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RESEARCH ARTICLE

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Riparian Land-Use Change and Selected Water Quality Parameters in the Upper Brantas River: A 10-Year Buffer Zone Analysis

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ABSTRACT

Land-use changes and human activities continue to pressure the upper Brantas River. This study investigated land-use change within a 200 m river buffer from 2014 to 2024 and checked its patterns to water quality along the Upper Brantas River. Selected indicators for domestic wastewater, organic pollution, and nutrient input were chosen. Land use was mapped from satellite imagery using ArcGIS, while water quality was evaluated according to Government Regulation No. 22/2021. Paired t-test and Spearman's correlation were used to check the differences and relationships among land-use proportions, individual water quality parameters, and the Pollution Index (PI). Principal Component Analysis (PCA) was used to describe spatial patterns of pollution. Natural areas decreased significantly (p = 0.022), while urban areas increased significantly (p = 0.014). Agricultural land also increased, but not significantly (p = 0.152). Several parameters exceeded regulatory thresholds: NH_3, COD, BOD, TSS, and total coliform, especially in the upstream segments between SLK and BTU stations (PI = 4.42-4.68). Most Spearman correlations were not significant, except for a positive correlation between urban land and NO_3 (ρ = 0.683, p = 0.042). PI showed no significant correlation with land-use proportions. PCA indicated water quality varied by location and pollutant type. These findings suggest that river management should not rely only on PI or broad land-use proportions. It should also include parameter monitoring, runoff control, and local pollution-source management.

Introduction

The Brantas River is one of the most important river systems in East Java. It supports domestic water supply, irrigation, and electricity generation for nearly 15 million downstream population [1,2]. However, its water quality has continued to worsen under pressure from domestic water, agriculture, urban development, and industrial activities [3–5]. This problem is critical in the upper Brantas River, because land-use changes in the headwaters and upstream reaches can affect water quality before the river flows through more densely urbanized areas.

Previous studies have reported pollution in the upper Brantas River through water quality parameters such as Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), NH_3, and Pollution Index (PI) values [1,6–8]. Other studies have also examined the effect of land use on water quality in the Brantas basin [9,10]. Domestic wastewater carries organic matter, suspended solids, nitrogen compounds, and fecal microorganisms into rivers [11]. These inputs can alter BOD, COD, TSS, NH_3, NO_3, DO, pH, and total coliform. Strong correlations between coliform counts and organic pollution parameters have also been reported, suggesting that they may share the same anthropogenic sources [12]. However, most existing studies have focused on catchment-scale land use or aggregated pollution categorization. This approach is useful for

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general assessment, but can skip two important aspects, i.e., land use change inside the regulated riparian buffer zone and parameter-specific water quality responses.

The riparian buffer is the part of the catchment that is most directly connected to the river. This part is the direct interface between human activities and water quality. Changes from natural cover to agricultural or urban land within this zone can affect runoff, erosion, infiltration, and pollutant transport [13–17]. Yet, no study has specifically assessed how land use within the 200 m conserved river buffer changes over a 10-year period and how these changes align with individual water-quality parameters along the upstream-downstream gradient of the upper Brantas River. Land use within riparian zones has been widely associated with river water quality, particularly where agricultural and residential activities are located close to the river channel [18]. Following the minimum riparian setback specified by Regulation of the Minister of Public Works and Housing No. 28/2015 concerning the Determination of River Buffer Lines and Lake Buffer Lines, for large rivers land use was evaluated within 100 m of each riverbank along the Upper Brantas River, forming a 200 m-wide corridor. Without this information, the determination of land-use impact may rely too heavily on a broad area, which may not directly channel pollutants to the river. Also, the over-reliance on PI values may limit our understanding of detailed parameter-level relationships.

Therefore, this study aimed to: (1) quantify land-use changes within the 200 m river buffer zone over of the upper Brantas River between 2014 and 2024, (2) characterize water quality conditions using individual parameters, including BOD, COD, NH_3, total suspended solids (TSS), dissolved oxygen (DO), and NO_3, and (3) assess spatial patterns between land-use proportions and water quality parameters along the upstream-downstream gradient. We hypothesized that urban land would be associated mainly with organic and microbial pollution, whereas agricultural land would be associated with nutrient and suspended-solid concentrations. Both land-use types were expected to be negatively associated with DO. This study does not claim direct causal attribution but provides spatial evidence to support more segment-specific land-use and water quality management in the upper Brantas.

Materials and Methods

Sampling Location

This study covered approximately 51.5 km of the Upper Brantas River, from the headwaters to the city boundary, across Batu City, Malang Regency, and Malang City. Ten sampling stations were positioned along the river to capture changes in the surrounding land-use pattern, forming nine segments between consecutive stations. Land use within each segment was paired with water quality measured at its downstream station. The river buffer zone width was set at 200 m, in line with Regulation of the Minister of Public Works and Housing No. 28/2015. The total area of buffer zones is 941 ha. Table 1 shows the river segmentation and sampling stations, while Figure 1 shows the coordinates, elevations, and area sizes of each segment.

Table 1. Geographic location of the ten water-quality sampling points in the upper Brantas River, East Java, Indonesia. The sampling points cover Batu City, Malang Regency, and Malang City, and divide the river into nine segments for buffer-zone and land-use analysis. Spatial data were projected using UTM Zone 49S with the WGS 84 datum.

