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Hydrological Monitoring and Urban Resilience: Assessment of the Flow of Ribeirão Morangueiro in Maringá, Brazil

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ABSTRACT: This study compares flow discharge measurement methods in the Ribeirão Morangueiro watershed, Maringá-PR, Brazil, evaluating the Float technique against the FlowTracker acoustic velocimeter to support Nature-based Solutions (NbS) for urban resilience. Thirteen months of monitoring at five points revealed hydrological instability characteristic of urbanized watersheds, with 15.47% flow variation and environmental degradation including riparian vegetation loss and siltation from gray infrastructure. Wilcoxon Signed-Rank Test and Bland-Altman analysis showed that the Float method systematically overestimates velocity (bias = 0.0968 m^3/s, $p = 0.0088$), requiring correction factors. The absence of statistically significant seasonal differences in discharge values at the watershed outlet ($p > 0.05$) suggests partial artificial stabilization of baseflow associated with urban water inputs. Results provide technical support for implementing NbS, such as rain gardens, permeable pavements, and restored riparian vegetation, as alternatives to conventional drainage, following successful Brazilian programs like Porto Alegre's Viva a Natureza (15 –20% flooding reduction). The research contributes to SDGs 6, 9, 11, 13, and 15, providing technical evidence to guide the transition from gray to green infrastructure in medium-sized cities.

KEYWORDS: Urban resilience; Hydrological monitoring; Green infrastructure; Urbanization impacts.

I. INTRODUCTION

Since the mid-20th century, urban population growth has intensified at an accelerated pace. According to estimates from the United Nations (UN), approximately 55.3% of the world's population resided in urban areas in 2018. Projections indicate that by 2050, this percentage is expected to reach 68.4% of the global population, corresponding to approximately 6.68 billion people living in urban centers (ONU, 2019).

In Brazil, according to Santos (2020), the urbanization process occurred rapidly and was marked by the absence of structured public urban policies, which hindered low-income populations' access to formal housing. Consequently, informal urban growth became consolidated, with the emergence of irregular settlements, frequently located in peripheral and environmentally fragile areas, characterized by deficiencies in urban infrastructure and basic sanitation (Tucci, 2008). From the technical standpoint of Urban Engineering, this pattern of occupation results in increased soil imperviousness and suppression of vegetation cover (Santos; Rufino; Filho, 2017). As explained by Oswald et al. (2023), these changes increase surface runoff and overload conventional drainage systems, which are often insufficient to prevent flooding and water quality degradation.

To mitigate these hydrological impacts, the concept of urban resilience has gained prominence. According to Chiroli et al. (2023), resilience in the urban context refers to the ability of a system to absorb disturbances while maintaining its basic functions, promoting population well-being and advancing toward sustainability. One of the primary ways to achieve such resilience is through the implementation of Nature-based Solutions (NbS).

The traditional approach to urban stormwater management relies on gray infrastructure, composed predominantly of concrete and steel structures such as stormwater pipe networks, pumping stations, and storage tanks, designed with the single objective of rapidly conveying rainwater out of the urban environment (Wang *et al.*, 2022; Yang; Zhang, 2021). Although effective in terms of drainage capacity, gray infrastructure lacks resilience and sustainability, as it transfers runoff loads downstream and fails to restore the natural hydrological cycle (Wang *et al.*, 2022). As alternative, compensatory techniques, broadly known as Sustainable Urban Drainage Systems (SUDS), Low Impact Development (LID), or Water Sensitive Urban Design (WSUD), have emerged to supplement and gradually replace purely conventional approaches. These systems employ decentralized practices designed to attenuate stormwater at the source through infiltration, detention, and evapotranspiration, thereby restoring pre-urbanization hydrological conditions (Yang; Zhang, 2021). Within this framework, Nature-based Solutions (NbS), including green infrastructure such as green roofs, permeable pavements, and bioretention cells, and blue infrastructure such as constructed wetlands and stormwater ponds, simulate natural hydrological processes while simultaneously delivering environmental, ecological, and social co-benefits, such as biodiversity enhancement, microclimate regulation, non-point source pollution control, and recreational function improvement (Esraz-Ul-Zannat; Dedekorkut-Howes; Morgan, 2024; Przestrzelska *et al.*, 2024; Zhou *et al.*, 2024). The integration of gray, green, and blue systems into a combined approach has proven to be the most effective strategy for urban flood risk reduction, offering synergistic benefits that exceed the performance of any single infrastructure type applied in isolation (Chen; Wang; Wu, 2024; Zhang *et al.*, 2023).

These strategies emerge as alternatives capable of reducing peak flow in the watershed through infiltration, stormwater retention, and restoration of urban ecosystems, offering environmental, social, and economic benefits that strengthen urban resilience (Silveira; Rodrigues; Dornelles, 2025).

Therefore, urban resilience depends not only on physical infrastructure but also on strategic planning, social participation, and efficient governance, ensuring that technical and environmental solutions are integrated with population needs and long-term public policies (Franz; Andreoli; Da Silva, 2021). To ensure effective solutions, continuous monitoring of water flow plays a fundamental role in this process by providing data for predictive models, sustainable management practices, and implementation of green and low-impact infrastructure, thereby strengthening urban resilience and supporting adaptation to climate change (Mattos *et al.*, 2021; Silva *et al.*, 2024). By understanding hydrological alterations and the impacts of urbanization on water bodies, managers and planners can adopt preventive measures, reduce flood risks, protect the population, and conserve aquatic ecosystems, promoting more sustainable, safe, and inclusive cities (Fletcher; Andrieu; Hamel, 2013).

This challenge of reconciling urbanization and sustainability is emblematic in the municipality of Maringá, Paraná State, southern Brazil. Founded in 1947, the city originated from an urban project developed by Jorge de Macedo Vieira, which incorporated references from European planning and influences from the "garden city" concept proposed by Ebenezer Howard. These influences are evident in the first Master Plan, which defined Maringá as an "exponent and national example of a standard conventionally referred to as a 'garden city'" (Brito; Alves, 2016). However, despite this urban planning legacy, the city's expansion dynamics have imposed severe pressures on its water bodies.

In the context of Maringá, Ribeirão Morangueiro stands out for crossing areas of high urban density and playing a fundamental role in the municipality's stormwater drainage system. Urban expansion and consequent increase in imperviousness of its banks have significantly altered the local hydrological regime, resulting in increased surface runoff and greater frequency of flooding in urban stretches. According to Fiorelli et al. (2015), the valley floor of Ribeirão Morangueiro shows signs of environmental degradation associated with irregular occupation, suppression of riparian vegetation, and discharge of urban effluents.

Despite the relevance of this topic, to the best of the authors' knowledge, no published studies were identified that systematically quantified the hydrological regime of Ribeirão Morangueiro or evaluated the applicability of NbS as an alternative to conventional infrastructure in Maringá, constituting a knowledge gap that this study seeks to fill. These effects are consistent with the processes described by Tucci (2002), who relates disorderly urban growth to intensified runoff and overload of drainage systems, and by Fletcher, Andrieu and Hamel (2013), who highlight the importance of sustainable stormwater management strategies to mitigate such impacts. Thus, understanding the hydrological behavior of this watershed is essential to support public policies aimed at integrated water resources management and strengthening Maringá's urban resilience.

Despite the importance of monitoring, the scarcity of river gauging stations and reliable data still limits response capacity and urban planning (Tucci, 2002). Various methods can be used to measure flow, ranging from simple techniques such as the float method (Santos and Ferreira, 2019) to advanced acoustic methods using FlowTracker, capable of measuring velocities and performing automatic calculations in accordance with international standards (Coelho; Silva; Farias, 2013). The adoption of these technologies represents an important investment in resilient infrastructure and urban innovation, strengthening cities' capacity to adapt to environmental and climatic challenges, in alignment with SDG 6 (Clean Water and Sanitation), SDG 9 (Industry, Innovation and Infrastructure), SDG 11 (Sustainable Cities and Communities), SDG 13 (Climate Action), and SDG 15 (Life on Land) (Sezini; Dias, 2025). Moreover, in medium-sized cities with budget constraints, validating simplified measurement techniques becomes strategically relevant for expanding monitoring coverage.

Given this scenario, the present study aims to evaluate the impacts of urbanization on the hydrological regime of Ribeirão Morangueiro and provide a technical basis for the potential integration of NbS into municipal water management. Specifically: i) quantify seasonal and spatial variations in flow; ii) identify and characterize sources of degradation; iii) compare measurement methods applicable in resource-limited contexts; iv) provide technical evidence to inform urban resilience strategies. The results aim to provide technical support for resilient urban management strategies, contributing to the development of cities capable of effectively addressing disasters, preserving water resources, and promoting population quality of life.

