



INFLUENCE OF THE RAINFALL REGIME ON THE HYDROCHEMISTRY OF URBAN LAKES: A STUDY ON THE UFMA CAMPUS USING GLOBE OBSERVER

Researchers

Ana Luiza de Cássia Santos Raymundo¹, Amanda Lilia Santos Leão¹, Rebeca Bezerra Praseres¹, Viviane Florêncio Gonçalves Da Silva¹, Arthur Saminez Franco¹, Gabriel Câmara Cavalcanti¹, Danilo Castro Ribeiro², Grazyelly Kauany², Leite da Luz², Letícia dos Santos Sousa², Luis Fernando Baldy Gomes², João Victor Rodrigues Serra², Mirian Francisca Ribeiro de Aquino², Nicole Vieira Guimarães², Endrelly Rayanne Coelho Moraes².

School/Host Institution

University College – COLUN / UFMA

São Luís, Maranhão, Brazil

Professores / Mentores

Hilton Costa Louzeiro¹, João Paulo Tenório da Silva Santos¹, Núbia Fernanda Marinho Rodrigues¹, Priscila Bernardes Silva¹, Alana Gandra Lima De Moura¹, Harvey Alexander Villa Velez¹, Aline Bessa Veloso³, Geyse Adriana Corrêa Ribeiro¹

ABSTRACT

This study investigated how the rainfall regime influences water composition in two urban lakes located on the UFMA campus in São Luís, Brazil. Between November 2025 and January 2026, students from the Technical Course in Environmental Studies became citizen scientists. Using the GLOBE Observer program protocol, they collected physicochemical data and recorded observations of the water bodies. The results showed that the transition to the rainy season alters water dynamics, but in different ways in each lake. Lagoa Dom exhibited greater stability, while Lagoa do Jambreiro, which is more exposed to the surrounding urban environment, responded with more pronounced changes. In both lakes, rainfall produced two simultaneous effects: a dilution effect, reducing salt concentrations and pH, and a sediment enrichment effect, increasing water turbidity. The study reinforces that the behavior of these ecosystems is seasonal and strongly influenced by their surroundings. In addition, it highlights the importance of continuous monitoring and the potential of citizen science to generate relevant knowledge and promote the preservation of aquatic environments under urban pressure.

Keywords: Hydrochemistry; Urban lakes; GLOBE; Citizen science.

¹ Federal University of Maranhão (UFMA)

² University College – COLUN

³ Brazilian Space Agency (AEB)

INTRODUCTION

The presence of lakes in urban areas often goes unnoticed in daily city life; however, these lentic environments perform important functions: they store water, buffer runoff peaks, support biodiversity, and contribute to spaces for social interaction (Dos Santos Lima & Pamplin, 2023). As highlighted by Esteves (2011), continental aquatic ecosystems play fundamental ecological roles, especially in urban areas, where they help regulate the water cycle and the surrounding environment.

In different cities, studies have shown that water quality in urban lakes varies markedly between dry and rainy periods, with changes in parameters such as dissolved oxygen, nutrients, and physicochemical indicators, depending on surrounding land use and the type of hydrological inputs received (Matos Silva et al., 2021; Fukushima, Kitamura & Matsushita, 2021). Wetzel (2001) states that in tropical lentic systems, the input of rainwater causes abrupt changes in water characteristics, particularly with regard to nutrients and particulate matter.

In many cases, the rainy season is associated with a deterioration in water quality, especially in areas with extensive impervious surfaces and diffuse pollution sources. This occurs because the first flush of rainfall “washes” urban surfaces and transports pollutants into lakes (Zhou et al., 2022; Jia et al., 2021). In addition, intense rainfall events can trigger even more abrupt responses, altering ionic concentrations and variables related to biological production—reinforcing the importance of monitoring programs that take recent rainfall history into account (Fukushima, Kitamura & Matsushita, 2021).

When analyzing transformations in water, rainfall affects urban lakes mainly in two ways. The first is a dilution effect: as rainwater mixes with lake water, it reduces the concentration of salts and other dissolved compounds, leading to lower electrical conductivity. The second is an input effect: rainfall acts as runoff that “washes” streets and surrounding land, carrying pollutants—both dissolved and particulate—into the lake. This transport increases water turbidity and nutrient loads (Zhou et al., 2022; Yang et al., 2021).