Segment	Upstream Sampling Point	Downstream Sampling Point	Length (km)	River Buffer Zone (ha)
Seg. 1	Sumber Brantas (SBR) *112°31'35.44"E-7°45'16.83"S*	Coban Talun (TLN) *112°30'57.02"E-7°47'58.79"S*	6.85	123.03
Seg. 2	Coban Talun (TLN) *112°30'57.02"E-7°47'58.79"S*	Taman Selecta (SLK) *112°31'21.34"E-7°49'33.19"S*	3.55	66.07
Seg. 3	Taman Selecta (SLK) *112°31'21.34"E-7°49'33.19"S*	Kota Batu (BTU) *112°31'36.49"E-7°51'50.61"S*	6.41	114.19
Seg. 4	Kota Batu (BTU) *112°31'36.49"E-7°51'50.61"S*	Jembatan Pendem (PDM) *112°34'31.30"E-7°54'10.20"S*	10.16	183.79
Seg. 5	Jembatan Pendem (PDM) *112°34'31.30"E-7°54'10.20"S*	UMM Dome (UMM) *112°35'43.89"E-7°55'13.17"S*	3.78	69.86
Seg. 6	UMM Dome (UMM) *112°35'43.89"E-7°55'13.17"S*	Dam Kadalpang (KDL) *112°37'28.25"E-7°57'27.57"S*	6.41	117.74

Segment	Upstream Sampling Point	Downstream Sampling Point	Length (km)	River Buffer Zone (ha)
Seg. 7	Dam Kadalpang (KDL) *112°37'28.25"E-7°57'27.57"S*	Jodipan (JDP) *112°38'14.12"E-7°58'57.05"S*	4.07	74.57
Seg. 8	Jodipan (JDP) *112°38'14.12"E-7°58'57.05"S*	Mergosono (MGS) *112°38'1.11"E-8° 0'14.82"S*	3.86	70.52
Seg. 9	Mergosono (MGS) *112°38'1.11"E-8° 0'14.82"S*	Kendalpayak (KND) *112°37'42.86"E-8° 3'19.39"S*	6.41	121.20

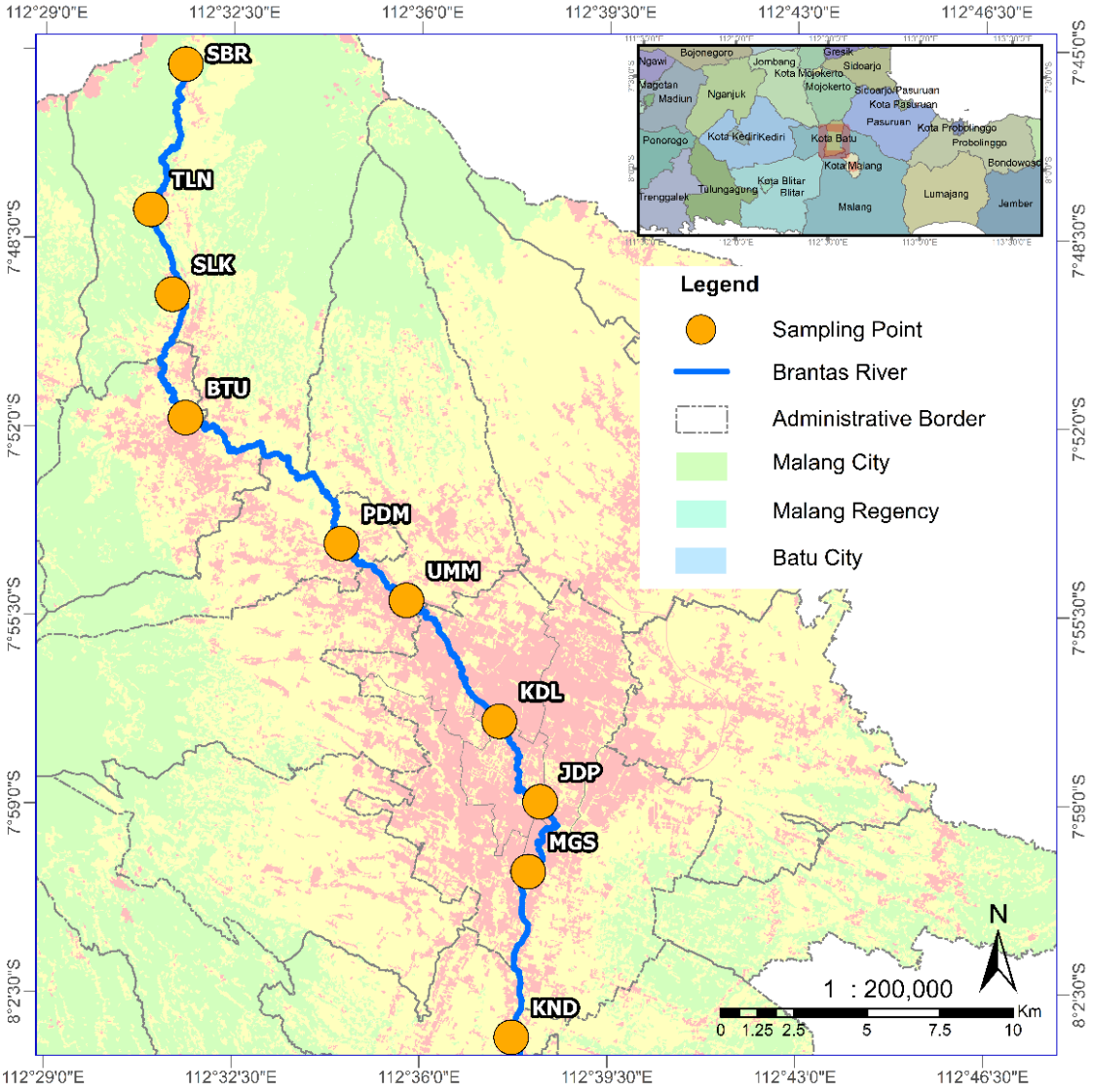


Figure 1. Spatial distribution of sampling points along the Upper Brantas River from the headwater (SBR) to the downstream boundary (KND), with land use classified as natural, agricultural, and urban. Each river segment is defined by two consecutive sampling points, and the corresponding segment areas are listed in Table 1.