II. METHODOLOGY

The research presents a quantitative-qualitative approach, with a predominance of quantitative methods in the collection and analysis of hydrological data, based on direct flow measurements and statistical treatment of results. Additionally, a qualitative interpretation of findings is adopted, relating them to aspects of urban planning, water resilience, and application of NbS.

To ensure clarity and reproducibility of the research stages, the methodology was organized into four integrated phases: (i) collection of climatic and hydrological data from the INMET station in Maringá; (ii) field campaigns and monthly flow measurements at five points along Ribeirão Morangueiro, employing weir, float, and acoustic (FlowTracker) methods; (iii) statistical treatment and comparison of the measurement methods; and (iv) interpretation of results and their integration with urban resilience strategies and NbS.

The flowchart presented in Figure 1 illustrates, in a concise manner, the methodological sequence adopted in this study.

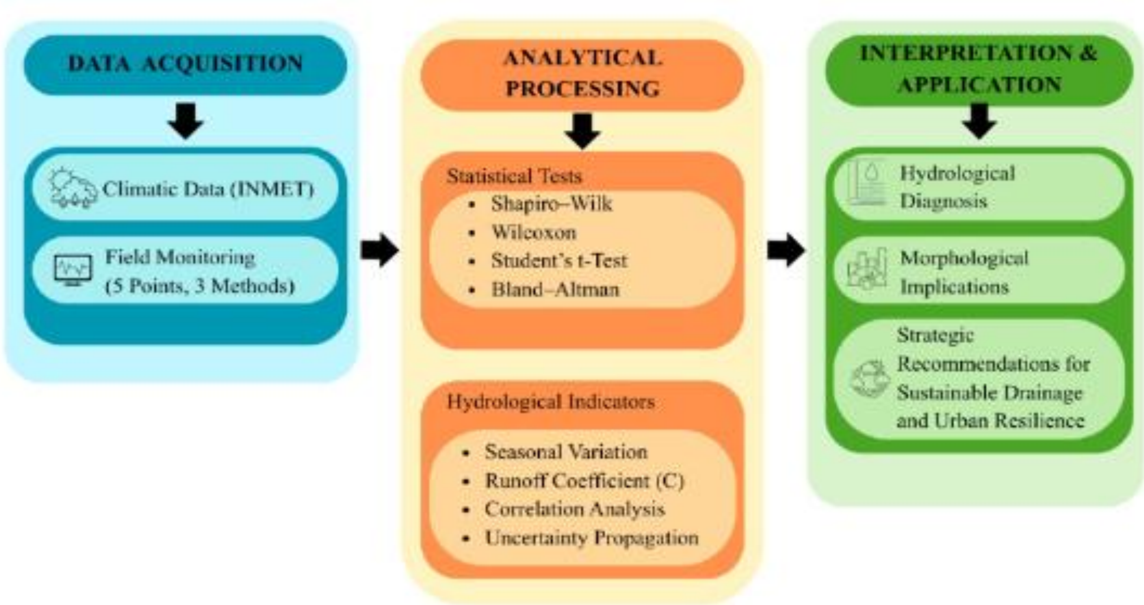

Figure 1. Research Methodological Flowchart

A. Location and Characterization of the Study Area

The study area corresponds to Ribeirão Morangueiro, located in the municipality of Maringá, in the north-central region of Paraná state, Brazil, at approximately 23°24'S and 51°55'W, as presented in Figure 2. The Ribeirão Morangueiro watershed has an area of 41.9 km², while the watercourse has an approximate length of 12.5 km, with its source located in Alfredo Werner Nyffeler Park and its mouth in Ribeirão Sarandi.

From a physical standpoint, the watershed lies on the Serra Geral Formation, with predominance of basaltic rocks from the Cretaceous period (Reis *et al.*, 2014). On this geological substrate, soils predominantly of the dystroferric Red Latosol type develop, characterized by high depth and porosity (Bhering *et al.*, 2007).

The regional climate is classified as Cfa (humid subtropical) according to Köppen (1948), presenting hot summers (mean temperatures above 22°C) and absence of a defined dry season, with precipitation exceeding 30 mm even in the driest months.

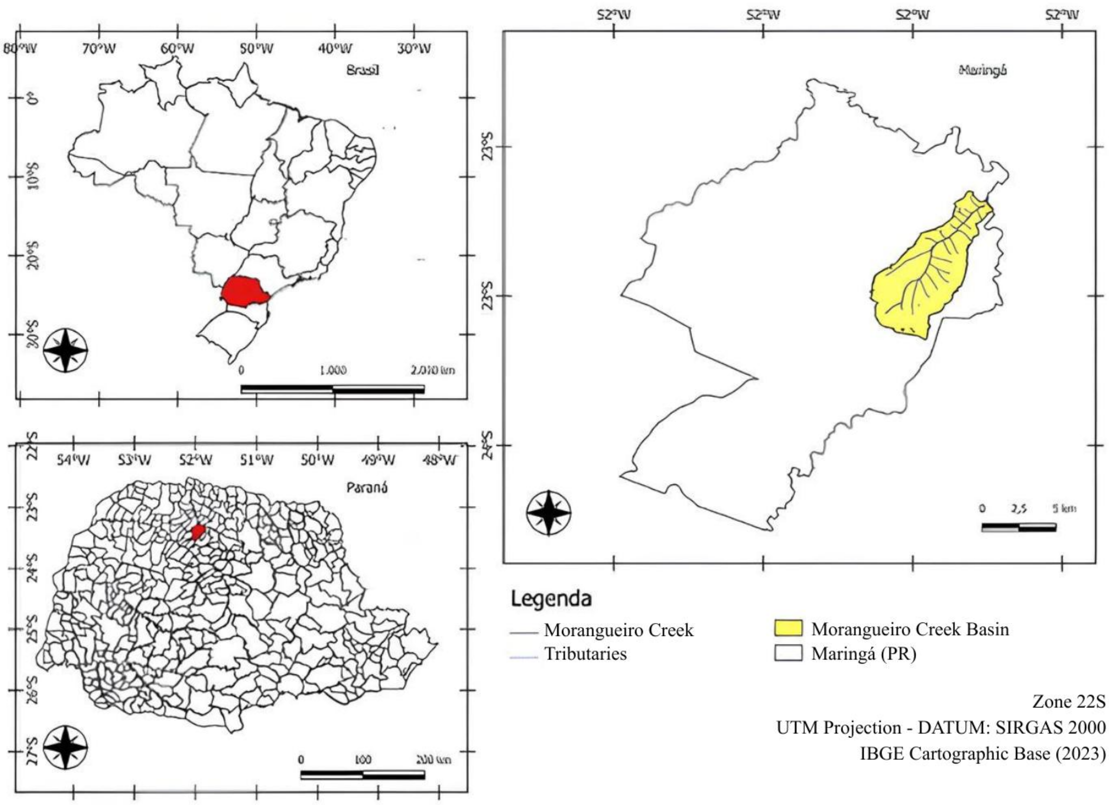

Figure 2. Location Map of the Watershed in the City of Maringá

Regarding land use and occupation, the watershed presents a diversified and complex configuration (Figure 3). The headwaters and upper course region are located within a consolidated urban fabric, composed of Residential Zone, Industrial Zone, Special Zone of Social Interest (ZEIS), and Specific Urbanization Zone (ZUE). This intense urban occupation results in soil imperviousness in the headwater areas, exerting strong hydrological pressure on the system. The middle and lower courses, meanwhile, are situated predominantly within Rural Zone (ZRU) up to the watershed outlet.