Long-term monitoring studies of urban lakes provide clear confirmation that spatial heterogeneity within a single lake and seasonal changes are not anomalies, but rather the standard condition of these ecosystems (Zhou et al., 2022; Yang et al., 2021). This means that, to correctly interpret their behavior, it is essential to integrate three types of information: in-lake water processes, prevailing climatic conditions, and the characteristics of surrounding soils and land use (Li et al., 2025).

Gomes and Ibañez (1994) observed that climatic seasonality exerts strong control over the physicochemical dynamics of urban lagoons, mainly affecting conductivity and dissolved oxygen levels. According to Tundisi and Tundisi (2008), excessive nutrient enrichment in urban aquatic environments is directly associated with the lack of monitoring and inadequate land-use management.

On the campus of the Federal University of Maranhão (UFMA), in São Luís, Lagoa Dom and Lagoa do Jambeiro are examples of lentic environments embedded in an urban and academic matrix. Despite their landscape and ecological relevance, there is still limited accessible documentation about these lakes, making local monitoring particularly valuable for understanding their patterns of variation and supporting management actions. In this context, citizen science initiatives gain strength, as they expand the capacity for environmental observation and data systematization—especially when they follow standardized protocols.

The GLOBE Observer program, linked to the international GLOBE initiative, provides protocols and guidelines for collecting and sharing environmental observations in open-access databases, with the potential to support both scientific investigations and educational activities (GLOBE, 2022; GLOBE Protocols, 2023). By integrating precipitation information (such as accumulated rainfall) with in situ measurements (pH, conductivity, and observational variables), it is possible to more consistently assess how rainfall seasonality relates to the hydrochemistry of urban lakes.

In this context, the guiding research question is: to what extent does seasonal variation in precipitation (accumulated over 24 h and 48 h) influence hydrochemical parameters—especially pH and electrical conductivity—and visual indicators of water quality in Lagoa Dom and Lagoa do Jambeiro on the UFMA campus?

Thus, this study evaluates how accumulated precipitation influences pH, electrical conductivity, and turbidity in these lakes, using citizen science protocols from the GLOBE Observer program to ensure data standardization and reproducibility.

MATERIALS AND METHODS

Study Area

The study area comprises two urban lakes located on the campus of the Federal University of Maranhão (UFMA), in São Luís, Maranhão, Brazil (Figure 1). Lagoa Dom is situated in the central portion of the campus, near academic buildings and circulation areas, at approximate coordinates of latitude -2.560245° and longitude -44.313671°

(GLOBE, 2022). Lagoa do Jambeiro is located in the eastern portion of the campus, close to sports facilities and the adjacent urban boundary, with approximate coordinates of latitude -2.563063° and longitude -44.308135° (GLOBE, 2022).

Both water bodies are embedded within an urban-university context and are subject to the influence of surrounding land use and occupation, as well as the local rainfall regime.



Figure 1 – Location map of Lagoa Dom and Lagoa do Jambeiro on the UFMA campus, São Luís, Maranhão, Brazil.

Source: Prepared by the authors based on GLOBE Observer data.

Sampling Design, Team, and Monitoring Period

Monitoring of Lagoa Dom and Lagoa do Jambeiro was conducted between November 2025 and January 2026, totaling three months of observation. Sampling was carried out at biweekly intervals, allowing the assessment of hydrochemical variations associated with the transition between periods of lower and higher precipitation during the study period (Figure 2).



Figure 2 – Field sampling conducted at Lagoa Dom and Lagoa do Jambreiro within the GLOBE Project.

Source: Prepared by the authors.

Field activities were conducted by students from the Technical Course in Environmental Studies (secondary-level education), who were previously trained by mentors affiliated with the project. Training included guidance on the correct use of instruments, standardization of data recording, and sampling procedures, based on the GLOBE Program Hydrosphere–Water Protocol, aiming to reduce operational variability between sampling campaigns and ensure greater consistency of the dataset (GLOBE, 2022; GLOBE Protocols, 2023).

Analytical Procedures

During each sampling event, in situ measurements were performed and water samples were collected for laboratory analyses. To obtain water at an appropriate point and depth, a manual sampling device was used, allowing sample collection without excessive disturbance of the water surface and reducing interference associated with sampling limited to the surface layer. Water temperature was measured using an infrared thermometer, enabling rapid surface temperature readings—a variable that, according to Wetzel (2001), regulates aquatic biota metabolism. pH was determined using a previously calibrated pH meter, while electrical conductivity was measured with a portable conductivity meter, a parameter related to the concentration of dissolved ions and sensitive to dilution and runoff input processes (Esteves, 2011; Oliveira et al., 2019).