Land Use Mapping

Landsat 8 imagery acquired on 24 October 2014 was obtained from USGS EarthExplorer (https://earthexplorer.usgs.gov/), while Sentinel-2A imagery acquired on 20 March 2024 was obtained from the Copernicus Open Access Hub (https://browser.dataspace.copernicus.eu/). Both images were processed in ArcGIS 10.8. Digital Numbers (DN) were converted to top-of-atmosphere (TOA) reflectance and corrected using Dark Object Subtraction (DOS1) [19,20]. The Landsat 8 image was resampled from 30 m to 10 m using

the nearest-neighbor method to match the Sentinel-2A pixel size, following the resampling approach of Skakun et al. [21]. Interactive Supervised Classification was then applied to both images. Land use was categorized into three primary land-cover types according to Indonesian standards (SNI 7645-1:2014): urban (e.g., residential, commercial, and industrial zones), agricultural (e.g., dryland farming, rice paddies, and plantations), and natural (e.g., forests and shrublands. To assess the influence of land use on river water quality, a 200-meter buffer zone was established along the river [22]. Classification accuracy was assessed using a confusion matrix based on 150 randomly selected validation points, with 50 points per land-use class, and verified with high-resolution imagery in Google Earth Pro. Overall accuracy and the Kappa coefficient (κ) were calculated, with 80% overall accuracy and $\kappa \geq 0.75$ used as acceptable thresholds for classification reliability.

Water Quality Assessment

Water samples were collected once from each station during March–April 2024, between 07:00 and 09:00, using a water sampler (WSH-Gopas 1.2 H) at a depth of approximately 20 cm depth in a sterile bottle. Water samples from each station were then brought to the laboratory on ice and analyzed for key parameters of domestic wastewater contamination in accordance with the Ministry of Environment Regulation No. P.68/2016, including pH, NH_3, BOD, COD, TSS, and total coliform. To assess self-purification mechanisms, DO was measured [23]. NO_3 was also measured to indicate the presence of agricultural runoff [8]. Water quality measurements followed APHA standards: 4500-NH3 A Nesslerization for NH_3, 4599-NO_3 B Ultraviolet Spectrophotometric Screening for NO_3, 5220 D Closed Reflux, Colorimetric Method for COD, 5210 D Respirometric Method for BOD, 2540 D Total Suspended Solids Dried at 103-105°C, and 9222 B Standard Total Coliform Membrane Filter Procedure for Total Coliform [24]. In contrast, pH and DO were measured using a direct-reading apparatus (Hach HQ4200). The pH and DO meter were calibrated before use following the manufacturer's instructions, and laboratory analyses were performed in duplicate.

Data Analysis

Changes in land use between 2014 and 2024 were calculated as the absolute area change, the relative change from the 2014 area, and the annual change over the ten-year period. Land-use areas and proportions in the two years were compared across the nine segments using a paired t-test. Measured water parameters were evaluated against the threshold values in the national water quality standards as stated in Government Regulation No. 22/2021, Appendix VI. The water parameters were then used to calculate the Pollution Index (PI) developed by Sumitomo and Nemerow [7,25]. The PI represents the extent of pollution relative to the applicable water-quality class limits and was calculated using Equation 1. Pollution levels were then interpreted following Ministry of Environment Decree No. 115/2003, with PI ≤ 1.0 classified as compliant, 1.0 < PI ≤ 5.0 as slightly polluted, 5.0 < PI ≤ 10.0 as moderately polluted, and PI > 10.0 as heavily polluted.

$$PI_j = \sqrt{\frac{\left(\frac{C_i}{L_{ij}}\right)_M^2 + \left(\frac{C_i}{L_{ij}}\right)_R^2}{2}} \quad (1)$$

Where:

PI_j = pollution index (PI) for class limit j

C_i = parameter concentration for i

L_{ij} = parameter i threshold value for class limit j

M = maximum value

R = average value

Class limits were derived from East Java Governor Regulation No. 61/2010, which classified the SBR-PEN segment as Class I water and the PEN-KND segment as Class II water. The PI values calculated for each segment were used to determine pollution level based on the categories in the Ministry of Environment Decree No. 115/2003, Appendix II. Each water quality parameter was also analyzed separately. Spearman's rank correlation was used to avoid problems related to unknown data distribution and possible non-linear relationships between variables [26]. Land-use proportions were correlated with NH_3, NO_3, BOD, COD, TSS, total coliform, DO, pH, and PI at the downstream point of each segment. Statistical significance was set at 0.05. Principal component analysis (PCA) was used to summarize water quality variation from the ten sampling points. The analysis was carried out in R version 4.5.1 [27].

Results and Discussion

Results

Land-use within the upper Brantas River buffer changed between 2014 and 2024. In 2014, agriculture was the dominant land use, covering 485.04 ha (51.55%), followed by natural areas at 265.52 ha (28.22%) and urban areas at 190.41 ha (20.24%). By 2024, natural areas had declined to 159.42 ha (16.94%), while agricultural and urban areas had increased to 544.48 ha (57.86%) and 237.06 ha (25.19%), respectively. Figures 2 and 3 show the spatial distribution of these land use classes across the nine river segments.