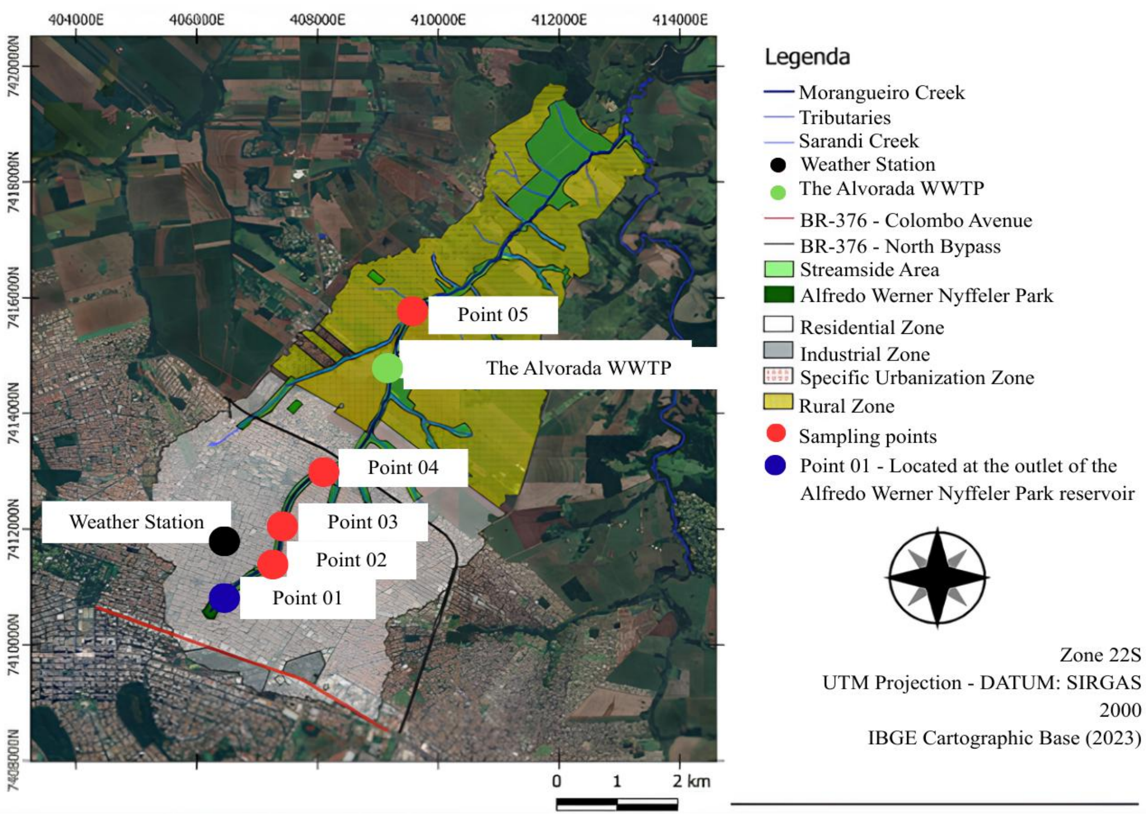

Figure 3. Land Use, Occupation, and Flow Monitoring Points Map

Alfredo Werner Nyffeler Park, where the source is located, was designed by the Urban Services Department in 1986 and completed in 1988, with the objective of containing erosive processes (Bovo, 2009). Besides protecting the source, the park currently functions as a retention basin, controlling stormwater runoff through temporary storage and outlet restriction, thereby contributing to the reduction of peak flows released to downstream sections (Valim *et al.*, 2019).

B. Hydrological Data Collection

For this analysis, data from the climatological station of the National Institute of Meteorology – INMET (83767), located in the municipality of Maringá, were used. From this station, monthly values of precipitation, and maximum and minimum temperatures were obtained.

Based on precipitation data from the sub-basin of interest, obtained from the rainfall station, descriptive statistics were calculated to allow an individual analysis of the distribution and variability of each parameter. Measures of central tendency (mean, median, and mode) and measures of dispersion (standard deviation and variance) were considered.

C. Flow Measurement

Flow measurements were conducted monthly between December 2023 and December 2024 at five points located along Ribeirão Morangueiro, in the municipality of Maringá-PR (Figure 3). This period was intentionally selected to encompass a complete hydrological year, allowing seasonal variability to be captured within a continuous monitoring framework. The monitoring strategy prioritized the urbanized portion of the watershed, where land-use changes and impervious surface expansion exert greater influence on the hydrological response. Data collection sites were selected based on ease of access and the rectilinear geometry of the channel sections. Three distinct methods were adopted for flow determination: the weir method at Point 01, the float method at Points 02, 03, 04, and 05, and the acoustic method (ADV) at Point 04, using FlowTracker equipment manufactured by SonTek/YSI Inc. (SonTek, 2007).

For flow calculation at Point 01, a thin-walled rectangular weir with two lateral contractions was employed. The Francis formula (1868) was used, according to Eq. 1 (Porto, 2006), where Q is the flow (m³/s), L is the weir width (m), and h is the head over the weir (m).

$$Q = 1{,}838 \cdot (L - 0{,}20 \cdot h) \cdot h^{3/2} \qquad (1)$$

For discharge measurement by the float method, EPS (expanded polystyrene) floats were used, following the methodology proposed by Palhares et al. (2007). The method involves installing two ropes with markings every 0.50 m, positioned perpendicular to the riverbanks and spaced at least 5 meters apart, allowing for cross-sectional bathymetry measurement and the determination of float travel time.

The flow was calculated by Eq. 2, where A is the wetted area, calculated as the average of the cross-sectional areas (m²), L is the distance traveled by the float between measurement sections (m), t is the travel time (s), and C is the correction coefficient, adopted as 0.8 for rivers with rocky bottoms or 0.9 for muddy bottoms. In this case, the adopted coefficient value was 0.8.

$$Q_{float} = \frac{A \cdot L \cdot C}{t} \qquad (2)$$

For verification with the acoustic method (Point 04), the procedure described in the FlowTracker Handheld ADV User Manual (SonTek, 2007) was followed. The cross-section was divided into measurement verticals; in each, depth and point velocity were measured. Sensor positioning followed technical standards: velocity was measured at 60% of the depth for water depths below 60 cm, and the two-point method (20% and 80%) was applied for greater depths. Total flow was calculated using the mid-section method.

Finally, to validate the reliability of the simplified method, data obtained simultaneously by the Float and acoustic methods at Point 04 were statistically compared. The normality of both data series (Float and FlowTracker, n = 13) was preliminarily assessed using the Shapiro-Wilk test ($\alpha = 0.05$), which is recommended for small samples ($n < 50$) due to its superior statistical power compared to alternative normality tests. The null hypothesis (H_0) assumed that the data followed a normal distribution and was rejected if $p < 0.05$. In cases where at least one of the paired series violated normality, the non-parametric Wilcoxon Signed-Rank Test was adopted for method comparison, as it does not require the assumption of normality, in contrast to the parametric t-test, with a significance level of 5%.

D. Uncertainty Analysis

The uncertainty in flow measurements was estimated by propagating the individual errors of the variables involved in the Float and Acoustic methods. For the Float method, the combined standard uncertainty ($U_{C(Q)}$) was calculated considering the independent sources of error: wetted area (A), distance (L), travel time (t), and the correction coefficient (C), following the GUM (Guide to the Expression of Uncertainty in Measurement) framework. The sensitivity of the flow rate to the coefficient (C) was specifically evaluated, as literature suggests values ranging from 0.80 to 0.90 for urban channels. For the Acoustic method (FlowTracker), uncertainty was determined based on the equipment's technical specification (±1% of measured velocity) and the statistical sampling error of the mid-section method. The bias and limits of agreement were further quantified using the Bland-Altman method to establish the reliability of the simplified technique in urban monitoring.

E. Analysis Methodology

Data analysis was structured to enable an integrated understanding of the watershed's hydrological behavior in the face of urbanization. Initially, to evaluate the influence of seasonality, average flows for each monitoring point were

calculated, with the data segregated between wet and dry periods.
For comparison between measurement methods (Float vs. FlowTracker), the Wilcoxon Signed-Rank Test was chosen over Student's t-test due to the small sample size (n < 20), the presence of outliers, and violations of normality assumptions. Additionally, technical agreement analysis was performed using the Bland-Altman plot to quantify systematic bias and agreement limits between methods. For comparison between seasonal periods, Student's t-test for independent samples was applied, with a significance level of 5% (α = 0.05).
Subsequently, the magnitude of flow changes was quantified. For this, the percentage variation (ΔQ) between seasonal periods and between different monitoring points was calculated using Eq. 3. This metric allows the quantification of runoff peak amplification, a phenomenon highlighted by Tucci (2008), who documents flow increases of up to sevenfold in fully impervious watersheds when compared to natural conditions.

$$\Delta Q = \frac{|\bar{Q}_{wet} - \bar{Q}_{dry}|}{\bar{Q}_{dry}} \cdot 100 \qquad (3)$$

Finally, quantitative results were cross-referenced with qualitative observations made in the field, such as the identification of erosive processes, effluent discharge points, and suppression of riparian vegetation. This integrated To quantify this volume for each month, the instantaneous flow rate measured at Point 05 (the most downstream monitoring point) was multiplied by the duration of a standard month (2.592 × 10⁶ seconds). From this relationship, based on Eq. 4, the Surface Runoff Coefficient (C) was determined: one of the basic indicators of the degree of imperviousness of the watershed.

$$C = \frac{V_{runoff}}{V_{precipitaded}} \qquad (4)$$

III. RESULTS AND DISCUSSION

The results of flow measurements conducted throughout hydrological year of field research are presented in Table 1.

analysis supported the identification of critical areas in the watershed and supported the proposition of guidelines for municipal water management, guiding the selection of NbS, which is most suitable for mitigating the identified hydrological impacts.