The collected samples were analyzed at the COLUN/UFMA Chemistry Laboratory by the students of the Technical Course in Environmental Studies themselves,

under the close supervision of the project's teachers and mentors, and the results obtained were uploaded to the GLOBE Observer application.

Determinations of dissolved oxygen, ammonia, chlorine, and nitrite were performed using colorimetric methods, employing kits with specific reagents widely used in monitoring routines due to their practicality and rapid results (Gomes & Ibañez, 1994). Turbidity was measured using a turbidimeter, allowing the assessment of the influence of suspended particles and changes in water transparency, especially under the influence of rainfall events (Esteves, 2011). Total solids were determined using the gravimetric method, which consists of complete evaporation of the sample in an oven followed by weighing of the dry residue, enabling quantification of the total load of dissolved and suspended materials.

Alkalinity, which represents the buffering capacity of the aquatic system against pH variations, was determined by acid–base titration. The calculation was based on the volume of acid required to reach the sample's endpoint, according to the formula grounded in the principles described by Tundisi and Tundisi (2008):

$$\text{Alkalinity (mg L}^{-1} \text{ as CaCO}_3\text{)} = \frac{V_{\text{acid}} \times N \times 5000}{V_{\text{sample}}}$$

Onde (*where*):

V_{acid} = volume of acid used in the titration (mL)

N = normality of the acid solution

V_{sample} = volume of the water sample (mL)

These analyses, integrated with records of accumulated precipitation (24 h and 48 h), made it possible to distinguish the stable hydrochemical conditions observed in November from the dynamic changes imposed by December rainfall events, ensuring data integrity in accordance with GLOBE guidelines (GLOBE, 2022).

As a control and standardization measure, field records included observations of water color, odor, presence of algae, and visible debris, as well as date and time information, following the program's datasheets, ensuring traceability and comparability among sampling campaigns (GLOBE, 2023).

DATA AND RESULTS

Lagoa do Jambeiro presented a mean water temperature of 27.4 °C, mean pH of 8.93, mean electrical conductivity of 296.5 $\mu\text{S cm}^{-1}$, and mean turbidity of 31.5 NTU, indicating generally more turbid water and greater variability in the analyzed parameters.

This pattern suggests higher system sensitivity to inputs of particulate matter and dissolved ions, possibly associated with surface runoff and interactions with adjacent urbanized areas—a pattern widely described for tropical urban lentic environments (Esteves, 2011; Oliveira et al., 2019; Zhou et al., 2022).

In turn, Lagoa Dom presented a mean water temperature of 26.8 °C, mean pH of 8.82, mean electrical conductivity of 282.3 $\mu\text{S cm}^{-1}$, and mean turbidity of 31.9 NTU. These values are close to those observed in Lagoa do Jambeiro; however, they are generally slightly lower for temperature, pH, and electrical conductivity. These results indicate a relatively more stable hydrochemical environment, although still subject to seasonal influences of the rainfall regime. According to Wetzel (2001) and Tundisi and Tundisi (2008), small differences between nearby water bodies may be related to morphology, water residence time, and the degree of anthropogenic interference in the immediate surroundings.

Taken together, the findings reinforce that both lakes respond in a similar manner to regional climatic conditions, but that Lagoa do Jambeiro tends to exhibit greater variability and intensity in hydrochemical responses, reflecting differences in land use and occupation and in the processes of input and dilution associated with rainfall.

As shown in Figure 3, the results obtained for turbidity and electrical conductivity indicate that both parameters exhibited seasonal behavior, with marked differences between the period prior to the onset of rainfall and the samples collected during the rainy season.