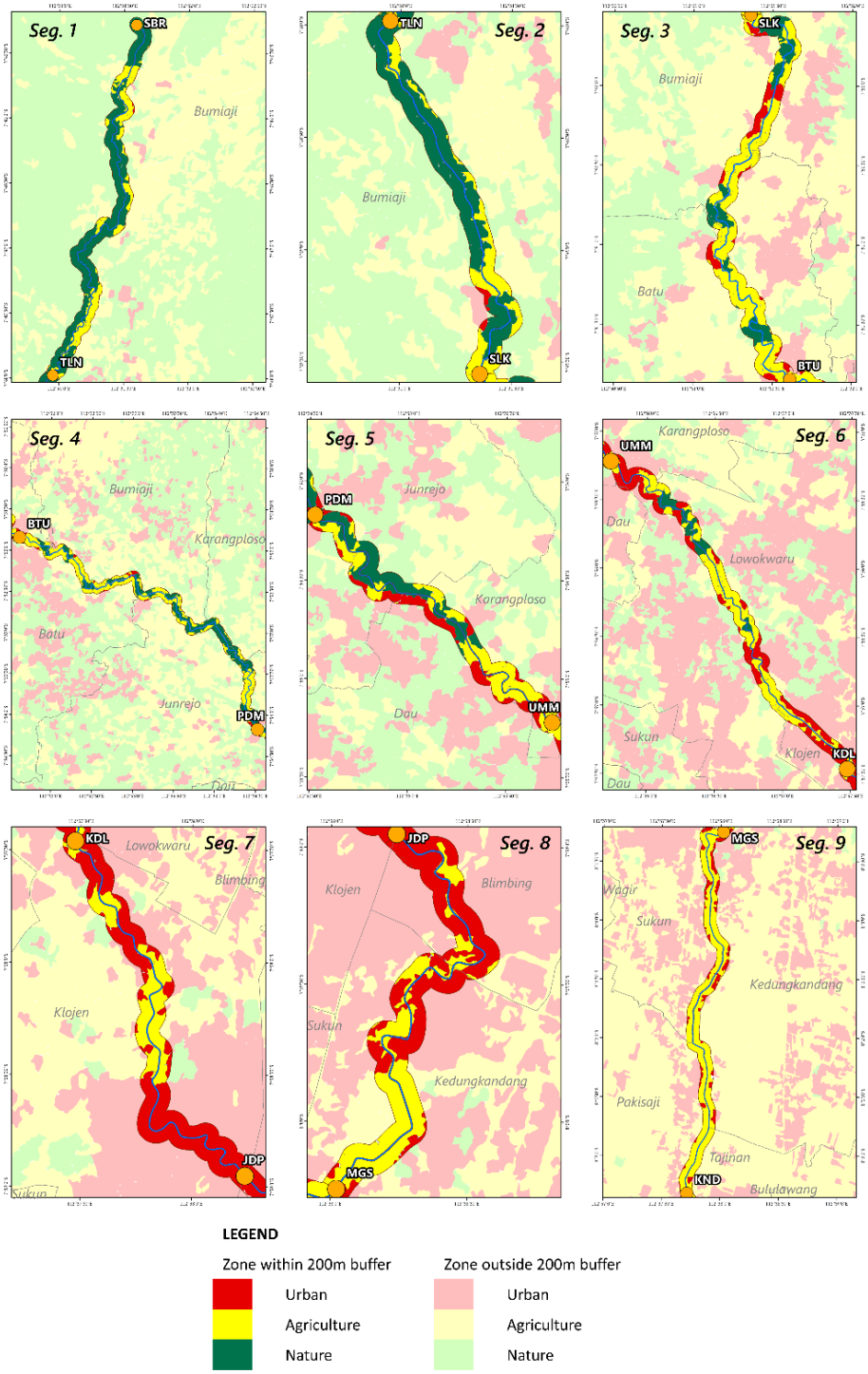


Figure 2. Land-use distribution along the upper Brantas River in 2014, shown by segment from upstream to downstream. For areas within the 200 m riparian buffer: Red indicates urban areas, yellow agricultural areas, and green natural areas. Segment maps are not shown at the same scale; segment lengths should not be compared.