F. Integration Between Climatic and Hydrological Data

Integration between climatic and hydrological variables was conducted through statistical and volumetric approaches. Initially, linear regression analysis was applied to obtain the Coefficient of Determination (r) between accumulated monthly precipitation and average flow observed at each monitoring point. This indicator was used to quantify how much rainfall variation explains flow variability, allowing an assessment of the influence of imperviousness on the watershed's immediate hydrological response.
Due to the monthly temporal resolution of the available precipitation dataset and the limited length of the time series, lagged correlation analyses were not applied, as they would not provide statistically robust results. Subsequently, the watershed's volumetric balance was performed. Total precipitated volume ($V_{precipitated}$) was estimated by multiplying accumulated precipitation in the period by the total watershed area (41.9 km²). This was compared to the total volume of runoff (V_{runoff}) computed for Point 05 by summing the individual monthly volumes.

where: C is the runoff coefficient (dimensionless); V_{runoff} is the estimated total runoff volume (m³); and $V_{precipitated}$ is the total precipitated volume (m³).

Finally, water retention potential was estimated, defined as the fraction of precipitated volume that is not converted into direct surface runoff (infiltration + evapotranspiration). This parameter was used to assess the need for implementing NbS, aiming to recover the watershed's natural buffering capacity lost through urbanization.

Table 1. Results of Flow Monitoring

Flow (m³/s)	Dec/23	Jan/24	Feb/24	Mar/24	Apr/24	May/24	Jun/24	Jul/24	Aug/24	Sep/24	Oct/24	Nov/24	Dec/24
Weir Method													
Point 01	0.013	0.013	0.013	0.005	0.005	0.005	0.005	0.003	0.003	0.001	0.0004	0.0004	0.006
Float Method													
Point 02	0.083	0.078	0.071	0.077	0.182	0.049	0.061	0.354	0.022	0.0398	0.0582	0.0951	0.0278
Point 03	0.209	0.328	0.132	0.111	0.189	0.116	0.258	0.2369	0.1121	0.1231	0.068	0.3086	0.124
Point 04	0.216	0.17	0.336	0.192	0.192	0.134	0.226	0.4172	0.5423	0.3294	0.223	0.4172	0.304
Point 05	0.947	2.386	0.917	1.26	1.663	0.636	2.379	2.324	1.346	1.337	1.361	1.11	1.57
Acoustic Method													
Point 04	0.206	0.073	0.197	0.193	0.224	0.155	0.183	0.2397	0.1872	0.23	0.1153	0.222	0.2156

To complement the results measured in the field, a statistical analysis of the data was conducted, with calculation of means and percentage differences between the wet period (October to March) and the dry period (April to September). For seasonal comparison between these periods, Student's t-test was applied, with a significance level of 5%. The results are presented in Table 2.

Table 2. Flow Averages, Percentage Variation, and Student's t-Test for Comparison Between Dry and Wet Periods

Point	Method	Mean flow during the wet period (m³/s)	Mean flow during the dry period (m³/s)	% variation	p-value (t test)
Point 01	Weir	0.0073	0.0037	97.92	0.1593
Point 02	Float	0.0700	0.1180	-40.64	0.4094
Point 03	Float	0.183	0.1725	6.04	0.8276
Point 04	Float	0.265	0.3068	-13.48	0.9241
Point 04	Acoustic	0.1745	0.2032	-14.07	0.2879
Point 05	Float	1.0000	1.6142	-15.47	0.4703

Regarding seasonal comparison, Student's t-test results did not detect statistically significant differences between average flows in dry and wet periods for any of the monitored points ($p > 0.05$). At first glance, this finding would suggest that seasonality did not influence flows during the monitored period, considering the adopted monthly temporal resolution and sample size. However, this temporal homogenization behavior is characteristic of the "urban stream syndrome", described by Walsh et al. (2005). According to the authors, in highly anthropized watersheds, water importation (via the water supply system) and its subsequent continuous discharge as domestic or industrial effluents (as observed at the Alvorada WWTP) generate an elevated artificial base flow. This constant contribution masks the natural reduction expected during drought periods, reducing variance between seasons and making the hydrological regime more dependent on the urban water use cycle than on local climatology.

The weir method proved adequate for measuring flow at the reservoir outlet, while the float method demonstrated effectiveness in sections with reduced water depth. Regarding values obtained at Point 04, substantial differences among measurements collected throughout the monitoring period were observed. Flows measured by the float method ranged from 0.134 m³/s (May 2024) to 0.542 m³/s (August 2024), whereas the acoustic method (FlowTracker) recorded values between 0.073 m³/s (January 2024) and 0.2397 m³/s (July 2024). This variation reflects both natural flow oscillations throughout the hydrological cycle and methodological differences and limitations inherent to each technique.

The agreement between the Float and FlowTracker methods was further examined using the Bland–Altman approach at Point P04, as illustrated in Figure 4.

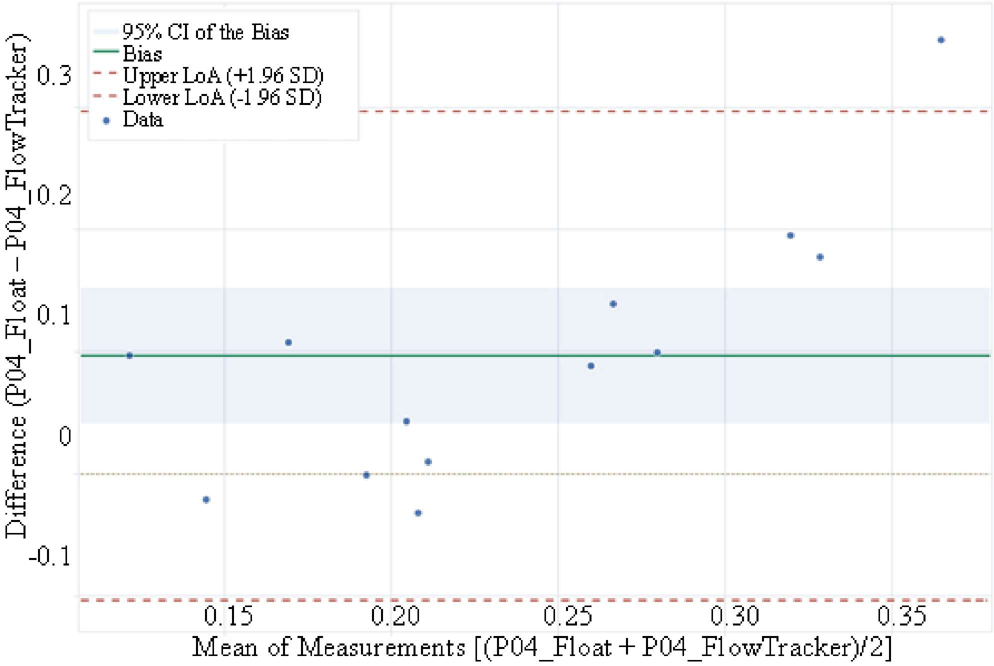

Figure 4. Bland–Altman analysis comparing differences between Float and FlowTracker discharge measurements at Point 04 during the 2024 monitoring period. LoA = Limits of Agreement; CI = Confidence Interval

Uncertainty analysis revealed that the Float method's systematic overestimation (bias= 0.0968 m³/s) is primarily driven by the surface velocity profile and the choice of correction coefficient. While this study initially adopted the standard value (C = 0.8), the ratio analysis ($Q_{flowtracker}/Q_{float}$) indicated an empirical adjustment factor of 0.74 specific to Ribeirão Morangueiro. This discrepancy suggests that the standard uncertainty of simplified methods can exceed 20% in urban channel sections characterized by high turbulence intensity or irregular cross-sectional geometry. Nevertheless, the internal consistency demonstrated by the Wilcoxon signed-rank test (p = 0.0088) confirms that the Float method, once calibrated by the site-specific factor of 0.74, constitutes a statistically valid instrument for hydrological trend monitoring. This finding aligns with Santos and Ferreira (2019) and Ribeiro et al. (2017), who defend simplified techniques as essential, cost-effective, and reproducible tools for urban watershed management in resource-scarce scenarios.