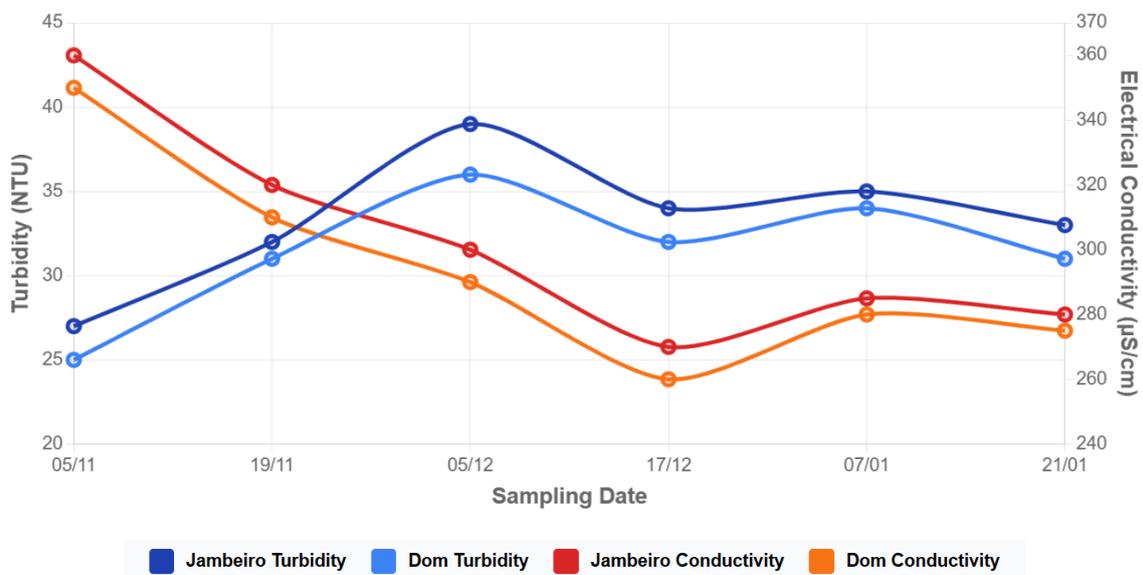


Figure 3 – Temporal variation of turbidity (NTU) and electrical conductivity ($\mu\text{S cm}^{-1}$) in Lagoa Dom and Lagoa do Jambeiro.

Source: Prepared by the authors based on GLOBE Observer data.

Comparatively, Lagoa do Jambeiro presented slightly higher turbidity and electrical conductivity values throughout the entire monitoring period when compared to Lagoa Dom, suggesting greater sensitivity to anthropogenic pressures and contributions from the surrounding urban environment. Nevertheless, the temporal pattern of variation was similar in both systems, reinforcing the regional influence of the rainfall regime as the main controlling factor of the analyzed variables (Table 1).

Table 1 – Mean values of physicochemical parameters and observational summary for Lagoa Dom and Lagoa do Jambeiro.

Period	Rainfall Condition	Turbidity	Electrical Conductivity	pH	Observation
Nov/2025	Dry period (0 mm)	Low (26.4 NTU)	High (360.2 μ S/cm)	Alkaline (9.18)	More stable and clearer water
Dez/2025 - Jan/2026	Rainy period (6–28 mm)	High (34.8 NTU)	Low (266.0 μ S/cm)	Less alkaline (8.48)	Turbid water; simultaneous dilution and runoff input effects

Source: *Authors elaboration based on GLOBE Observer data.*

Records of accumulated precipitation in the 24 h and 48 h preceding the sampling events indicated an increase in rainfall volume beginning in December, characterizing the transition to the rainy season. This pluviometric shift coincided with immediate changes in lake water quality, indicating that precipitation acts as the main driver of externally transported material, as stated by Wetzel (2001) and Esteves (2011).

Turbidity increased during the rainy period in both lakes, accompanied by higher total solids values. This behavior indicates a greater input of suspended particles, likely originating from surface runoff in urbanized areas and from shorelines lacking vegetation cover. This pattern was visually confirmed by field observations of turbid water and brownish coloration recorded on the GLOBE Protocol field datasheets.

Water pH remained close to neutrality throughout the sampling period but showed a decrease during the rainy months. This trend indicates the influence of rainfall and the input of dissolved organic matter, a process commonly observed in tropical urban environments (Tundisi & Tundisi, 2008).

Alkalinity proved to be a particularly informative parameter for interpreting these results, as it showed that despite fluctuations in pH (Figure 3), the systems exhibit buffering capacity associated with the presence of dissolved carbonates and bicarbonates.