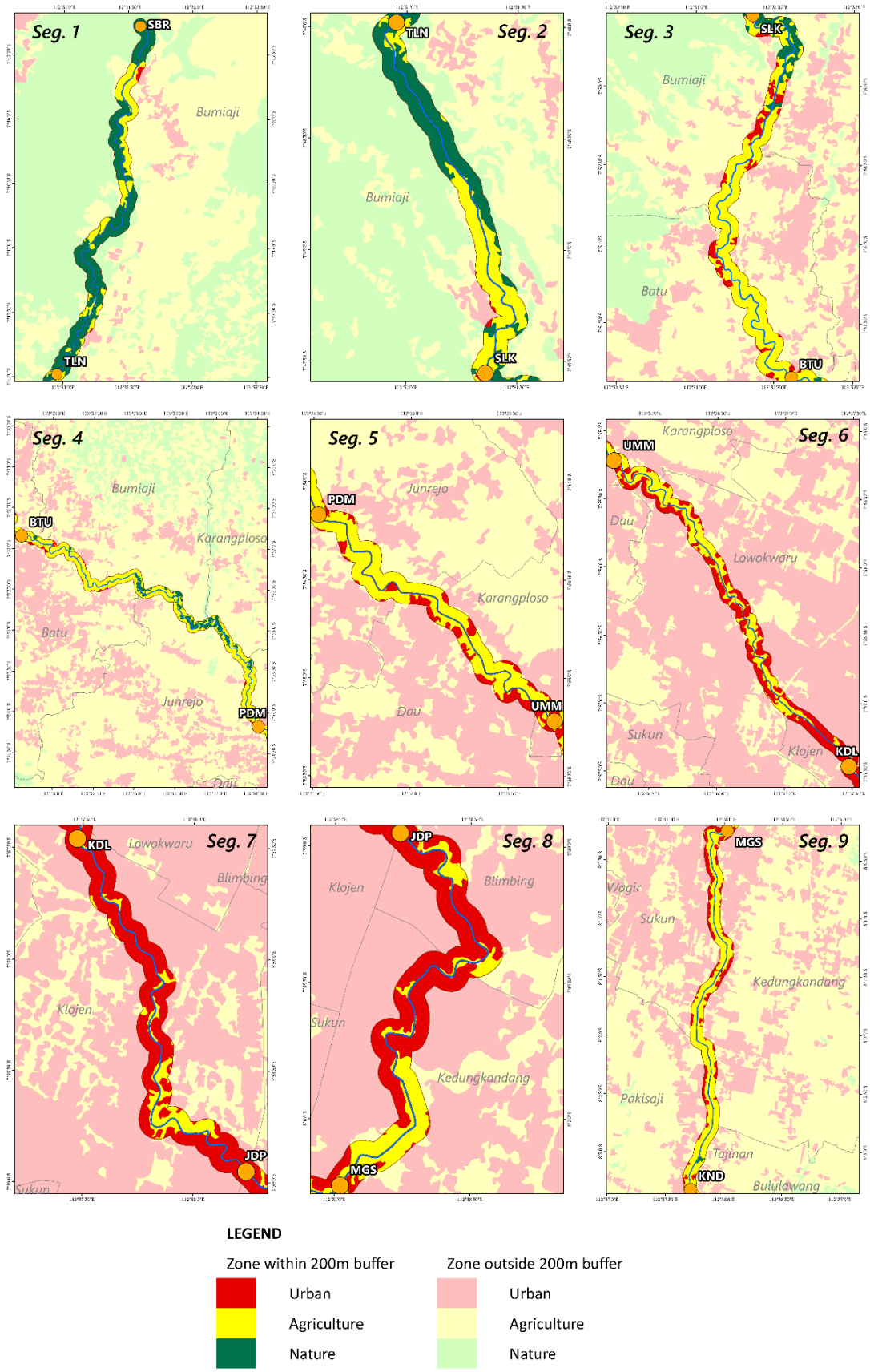


Figure 3. Land-use distribution along the upper Brantas River in 2024, shown by segment from upstream to downstream. For areas within the 200 m riparian buffer: Red indicates urban areas, yellow agricultural areas, and green natural areas. Segment maps are not shown at the same scale; segment lengths should not be compared.

Natural areas were concentrated in Segments 1 and 2, while Segments 7-9 had no natural area in either year. By 2024, natural areas had also disappeared from Segments 5 and 6. Agriculture dominated several middle and downstream segments in 2014, but urban land became dominant in Segment 6 by 2024. The highest urban proportions shifted from Segments 7 and 8 in 2014 to Segment 6 in 2024 (Figure 4). At the segment level, natural land remained dominant only in Segment 1, although its proportion slightly decreased from 72.20% in 2014 to 70.51%. Urban land remained highest in Segment 7 in both years, but the largest urban expansion occurred in Segment 6. Agricultural dominance also shifted, with the largest share of agriculture moving from Segment 9 in 2014 to Segment 4 in 2024.

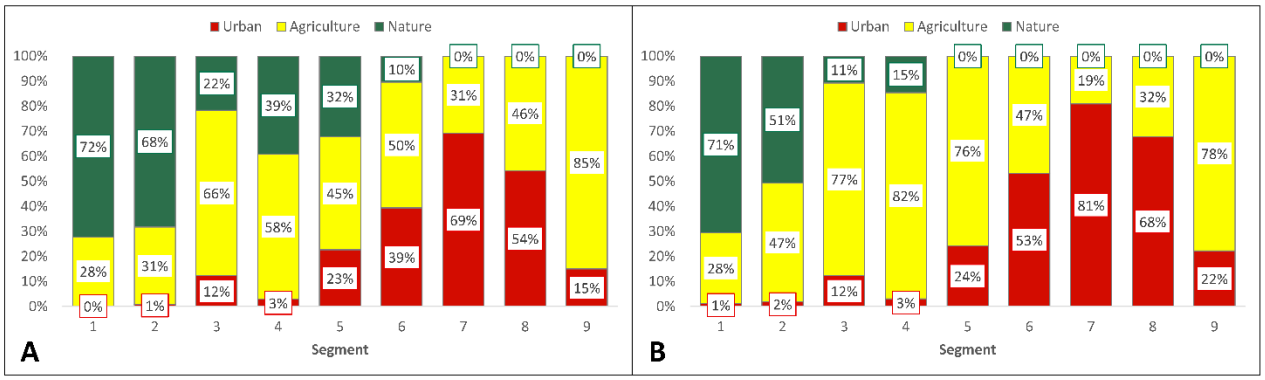


Figure 4. Proportion of land-use classes (urban, agricultural, and natural areas) across nine segments of the upper Brantas River in 2014 (A) and 2024 (B). Values represent the percentage composition within the defined river buffer zone for each segment.

Figures 5A-B show a clear difference between the upper and lower segments. Segments 1-5 (upper segments) generally gained agricultural land, while the natural area declined. Based on absolute land areas, Segment 4 showed the largest agricultural land gain (+448,905 m²) and the largest natural land decline (-452,975 m²). In the lower segments (Segments 6-9), urban land increased while agricultural land declined. The largest urban expansion was recorded in Segment 6 (+161,302 m²). Yet in relative land areas, urban land increased most sharply in Segment 1 (+307.8%) and Segment 2 (+117.4%), although their urban areas remained small compared with the lower segments. Natural land declined in all segments where it was present in 2014, including a complete loss in Segments 5 and 6. In Segments 6-9, urban expansion mainly occurred at the expense of agricultural land. Natural areas were already absent. These changes indicate that annual land-use change rates showed two different patterns along the river. Segments 2-5 were characterized by agricultural expansion at the expense of natural land. Segments 6-9 showed urban expansion, accompanied by a decline in agricultural land. The most extensive conversion happened in Segment 4. Here, agricultural land increased by 44,89 ha/year while natural land declined by 45,30 ha/year.