Precipitation data provided by INMET (2025) confirmed the climatological contrast between dry and wet seasons in Maringá. However, Student's t-test results (p > 0.05) across all monitoring points (Table 2) indicate that this seasonal difference did not translate into a statistically significant difference in mean monthly streamflow in Ribeirão Morangueiro under the adopted sampling resolution. This supports the “urban stream syndrome” hypothesis (Walsh *et al.*, 2005).

In this scenario, soil imperviousness and continual anthropogenic inputs, including discharges from the Alvorada Wastewater Treatment Plant, stabilize base flow and mask the natural reduction that is seen in the dry season. While Mattos et al. (2021) indicate that urbanized watersheds respond remarkably to rainfall hydrological effects, this sensitivity is reflected in the immediate inundation event peaks at urbanized watersheds but not as ongoing seasonal mean streamflow dynamics, which reinforces the low linear correlation findings.

The descriptive statistics of precipitation and temperature for the monitored hydrological year are presented in Table 3.

Table 3. Precipitation and Temperature Statistical Data from the Rainfall Station of the Sub-basin of Interest

Descriptive Statistics	**Daily precipitation (mm)**			**Monthly maximum temperature (°C)**	**Monthly average temperature (°C)**	**Monthly average minimum temperature (°C)**
	Hydrological year	**Dry period**	**Wet period**			
Mean	3.579	1.786	5.112	31.146	24.6	19.346
Median	0	0	0	31.6	25.5	20.4
Mode	0	0	0	31.6	26.5	20.6
Maximum	95	41	95	33.9	33.9	33.9
Minimum	0	0	0	27.6	20.1	14.3
Range	95	41	95	6.3	13.8	19.6
Variance	105.411	34.597	161.293	3.984	5.142	6.363
Std. Deviation	10.267	5.882	12.700	1.996	2.267	2.522

Source: INMET, 2025.

The descriptive statistics presented in Table 3 confirm the marked seasonal contrast in precipitation between wet and dry periods, with higher mean and variance values during the wet season. The median precipitation equal to zero in all periods indicates the predominance of dry days punctuated by high-intensity rainfall events, reflecting a highly asymmetric distribution pattern. Despite this clear climatic differentiation, the absence of significant differences in mean discharge between seasons at the watershed outlet (Point 5) suggests that watershed hydrological response is partially decoupled from short-term precipitation variability, reinforcing the influence of urbanization and artificial baseflow stabilization.

Statistical analysis was also performed to verify the correlation between discharge and accumulated monthly precipitation data during the monitoring period and along the studied stream reach. Thus, Pearson correlation analysis between monthly precipitation and flow revealed predominantly weak associations at monitored points. Point 03 presented the highest positive correlation (r = 0.39), followed by Points 01 (r = 0.20) and 04 (r = 0.09). On the other hand, negative correlations were identified at Points 05 (r = -0.24) and 02 (r = -0.10), suggesting a dissociation or delay in flow response relative to precipitation at these specific locations. This low linear correlation suggests a temporal mismatch between volume precipitated over 30 days and instantaneous flow measured, a characteristic behavior of watersheds with a high degree of imperviousness and low time of concentration.

Regarding volumetric balance, an annual precipitated volume of 54.7×10^6 m³ was estimated, compared to a runoff volume of 49.9×10^6 m³. The relationship between these volumes resulted in a high runoff coefficient (C) of approximately 0.90, suggesting a high proportion of precipitation converted into surface runoff under the adopted estimation approach. This hydrological behavior corroborates patterns observed in similar urban contexts, such as that reported by Mansour and Pinheiro (2023) in the city of Londrina-PR. For the Cambé River watershed (51.75 km²), the authors estimated an average Curve Number (CN) value of 86.37. Although they are distinct indices, with C being a volumetric ratio and CN an empirical parameter derived from the Soil Conservation Service (SCS) method of the United States Department of Agriculture (USDA) (ASCE, 2008), both results converge in evidencing watersheds with high degree of imperviousness and elevated surface runoff generation capacity.

In contrast to the high imperviousness scenarios observed in Northern Paraná, the city of Ljubljana, Slovenia, internationally recognized as a reference in resilient urban planning and green infrastructure, Pichler-Milanovič and Foški (2015), presents substantially more balanced hydrological indicators. A recent study conducted by Alivio et al. (2024) in an urban watershed of the Slovenian capital identified an average runoff coefficient (C) of 0.60.

Beyond the magnitude of surface generation, the temporal stability of the flow is also affected; in semi-arid river basins, Lyu et al. (2025) identified that interannual runoff volume variation coefficients range from 0.35 to 0.37. While the previous indices (C and CN) describe the watershed's efficiency in generating runoff, these variation coefficients indicate significant hydrological instability over the years. In this context, while climate change is the primary driver of these fluctuations, human activities accounted for 33.42% of annual runoff changes between 2000 and 2020, with reservoir operations causing an average reduction of approximately 25% in downstream annual runoff.

Complementing these findings, Son and Kwon (2022) identified that while vegetation areas in urban parks have a runoff coefficient of 0.245, impervious sidewalks reach a total coefficient of 1.000, indicating total water loss through surface runoff. As a mitigation strategy for such high-runoff environments, the authors demonstrate that the conversion of only 1% of the area into wetlands or gravel sidewalks can reduce annual runoff by approximately 10.32 mm, representing a significant contribution to urban resilience through NbS.

Comparative analysis evidences the disparities between occupation models: while Ribeirão Morangueiro, with C of 0.90, and Londrina's watershed, with CN above 86 (Mansour; Pinheiro, 2023), convert almost all rainfall into rapid surface runoff, Ljubljana's case demonstrates how preservation of permeable areas and sustainable management can retain about 40% of precipitated volume.

This magnitude difference suggests that the implementation of NbS in Maringá may have the technical potential to mitigate current degradation trends and promote more resilient hydrological patterns in the watershed. A hypothetical reduction of the runoff coefficient from 0.90 to 0.70 through the implementation of NbS could represent a decrease of approximately 11.0 million m³ per year in surface runoff, significantly mitigating flood risks, reducing channel erosion, and improving baseflow regulation.

Although simplified, this estimate highlights the substantial hydrological benefits that urban green infrastructure could provide in the study area. Consequently, the watershed's current retention potential (NbS indicator) is estimated at only 0.10, evidencing the low natural infiltration capacity of the system and reinforcing the urgent need for interventions for sustainable stormwater management.

To contextualize the hydrometeorological conditions under which this behavior was monitored, Figures 5 and 6 present, respectively, monthly average temperatures recorded at the Maringá Climatological Station (period from December 2023 to December 2024) and the accumulated monthly precipitation with its corresponding standard deviation.

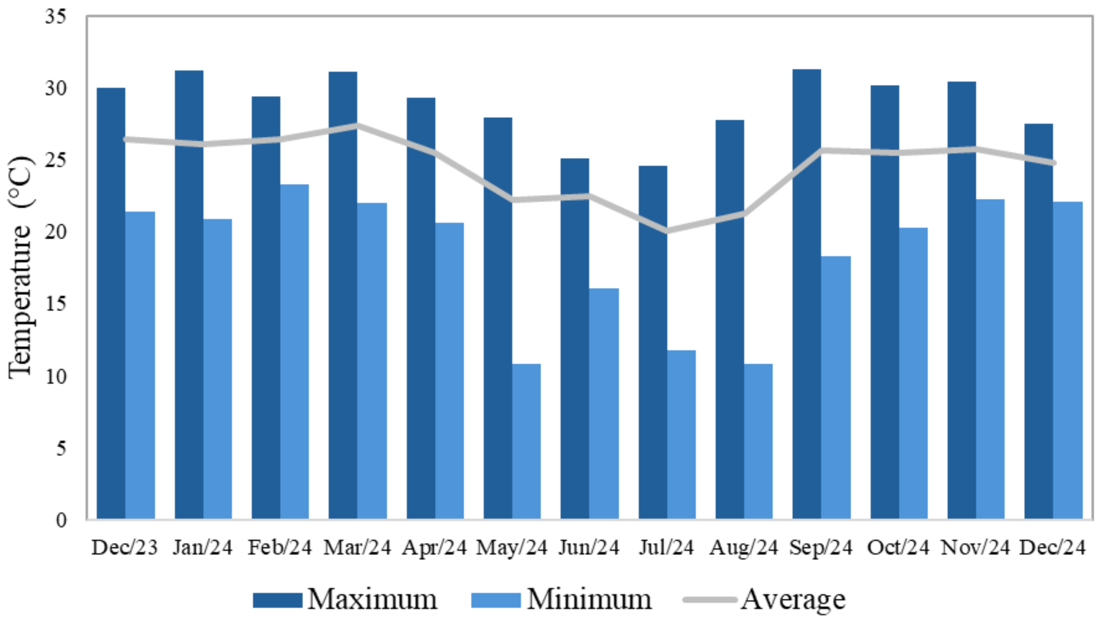

Figure 5. Monthly Average Temperatures for Maringá Climatological Station Between December 2023 and December 2024

Source: INMET, 2025.