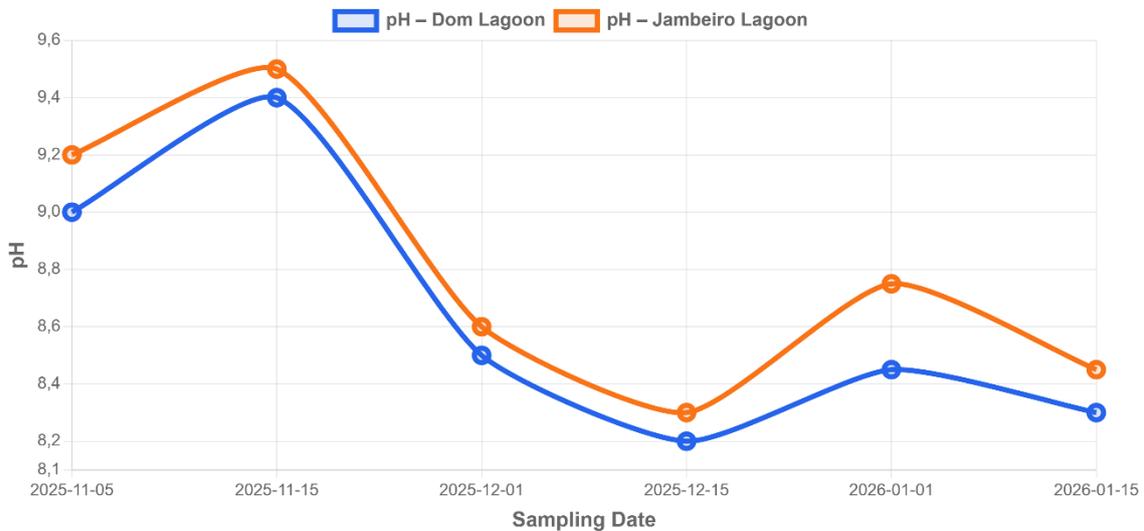


Figure 3 – Temporal variation of pH in Lagoa Dom and Lagoa do Jambreiro. **Source:** Authors elaboration based on monitoring data from the GLOBE Program Water Protocol (2025–2026).

Correlation analysis between pH and accumulated precipitation over 48 h indicated a strong negative correlation for both lakes, reinforcing the direct influence of the rainfall regime on water chemistry, as observed in other urban lakes (Jia et al., 2021; Yang et al., 2021).

Electrical conductivity exhibited marked seasonal variations, with higher values during periods of low precipitation and reductions during intense rainfall events. This behavior indicates the predominance of the dilution effect over ionic input during the analyzed period.

Oliveira et al. (2019) emphasize that in urban environments, conductivity may respond dually to rainfall, depending on the balance between dilution and electrolyte runoff. In the studied lakes, the data suggest that the increase in water volume was sufficient to temporarily reduce the concentration of dissolved ions, especially following rainfall accumulated over 48 h.

The presence of ammonia and nitrite was detected mainly in samples collected after rainfall events, suggesting organic matter input and intensification of decomposition processes. These compounds are sensitive indicators of anthropogenic impact and represent early signals of eutrophication processes (Tundisi & Tundisi, 2008).

Dissolved oxygen showed punctual reductions during the rainy period, consistent with increased biochemical oxygen demand associated with the decomposition of organic material transported into the lakes. Gomes and Ibañez (1994) highlight that this behavior is typical of lentic systems subjected to pulses of organic matter during the rainy season.

DISCUSSION

Analysis of the results shows that Lagoa Dom and Lagoa do Jambreiro respond sensitively and relatively rapidly to variations in the rainfall regime, confirming precipitation as one of the main controlling factors of hydrochemical dynamics in urban lentic environments. Although the mean values of the analyzed parameters indicate similar conditions between the two systems, the differences observed over time reinforce that each lake exhibits distinct behavior, conditioned by surrounding characteristics and the degree of anthropogenic interference.

The transition from the less rainy to the rainy period proved to be a key driver of the reorganization of physical, chemical, and biological processes in the water. As discussed by Wetzel (2001), in tropical systems, the input of rainwater not only alters the chemical composition of the water column but also interferes with mixing processes and the redistribution of particles and nutrients. In the studied lakes, rainfall acted simultaneously as a dilution agent and as a source of external inputs, reflecting a dynamic balance between these two processes.

The increase in turbidity during the rainy period indicates enhanced transport of particles derived from surface runoff, a phenomenon common in urbanized areas with reduced vegetation cover. This behavior is consistent with the findings of Esteves (2011), who highlights turbidity as one of the most sensitive parameters to the input of allochthonous material in lentic environments. Reduced water transparency implies a decrease in the photic zone, which may limit primary production and affect aquatic community structure, especially in shallow systems with high solar radiation incidence, such as those on the UFMA campus.