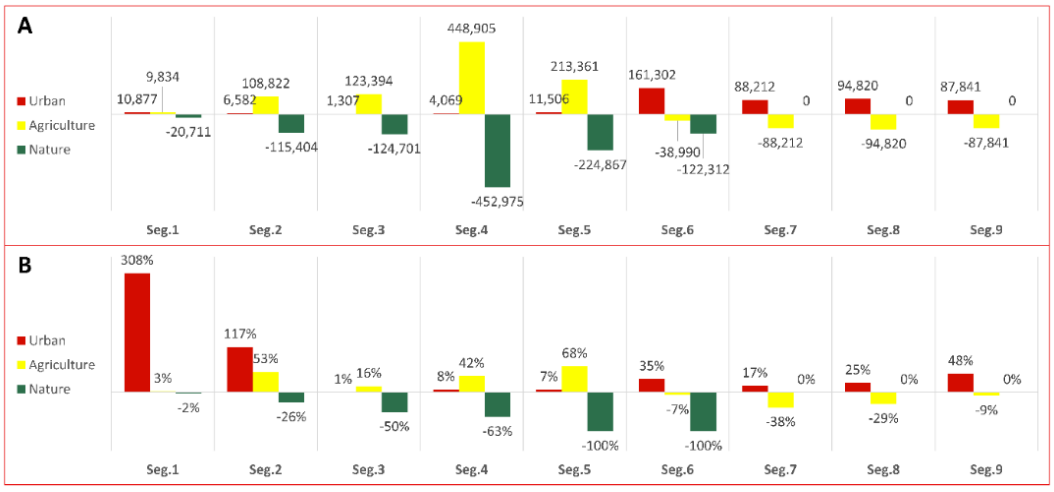


Figure 5. Changes in land-use classes (urban, agricultural, and natural areas) across nine segments (Seg. 1–Seg. 9) of the upper Brantas River between 2014 and 2024. Panel A shows absolute area change (m²), Panel B shows relative change (%). Positive values indicate land-use expansion, while negative values indicate land-use reduction.

A paired t-test was used to compare land-use areas between 2014 and 2024 across the nine segments. Natural areas decreased significantly from 29.50 ± 32.72 ha in 2014 to 17.71 ± 28.94 ha in 2024 ($t(8) = -2.391$, $p = 0.022$). Urban areas increased significantly from 21.16 ± 19.53 ha to 26.34 ± 24.60 ha ($t(8) = 2.695$; $p = 0.014$). Agricultural areas also increased, from 53.89 ± 33.73 ha to 60.50 ± 43.71 ha, but this change was not significant ($t(8) = 1.097$; $p = 0.152$). The same analysis was also conducted on land-use proportions. Natural land decreased from 27.1 ± 28.3% to 16.3 ± 26.2 %, while agricultural land and urban areas increased from 48.8 ± 18.7% to 54.1 ± 24.5 % and from 24.1 ± 24.9% to 29.6 ± 30.2%, respectively. However, these changes in relative proportions were not significant.

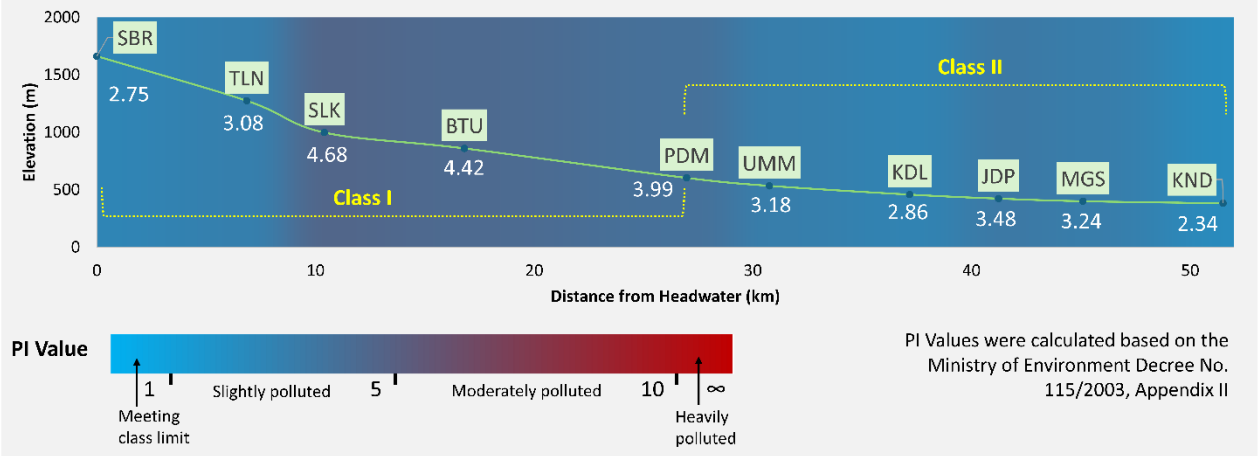


Figure 6. Longitudinal distribution of Pollution Index (PI) values along the upper Brantas River from headwater (SBR) to downstream boundary (KND). Segments SBR–PDM follow Class I water thresholds, while segments PDM–KND follow Class II thresholds. Color gradients indicate the pollution level.

Water quality varied along the upper Brantas River, with several parameters exceeding the relevant class thresholds (Figure 6). At the headwater (SBR), NH_3, COD, and BOD already exceeded Class I standards, resulting in a PI value of 2.75. This indicates that the headwater was slightly polluted. The highest PI was recorded at SLK (PI = 4.68), which is closest to the threshold for moderate pollution. At this point, NH_3, COD, BOD, TSS, and total coliform exceeded their Class I thresholds. In general, the segments of the upper Brantas River covered in this study are slightly polluted, with the highest pollution occurring between the SLK and BTU segments. Spearman's correlation indicated that most individual water quality parameters showed no significant correlations with land-use proportions (Figure 7). The only significant correlation was found between NO_3 concentration and the proportion of urban areas ($\rho = 0.683$, $p = 0.042$). No significant correlations were found between agricultural and natural areas and the measured water quality parameters. Analysis also found that PI values are moderately positively correlated with natural areas ($\rho = 0.456$), not correlated with agricultural areas ($\rho = 0.100$), and weakly negatively correlated with urban areas ($\rho = -0.233$). However, these correlations were not statistically significant.