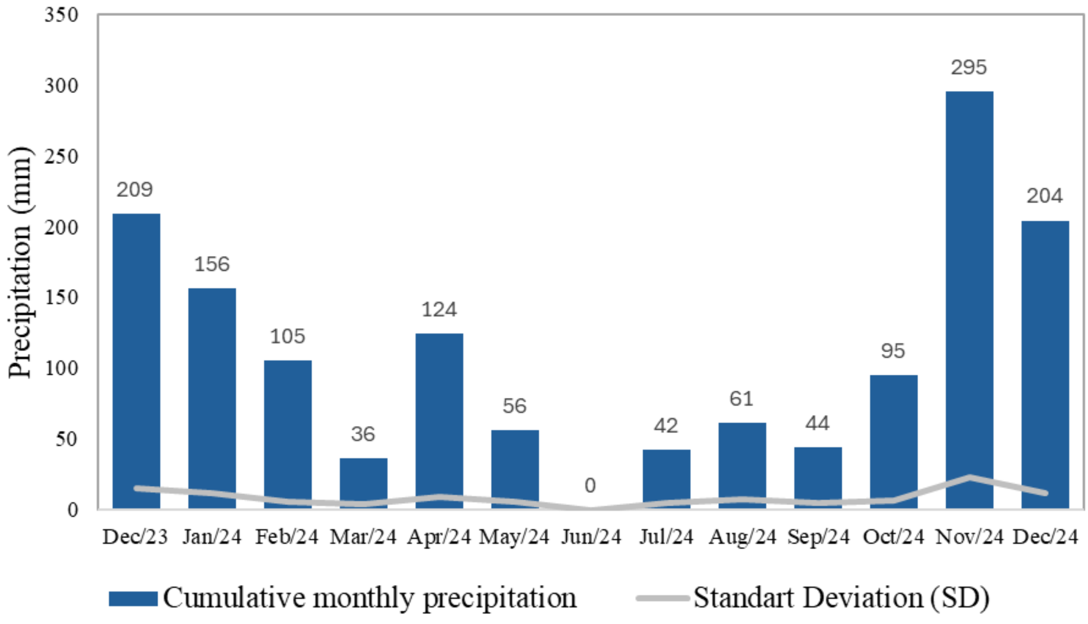

Figure 6. Combination of Accumulated Monthly Precipitation with its Standard Deviation
Source: INMET, 2025.

Analysis of data presented in Table 1 reveals a hydrological behavior characteristic of urbanized watersheds, divergent from the buffered pattern expected in natural systems. At Point 05, a flow variation of 15.47% was observed between dry and wet periods, a level considered reasonably low compared to rural or forested watersheds, according to the parameters described by Tucci (2002).

This hydrological instability is corroborated by the reduced response time between precipitation events and flow peaks, reflecting the high degree of imperviousness in the drainage area. Furthermore, anthropogenic intervention proved to be a determining factor at Point 05, where effluent discharge from Alvorada WWTP altered the natural runoff regime.

The month of June (drought period) stands out, as even with zero precipitation, a flow of 2.379 m³/s was recorded. This value, which is markedly higher than those observed at the other monitored points, reflects the continuous contribution that sustains an "artificial base flow", thereby impacting the water body's hydrodynamics and quality.

The field observations synthesized in Table 1 and corroborated by the photographs in Figures 7 and 8 reveal the cumulative geomorphological signature of intensive urbanization on Ribeirão Morangueiro. The amplification of surface runoff and the progressive modification of channel morphology through erosion and siltation are not isolated phenomena but rather the compounded product of interacting drivers: high impervious cover, suppression of riparian vegetation, and the proliferation of gray drainage infrastructure throughout the watershed.

The degradation of riparian vegetation, documented across several monitoring sections, eliminates a critical biogeomorphological buffer, removing the structural root cohesion and surface roughness that under natural conditions attenuate flow energy, trap fine sediments, and promote bank stability (Fletcher; Andrieu; Hamel, 2013; Oswald *et al.*, 2023; Santos; Rufino; Filho, 2017; Walsh *et al.*, 2005).

In urbanized catchments such as Ribeirão Morangueiro, this vegetation loss does not act independently; it is systematically coupled with the hydraulic effects of crossing and drainage structures, including culverts, discharge conduits, and concrete-lined channels. As demonstrated by Matos and Morais (2025) in a scientometric review encompassing studies from 1983 to 2024, these structures consistently generate asymmetric geomorphological responses: upstream reaches exhibit reduced flow power, increased sediment deposition, and elevated susceptibility to flooding, while downstream sections are subject to intensified bank erosion, higher flow velocities, and progressive channel incision. This upstream–downstream duality is spatially expressed along Ribeirão Morangueiro and constitutes a fundamental mechanism linking gray infrastructure to the channel morphological instability documented in this study.

Figure 7 illustrates localized hydraulic disturbances associated with gray drainage infrastructure and disturbed riparian zones along Ribeirão Morangueiro. In Figure 7A, direct stormwater discharge onto unprotected soil concentrates hydraulic energy, promoting soil detachment and sediment transport toward the channel. The absence of riparian vegetation removes an important geomorphological buffer, increasing susceptibility to erosion and facilitating fine sediment input, a process consistent with patterns described for urbanized streams (Paiva *et al.*, 2025). Figure 7B presents an energy dissipator intended to reduce flow velocity before discharge into the channel. Although such devices can mitigate erosive impacts, their effectiveness depends on maintenance and hydraulic adequacy. Structural displacement or sediment accumulation may compromise their buffering function and generate localized turbulence or depositional zones. The culvert shown in Figure 7C exemplifies the hydraulic constriction imposed by crossing infrastructure. By forcing flow through a reduced cross-section, culverts can increase downstream velocities while promoting upstream sediment retention, contributing to localized morphological adjustments (Matos; Morais, 2025). In highly impervious watersheds such as Ribeirão Morangueiro, these disturbances interact with elevated runoff generation, amplifying channel instability. Finally, Figure 7D highlights soil compaction in unvegetated access areas. Reduced infiltration capacity increases surface runoff and functions as a diffuse sediment source, because soil compaction alters pore structure and decreases hydraulic conductivity, thereby limiting infiltration and enhancing runoff generation (Talat; Wang; El-Sorogy, 2025). Collectively, these localized processes reinforce the broader pattern of siltation and morphological instability documented in the watershed, linking impervious land cover and gray infrastructure to the hydrological alterations observed in this study.

Figure 7. Drainage Structures and Siltation of Ribeirão Morangueiro

The localized disturbances illustrated in Figure 7 contribute cumulatively to the broader siltation pattern documented in Figure 8. In Ribeirão Morangueiro, elevated impervious cover intensifies runoff generation, while riparian degradation reduces sediment retention capacity. Gray drainage structures, including culverts and direct discharge outlets, further modify flow energy distribution, reinforcing upstream deposition and downstream instability. These interacting processes indicate that channel morphological adjustment in the watershed is not an episodic or random phenomenon but structurally linked to land-use configuration and infrastructure design. This geomorphological instability is consistent with the hydrological indicators obtained in this study, particularly the high runoff coefficient ($C \approx 0.90$) and the weak correlation between precipitation and discharge. Elevated imperviousness increases rapid surface runoff, while artificial baseflow inputs partially stabilize discharge throughout the year. The combined effect is a system characterized by reduced seasonal variability but increased structural pressure on channel morphology.

