation strategies in upper watershed areas.

4. Conclusion

This study shows that the existing riparian landscape condition of the upper Brantas River in Bumiaji District exhibits a consistent degradation gradient from the Upper Area toward the Lower Area, corresponding to increasing pressure from agricultural conversion and settlement encroachment on the river buffer zone. This condition confirms that flash-flood risk in the upper Brantas watershed is not merely a function of rainfall volume, but the result of an interaction between the loss of buffer vegetation, declining soil infiltration capacity, and uncontrolled land conversion.

The Water Sensitive Urban Design-based riparian landscape design concept formulated in this study integrates a three-layer vegetative buffer system (Core, Filter, and Infiltration Layers), with intervention intensity tailored on a site-specific basis to the seven observation points, ranging from minimal conservation in the Upper Area to intensive restoration in the Lower Area. This approach proves capable of integrating ecosystem recovery, water-cycle management, and community socio-economic sustainability within a single coherent design framework, making it relevant for replication in other upper-watershed riparian areas with similar steep topography and land-conversion pressure.

Based on these findings, it is recommended that the Batu City Government and Perum Perhutani, as manager of the Coban Talun tourism area, firmly establish and enforce the river buffer boundary, particularly in the Lower Area, and integrate WSUD principles into the tourism area management plan. Buffer-zone revegetation should be carried out gradually and participatorily together with local farmers through an economically valuable agroforestry approach, so that long-term maintenance of the buffer vegetation can be sustained. For further research, it is recommended that these findings be complemented with quantitative measurement of soil infiltration capacity through field permeability testing, GIS-based hydrological modeling to calculate peak runoff volume before and after WSUD implementation, and periodic monitoring of vegetation establishment success to numerically validate the effectiveness of the proposed three-layer concept.

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