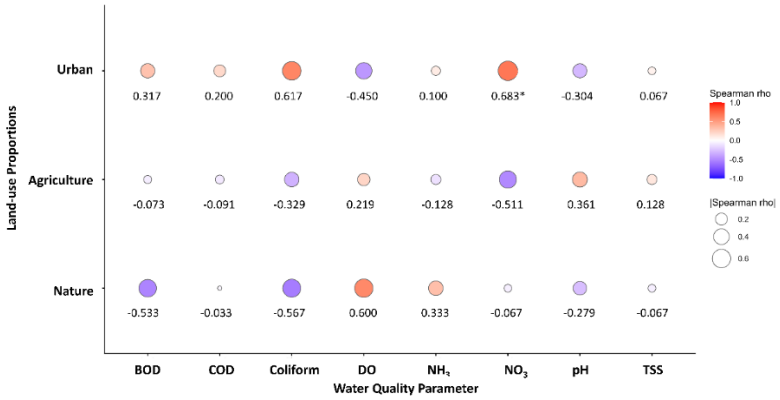


Figure 7. Spearman correlation (ρ) between land-use proportions and water quality parameters in the upper Brantas River in 2024. Circle size represents the strength of correlation, while color represents the direction (red = positive, blue = negative). Asterisks (*) show significance at 0.05.

PCA showed variation in water quality among sampling points (Figure 8). PC1 and PC2 explained 54.2% and 21.3% of the total variation, respectively. The pollutants, including coliform, TSS, BOD, and COD, were aligned with the positive side of PC1, whereas the parameter DO was on the opposite side. The sampling point SLK was clearly separated and positioned closer to TSS, BOD, and COD. Sampling point JDP was more associated with total coliform. Sampling points PDM and KDL were more related to NH_3 and NO_3. In contrast, DO, which generally shows better oxygen levels, was positioned closer to the sampling sites KND and TLN.

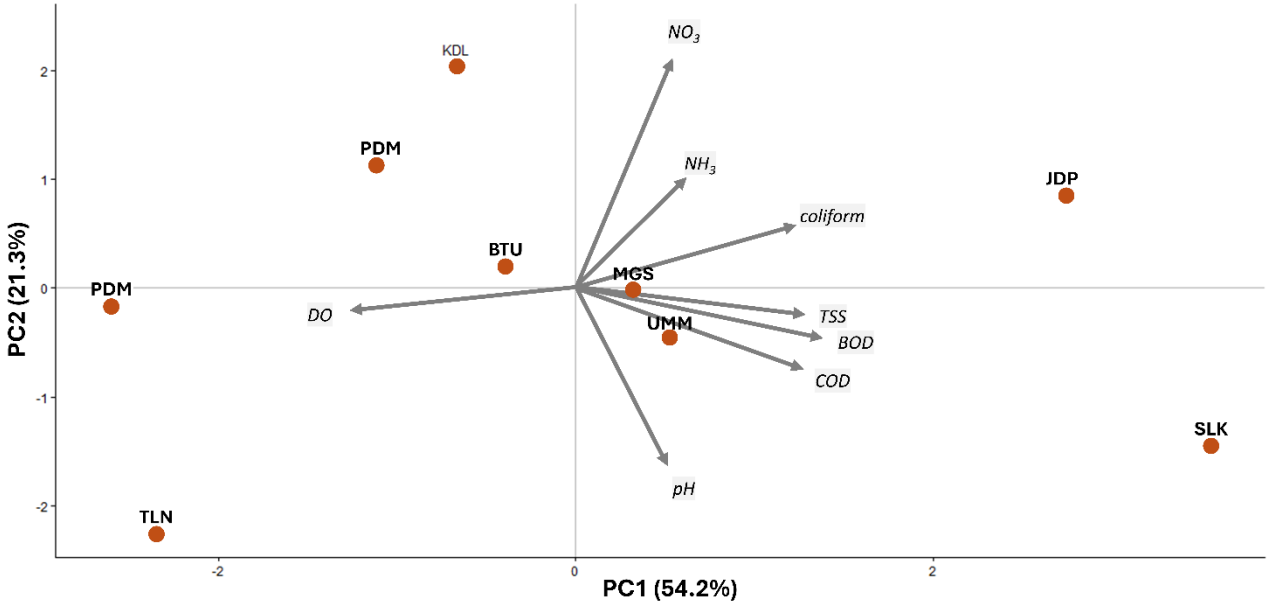


Figure 8. PCA biplot of water quality parameters among sampling sites at the upper Brantas River. The dots represent the sampling points, whereas the arrows show the contribution and direction of water quality parameters.

Discussion

Land-use changes along the Brantas River between 2014 and 2024 showed a clear pattern: natural areas declined, while agricultural and urban areas expanded. Urbanization in lower segments had already been observed for several years due to the expansion of infrastructure supporting human activities [1,8]. This shift is key to river water quality because natural, agricultural, and urban land differ in their effects on runoff, erosion, infiltration, and pollutant transport [28,29]. Segment 1 showed only a small decline, in line with the protected status of the Sumber Brantas headwater area [30]. The shift was more observed downstream from this segment. In 2014, the MGS–KND segment had the largest agricultural area. Kedungkandang was indeed the sub-district with the largest agricultural land area in Malang City at that time [31]. By 2024, the largest agricultural area had shifted to Segment 4, between BAT and PDM. This segment is located in Junrejo, where seasonal agriculture, for example, citrus cultivation, has been reported [32]. Natural areas also declined mainly in Segments 2–5. This pattern suggests that agricultural expansion in the middle segments occurred alongside the loss of natural cover.

The transition from agricultural to more urban land began at Segment 5. Segment 6 itself showed the largest urban expansion. Segment 7 also remained highly urbanized, with dense commercial and administrative activities [33]. Although urban land in Segments 1 and 2 also increased between 2014 and 2024, their urban areas remained smaller than those in the lower segments. This pattern indicates a stronger urban impact in the downstream part of the study reach. Urban expansion is important for river water quality because impermeable surfaces of urban infrastructure can reduce infiltration and increase direct runoff into rivers [34]. Runoff from roads, settlements, and drainage channels can transport nutrients, organic matter, suspended solids, and microbial contaminants into the water body [35,36]. Interestingly, the PI showed a comparable pattern where pollution between segments SLK-PDM aligns with agricultural land dominance, whereas segments JDP-MGS showed more resemblance to urban area dominance.