Figure 8. Siltation of Ribeirão Morangueiro

From an urban resilience perspective, monitoring data demonstrate the potential of these indicators to guide the implementation of Nature-Based Solutions (NbS). Interventions such as rain gardens, permeable pavements, and restored riparian vegetation strips can reduce runoff velocity, enhance infiltration, and contribute to flood mitigation, especially in watersheds with consolidated urbanization (Mattos *et al.*, 2021; Silveira; Rodrigues; Dornelles, 2025). Integration of these strategies in Maringá is supported by successful national experiences, such as the Viva a Natureza Program in Porto Alegre (2018-2022), which implemented 120 rain gardens and achieved a 15-20% reduction in flooding events (PMPA, 2019). Other examples include the Córrego Limpo Program in São Paulo, which recovered 150 km of watercourses with investments on the order of R$ 2.2 billion (SABESP, 2022), and Curitiba's model, which, situated in the same climatic region, demonstrates the state viability of these solutions through implementation of linear parks since the 1970s (Macedo, 2013). In this context, recent studies by Silveira, Rodrigues and Dornelles (2025) and Monachese et al. (2025) corroborate that integration of hydrological data into sustainable drainage planning amplifies NbS effectiveness, promoting the necessary synergy between green infrastructure and urban water management.

Thus, the monitoring of Ribeirão Morangueiro provides robust technical support for water resources management and constitutes a strategic tool for guiding sustainable urban interventions. The continuous incorporation of these data into municipal drainage planning and hydrological modeling frameworks can significantly strengthen the resilience of medium-sized cities facing rapid densification and increasing climate extremes, providing quantitative support for the revision of urban drainage regulations and land-use planning policies.

IV. CONCLUSIONS

This study suggests that the hydrological conditions of Ribeirão Morangueiro are no longer predominantly controlled by climatic seasonality, but by the structural effects of the watershed urbanization. The artificial stabilization of baseflow, the high surface runoff coefficient, and the documented geomorphological deterioration indicate a substantial deviation from natural hydrological dynamics and suggest that current watershed conditions are progressively reinforced over time rather than effectively mitigated by conventional gray drainage infrastructure.

This cost-effective monitoring approach, even in the presence of systematic bias, establishes the technical feasibility of deploying new hydrological observation systems in contexts where funding may be limited, provided that proper calibration procedures are implemented. This has direct governance implications: data are still critically lacking in evidence-based urban water management, and investment in monitoring is, in itself, a strategic decision.

The results indicate that the integration of nature-based infrastructure constitutes a technically justified strategy to enhance hydrological resilience in the watershed. Medium-sized cities such as Maringá find themselves in a strategic and temporally critical position for this transition: they are not yet comparable to large metropolitan urbanized centers, but they retain the institutional and spatial capacity to embed NbS before irreversible damage becomes entrenched.

Although medium-sized cities provide a pragmatic and temporary opportunity for the development of sustainable strategies before irreversible degradation occurs, the conclusions of this 13-month study remain conditioned by interannual climatic variability. Further research should extend beyond flow quantity to include water quality parameters, remote sensing-based imperviousness mapping, and socio-environmental vulnerability assessments. Continuous and automated monitoring over extended time horizons, particularly over periods exceeding five years and supported by NbS pilot projects integrated with in situ measurements, would enhance analytical robustness, reduce temporal uncertainty, and provide the evidence base necessary to translate technical guidance into effective policy implementation.

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REFERENCES

1. Alivio, M. B.; Radinja, M.; Šraj, M.; Gribovszki, Z.; Bezak, N. Comparative analysis of event runoff coefficients and curve numbers in contrasting urban environments based on observed rainfall-runoff data. Journal of Hydrology. v. 645. 2024. https://doi.org/10.1016/j.jhydrol.2024.13213
2. ASCE. Curve Number Hydrology. Reston, VA: American Society of Civil Engineers. 2008.
3. Bhering, S. B.; Santos, H. G. Dos; Manzatto, C. V.; Bognola, I. A.; Fasolo, P. J.; Carvalho, A. P. De; Potter, R. O.; Curcio, G. R. Mapa de solos do estado do Paraná. Rio de Janeiro: Embrapa Solos. 2007.
4. Bovo, M. C. Áreas verdes urbanas, imagem e uso: um estudo geográfico sobre a cidade de Maringá – PR. Presidente Prudente: Universidade Estadual paulista. 2009.
5. Brito, A. C. P.; Alves, A. A. D. A. Modernização e modernidade em Maringá 1947-1967: episódios de arquitetura e cidade em uma frente pioneira. Revista Brasileira de Estudos Urbanos e Regionais. v. 18, 1, p. 129–147. 2016. https://doi.org/10.22296/2317-1529.2016v18n1p129
6. Chen, J.; Wang, S.; WU, R. Optimization of the integrated green–gray–blue system to deal with urban flood under multi-objective decision-making. Water Science and Technology. v. 89, 2, p. 434–453. 2024. https://doi.org/10.2166/wst.2023.411
7. Chiroli, D. M. de G.; Menezes, M. G.; Zola, F. C.; Aragão, F. V.; Almeida, R. D. de; Tebcherani, S. M. Integrating resilience and sustainability: A systematic analysis of resilient cities using ISO 37123. International Journal of Disaster Risk Reduction. v. 96, 103960. 2023. https://doi.org/10.1016/j.ijdrr.2023.103960
8. Coelho, L. da S.; Silva, J. F. R.; Farias, J. A. M. Análise comparativa dos medidores descarga convencional (molinete) e medidores acústicos FlowTracker-ADV (Velocímetro Acústico Doppler) em medições a vau, nas sub-bacias 35 e 36 no estado do Ceará. XX Simpósio Brasileiro de Recursos Hídricos. v. 1, p. 1–8. 2013
9. Companhia de Saneamento Básico do Estado de São Paulo - SABESP. Sustainability Report. São Paulo: SABESP. 2022
10. Esraz-Ul-Zannat, M.; Dedekorkut-Howes, A.; Morgan, E. A. A review of nature-based infrastructures and their effectiveness for urban flood risk mitigation. Advanced Review. v. 15, 5, 2024. https://doi.org/10.1002/wcc.889
11. Fiorelli, M. N.; Alencar, J. L. S.; Simoni, J. H.; Neto, G. A.; Michiko, C. Caracterização ambiental do fundo do vale do Ribeirão Morangueiro na cidade de Maringá - PR. Revista Eletrônica em Gestão, Educação e Tecnologia Ambiental. v. 19, 2, p. 1452–1461. 2015. https://doi.org/105902/2236117016954
12. Fletcher, T. D.; Andrieu, H.; Hamel, P. Understanding, management and modelling of urban hydrology and its consequences for receiving waters: A state of the art. Advances in Water Resources. v. 51, 51, p. 261–279. 2013. https://doi.org/10.1016/j.advwatres.2012.09.001
13. Franz, N. M.; Andreoli, C. V.; da Silva, C. L. Gestão participativa, práticas de governança e o desenvolvimento sustentável em cidades turísticas de pequeno porte. Eure. v. 47, 141, p. 95–115. 2021. http://dx.doi.org/10.7764/eure.47.141.05
14. Instituto Nacional de Meteorologia - INMET. Dados meteorológicos históricos. Em: http://www.inmet.gov.br. 2025.
15. Köppen, W. Climatología: Con un estudio de los climas de la Tierra. 2. ed. México: Fondo de Cultura Económica. 1948.
16. Lyu, J.; Wang, Y.; Wang, K.; Liu, W.; Sun, D.; Luo, P.; Zhou, Z.; Jiao, M.; Huo, A.; Guo, P. Hydrological response to climate change and urbanization in a semi-arid urban river. Urban Climate. v. 64, 102668. 2025. https://doi.org/10.1016/j.uclim.2025.102668
17. Macedo, J. Planning a Sustainable City: The Making of Curitiba, Brazil. Journal of Planning History. v. 12, 4, p. 334–353. 2013. https://doi.org/10.1177/1538513213482093
18. Mansour, A. L. N.; Pinheiro, H. D. Estimativa do escoamento superficial das bacias hidrográficas urbanizadas inseridas no perímetro urbano do município de Londrina/PR. Ciência e Natura. v. 45, 18. 2023. https://doi.org/10.5902/2179460X68261
19. Matos, B. C. da S. de; Morais, E. S. de. How have bridges and culverts changed rivers? A scientometric investigation. Revista Brasileira de Geomorfologia. v. 26, 2, p. 2645. 2025. ttps://doi.org/10.20502/rbg.v26i2.2645
20. Mattos, T. S.; Oliveira, P. T. S.; Bruno, L. S.; de Oliveira, N. D.; Vasconcelos, J. G.; Lucas, M. C. Improving Urban Flood Resilience under Climate Change Scenarios in a Tropical Watershed Using Low-Impact Development Practices. Journal of Hydrologic Engineering. v. 26, 12, 05021031. 2021. https://doi.org/10.1061/(ASCE)HE.1943-5584.0002143
21. Monachese, A. P.; Gómez-Villarino, M. T.; López-Santiago, J.; Sanz, E.; Almeida-Ñauñay, A. F.; Zubelzu, S. Challenges and Innovations in Urban Drainage Systems: Sustainable Drainage Systems