Electrical conductivity exhibited variations associated with the rainfall regime, suggesting that, during the analyzed period, the dilution effect outweighed the input of dissolved ions. According to Oliveira et al. (2019), this pattern is common in urban environments when precipitation volumes are sufficiently high to temporarily reduce electrolyte concentrations in the water. Nevertheless, the persistence of relatively elevated

values even after rainfall events indicates the continuous presence of diffuse ionic sources associated with land use in the surroundings of the lakes.

Observed fluctuations in pH further reinforce the influence of precipitation and organic matter input on the acid–base balance of the water. The tendency toward pH reduction during the rainy period may be related both to the direct contribution of rainwater and to the release of organic acids resulting from the decomposition of material transported into the system, as discussed by Tundisi and Tundisi (2008). Even so, the presence of sufficient alkalinity to buffer sharper variations indicates that the lakes exhibit a certain buffering capacity, contributing to the chemical stability of the system in response to hydrological pulses.

The detection of nitrogen compounds, especially after rainfall events, suggests intensification of organic matter decomposition processes and reinforces the vulnerability of the lakes to early eutrophication processes. Gomes and Ibañez (1994) emphasize that in urban lentic environments, such nutrient pulses are often associated with punctual reductions in dissolved oxygen due to increased biochemical oxygen demand. This behavior highlights that the observed changes are not isolated, but rather part of an interconnected chain of responses linking precipitation, organic matter input, and aquatic metabolism.

Greater stability observed during periods of lower precipitation indicates longer water residence times, favoring particle sedimentation and the homogenization of hydrochemical characteristics. This pattern has been described in other tropical urban systems, in which the absence of rainfall allows lakes to reach a temporary equilibrium state (Gomes & Ibañez, 1994; Esteves, 2011). In contrast, the rainy period exposes the fragility of the system, particularly in areas with absent or degraded riparian vegetation, which plays a fundamental role in sediment and nutrient retention.

In this context, the use of GLOBE Program protocols proved to be particularly relevant, not only due to methodological standardization but also because they enable the integration of environmental data with citizen science practices. Student participation in monitoring activities contributes to scientific and environmental education while simultaneously generating consistent information for understanding the processes affecting aquatic ecosystems on campus. As noted by Tundisi and Tundisi (2008), continuous monitoring is an essential tool to support management actions and prevent the degradation of urban water bodies.

CONCLUSION

Monitoring of Lagoa Dom and Lagoa do Jambeiro demonstrated that these lentic environments respond rapidly to variations in the rainfall regime, confirming precipitation as one of the main controlling factors of hydrochemical dynamics on the UFMA campus. The transition between less rainy and rainy periods directly influenced water quality, particularly through particulate matter input, dilution of dissolved ions, and changes in the chemical equilibrium of the system. Although the lakes share similar general characteristics, they exhibited distinct responses depending on local conditions, such as surrounding land use and the degree of anthropogenic interference, reinforcing the need for site-specific analyses even within closely located areas. The application of GLOBE Program protocols proved effective in generating consistent data and highlighted the potential of citizen science as a tool for environmental monitoring and scientific education.

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DESCRIPTION OF BADGES

This project qualifies for the “I Am a GLOBE Researcher” badge because it was carried out following the official GLOBE Program protocols. Students collected, analyzed, and submitted data through the GLOBE Observer platform, actively participating in all stages of monitoring the lakes on the UFMA campus.

It also meets the criteria for the “I Am a Data Scientist” badge, as the project involved organizing and analyzing field measurements (pH, electrical conductivity, turbidity, nutrients, and dissolved oxygen) together with rainfall accumulated over 24 h and 48 h. The results were compared over time to identify seasonal patterns, correlations, and the effects of dilution and external inputs.

In addition, the study qualifies for the “I Am an Earth System Scientist” badge by demonstrating how the atmosphere (rainfall) is connected to the hydrosphere (lakes) and to the terrestrial/biological environment (runoff, organic matter, and sediments), revealing interdependent processes that control water quality.

Finally, the project meets the criteria for the “I Cause Impact” badge because it originates from a local environmental issue and generates useful information for management and conservation. The results show how rainfall events rapidly alter turbidity, pH, electrical conductivity, and nutrient levels, helping to guide stewardship actions and continuous monitoring of these urban lakes.