PI increased from SBR to SLK, then generally declined downstream. Part of this pattern may be related to the change in water-quality class, as SBR–PEN was assessed against the stricter Class I limits, whereas PEN–KND was assessed against the Class II limits. Land use may also contribute to the variation, since SLK, BTU, and PDM had less natural cover and more agricultural or urban land. The higher PI at JDP and MGS is consistent

with their large urban proportions. Thus, the lower PI in the Class II section does not necessarily indicate lower pollution. The over-threshold measured concentrations of NH_3, COD, BOD, TSS, and total coliform at SLK suggest more than one pollutant source. These parameters are commonly associated with organic inputs, suspended solids, nutrient enrichment, and fecal contamination from domestic activities, agriculture, settled areas, or local drainage [23,37,38]. Previous studies in the upper Brantas area have also linked agricultural activity with changes in nitrogen compounds, including NO_3, NO_2, and NH_3, as well as PO_4 [5,39]. However, most parameter-level Spearman correlations in this study were not significant, except for the positive correlation between NO_3 and urban land proportion. This is possible because water quality at each station may integrate upstream inputs, not only adjacent buffer land use [40]. Despite the land-use composition at the respective sampling point, point-source inputs, including domestic and industrial drainage, can override parameter concentrations [41]. This explains why simple buffer-based correlations can be weak,

PI values also showed no significant correlation with land-use proportions. These results do not mean that land use has no influence on water quality. They indicate that a simple one-to-one relationship was not detected in this dataset. This may be because land-use proportions alone do not capture recent rainfall, flow conditions, drainage pathways, or point sources [42]. However, PCA showed that water-quality variation was parameter-specific, with SLK associated with TSS, BOD, and COD, JDP with total coliform, and PDM/KDL with NH_3 and NO_3. This pattern may suggest spatial heterogeneity among river segments, as observed in several studies in Indonesia. SLK may reflect local input in an upstream agricultural and tourism area [43]. Coliform at JDP may be more relevant to dense settlement [44]. PDM and KDL nitrogen patterns may reflect mixing or self-purification from previous segments [45].

Runoff paths may differ among segments because natural, agricultural, and urban areas were unevenly distributed. In areas with low riparian vegetation, nutrient and sediment retention can be weakened because less vegetation is available for filtration, plant uptake, and other biogeochemical processes [46]. As a result, runoff may transport more nutrients, organic matter, and suspended sediment from cultivated land into the river when rain comes. This mechanism is relevant to the Brantas basin, where agricultural runoff has been linked to nutrient inputs and water-quality degradation [47]. Fertilizer applications can increase nitrogen and phosphorus in the agricultural runoff, but this depends on time, rainfall, slope, and riparian buffers [48–50]. Urban runoff may also transport suspended solids and microbial contamination from roads, settlements, and drainage channels [6,51]. However, because NO_3 was significantly correlated with urban instead of agricultural land, agricultural runoff should be treated as no more than a possible contributor.

Seasonal variability is also important when interpreting the water-quality results. In this study, sampling was conducted in March–April, near the end of the rainy season in East Java. During rainy periods, runoff can transport more pollutants from agricultural areas and urban surfaces into rivers [52]. At the same time, higher river flow may dilute some pollutant concentrations [53]. On the other hand, during drier periods, lower discharge may concentrate some dissolved pollutants, while reduced runoff may limit sediment transport [54]. The same land-use proportion may produce different concentrations under different rainfall and river flow conditions [55]. Because sampling was conducted only during this narrow period, the results represent a temporal snapshot when runoff was still high, and the concentration of pollution may not have shown robust estimates of the actual condition [56]. For this reason, a single sampling period cannot separate pollutant loading from dilution, so the water quality should be interpreted with caution.

We acknowledge some limitations in this study. The fixed 200 m buffer did not fully capture broader catchment, drainage pathways, or point-source discharges. Downstream water quality may integrate cumulative upstream inputs. The absence of rainfall, discharge, and flow data also limited our ability to separate runoff-driven loading from dilution effects. In addition, PI may hide parameter-specific responses because different pollutants respond differently to land-use and hydrological conditions. Non-significant correlations should therefore be interpreted as the absence of a one-to-one relationship in this dataset, not as evidence that land use has no effect. Future studies should combine parameter-level analysis with rainfall and discharge data, broader catchment information, point-source mapping, and seasonal sampling. Nevertheless, this study shows that land-use change and water-quality variation occur unevenly along the upper Brantas River. The elevated levels of NH_3, BOD, COD, TSS, and coliforms indicate local water-quality pressure. These findings support the need to consider riparian vegetation protection, runoff control, and local pollution-source management. By linking land use within consecutive river segments to water quality at their downstream points, the analysis identified spatial differences that would be obscured by a single catchment-wide land-use estimate.

Conclusions

Land-use change along the Upper Brantas River followed different spatial patterns between 2014 and 2024, with agricultural expansion in the middle segments and stronger urban expansion downstream. Water-quality variation did not follow these land-use proportions consistently, and most correlations were not significant. This indicates that segment-level land-use proportion within a fixed riparian corridor is insufficient to explain water quality where upstream inputs, point-source discharges, rainfall, and river flow also influence measured concentrations. The segment-based analysis nevertheless identified where land-use pressure and water-quality responses differed along the river. Management should therefore combine riparian protection in areas losing natural cover with control of agricultural runoff, urban drainage, and wastewater inputs. Future monitoring should include seasonal sampling, river discharge, rainfall, and individual water-quality parameters in addition to the Pollution Index.

Author Contributions

BMFR: Investigation, Software, Visualization, Writing – Original, Writing – Review & Editing; **RMR**: Conceptualization, Investigation, Formal Analysis, Supervision, Writing – Original, Writing – Review & Editing; **VAKD**: Methodology, Supervision

AI Writing Statement

During the preparation of this work, the authors used ChatGPT and Grammarly as language support tools to improve sentence structure, clarity, and the manuscript's overall readability. After using this tool, the authors reviewed and edited the content as needed and took full responsibility for the publication.

Conflicts of Interest

There are no conflicts to declare.

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