Focus. Water. v. 17, 76. 2025. https://doi.org/10.3390/w17010076
22. ONU. World Urbanization Prospects The 2018 Revision. New York: United States: United Nations. 2019.
23. Oswald, C. J.; Kelleher, C.; Ledford, S. H.; Hopkins, K. G.; Sytsma, A.; Tetzlaff, D.; Toran, L.; Voter, C. Integrating urban water fluxes and moving beyond impervious surface cover: A review. Journal of Hydrology. v. 618, 129188. 2023. https://doi.org/10.1016/j.jhydrol.2023.129188
24. Paiva, C. L. de; Bega, J. M. M.; Zambrano, K. T.; Cunha, D. G. F. The potential contribution of riparian vegetation in non-point source pollution control during rainfall events in a tropical urban watershed. Revista Brasileira de Recursos Hidricos. v. 30, 22. 2025. https://doi.org/10.1590/2318-0331.302520240123
25. Palhares, J. C. P.; Ramos, C.; Klein, J. B.; Muller, S.; Cestonaro, T. Medição da Vazão em Rios pelo Método do Flutuador. EMBRAPA. Comunicado Técnico, 455. Concórdia, SC. 2007.
26. Pichler-Milanovič, N.; Foški, M. Green infrastructure and urban revitalisation in central Europe: Meeting environmental and spatial challenges in the inner city of Ljubljana, Slovenia. Urbani Izziv. v. 26, p. S50–S64. 2015. https://doi.org/10.5379/urbani-izziv-en-2015-26-supplement-004
27. Porto, R. de M. Hidráulica Básica. 4. ed. São Carlos: EESC USP. 2006.
28. Prefeitura Municipal de Porto Alegre (PMPA). Programa Viva a Natureza: Jardins de Chuva. Porto Alegre: Secretaria Municipal de Serviços Urbanos (SMSURB). 2019.
29. Przestrzelska, K.; Wartalska, K.; Rosińska, W.; Jurasz, J.; Kaźmierczak, B. Climate Resilient Cities: A Review of Blue-Green Solutions Worldwide. Water Resources Management. v. 38, 15, p. 5885–5910. 2024. https://doi.org/10.1007/s11269-024-03950-5
30. Reis, G. S.; Mizusaki, A. M.; Roisenberg, A.; Rubert, R. R. Formação Serra Geral (Cretáceo da Bacia do Paraná): um análogo para os reservatórios ígneo-básicos da margem continental brasileira. Pesquisas em Geociências. v. 41, 2, p. 155–168. 2014. https://doi.org/10.22456/1807-9806.78093
31. Ribeiro, M. J.; Villas-Boas, M. D.; Kenup, R. E.; Neto, A. M.; Maciel da Silva, G.; Motta, B. dos A. da; Mota, B.; Pires, J. G.; Costa, F. da S.; Peralta, L. Comparação de medições com molinete e FlowTracker em rios de fundo rochoso: estudo de caso, bacia do rio Piabanha. Florianópolis: Associação Brasileira de Recursos Hídricos. 2017.
32. Santos, A. M. S. P. O município e os desafios da política urbana em aglomerados urbanos: a experiência da Metrópole Fluminense. Geo UERJ. v. 36, 36, p. e47268. 2020. https://doi.org/10.12957/geouerj.2020.47268
33. Santos, C. O. Dos; Ferreira, J. D. A. Método do flutuador como ferramenta para monitoramento do comportamento hidrológico de córrego urbano. Holos Environment. v. 19, 4, p. 614–639. 2019. https://doi.org/10.14295/holos.v19i4.12355
34. Santos, K. A.; Rufino, I. A. A.; Filho, M. N. M. B. Impactos da ocupação urbana na permeabilidade do solo: O caso de uma área de urbanização consolidada em Campina Grande – PB. Engenharia Sanitária e Ambiental. v. 22, 5, p. 943–952. 2017. https://doi.org/10.1590/S1413-41522016146661
35. Sezini, L. B.; Dias, F. M. V. Cidades inteligentes e resiliência urbana: preparando-se para o futuro das mudanças climáticas. Aracê. v. 7, 3, p. 13291–13310. 2025. https://doi.org/10.56238/arev7n3-183
36. Silva, D. F.; Tucci, C. E. M.; Kuele, P. M.; Costa, M. E. L.; Correa, A. C. S.; Monteiro, M. P.; Araújo, L. M. N. Drenagem e manejo de águas pluviais no Brasil: conceitos, gestão e estudos de caso. Revista de Gestão de Água da América Latina. v. 21, 1, p. 1–18. 2024. https://doi.org/10.21168/rega.v21e1
37. Silveira, G. B.; Rodrigues, L. H. R.; Dornelles, F. Uso de Soluções baseadas na Natureza (SbN) pela Gestão Pública Brasileira no Manejo de Águas Pluviais Urbanas. Urbe. v. 17, 17, p. e20240012. 2025. https://doi.org/10.1590/2175-3369.016.e20240012
38. Son, J.; Kwon, T. Evaluation and Improvement Measures of the Runoff Coefficient of Urban Parks for Sustainable Water Balance. Land. v. 11, 1098. 2022. https://doi.org/10.3390/land11071098
39. Sontek. FlowTracker ® Handheld ADV ® Technical Manual Firmware Version 3.3 Software Version 2.20 featuring. San Diego: San Diego. 2007.
40. Talat, A. E.; Wang, J.; El-Sorogy, A. S. Impact of Soil Compaction on Pore Characteristics and Hydraulic Properties by Using X-Ray CT and Soil Water Retention Curve in China's Loess Plateau. Water. v. 17, 8, 1144. 2025. https://doi.org/10.3390/w17081144
41. Tucci, C. E. M. Águas urbanas. Estudos Avançados. v. 22, 63. 2008.
42. Tucci, C. E. M. Regionalização de Vazões. 1. ed. Porto Alegre: ABRH. 2002.
43. Valim, F. A.; Oriol, M. A.; Freire, C. J. de A.; Pompeu, C. R.; Okawa, C. M. P. Diagnosis and proposal of erosion control downstream of the Park Alfredo Werner Nyffeler, in Maringá - Paraná. Revista Eletrônica em Gestão, Educação e Tecnologia Ambiental. v. 23, 4, p. 1–18. 2019. https://doi.org/10.5902/2236117038525
44. Walsh, C. J.; Roy, A. H.; Feminella, J. W.; Cottingham, P. D.; Groffman, P. M.; II, R. P. M. The

urban stream syndrome: current knowledge and the search for a cure. Am. Benthol. Soc. v. 24, 3, p. 706–723. 2005. https://doi.org/10.1899/04-028.1

45. Wang, J.; Liu, J.; Mei, C.; Wang, H.; Lu, J. A multi-objective optimization model for synergistic effect analysis of integrated green-gray-blue drainage system in urban inundation control. Journal of Hydrology. v. 609. 2022. https://doi.org/10.1016/j.jhydrol.2022.127725
46. Yang, W.; Zhang, J. Assessing the performance of gray and green strategies for sustainable urban drainage system development: A multi-criteria decision-making analysis. Journal of Cleaner Production. v. 293. 2021. https://doi.org/10.1016/j.jclepro.2021.126191
47. Zhang, C.; Wang, J.; Liu, J.; LV, Y.; Chen, J.; Yang, Z.; Zhang, N. Performance assessment for the integrated green-gray-blue infrastructure under extreme rainfall scenarios. Frontiers in Ecology and Evolution. v. 11. 2023. https://doi.org/10.3389/fevo.2023.1242492
48. Zhou, K.; Kong, F.; Yin, H.; Destouni, G.; Meadows, M. E.; Andersson, E.; Chen, L.; Chen, B.; Li, Z.; Su, J. Urban flood risk management needs nature-based solutions: a coupled social-ecological system perspective. Urban Sustainability. v. 4, 25. 2024. https://doi.org/10.1038/s42949-024-00162-z