Analysis of rainfall in Pinheiro, Maranhão, Brazil: comparison between official data and measurements with a conventional rain gauge

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Abstract

Rainfall is a climatic variable that plays a key role in understanding hydrological and environmental processes at the global scale. The analysis of historical precipitation time series is essential for identifying climate patterns, assessing the occurrence of extreme events, and supporting territorial planning and water resources management. The use of consistent observational and in situ data is indispensable for understanding climate dynamics and for validating predictive models. However, in Brazil, the low density of official meteorological stations limits the adequate representation of spatial and temporal precipitation variability. Therefore, this study analyzed precipitation variability in the municipality of Pinheiro, Maranhão, by comparing data obtained from a conventional rain gauge with records from automatic stations. Data were collected using an Incoterm 150 mm rain gauge installed at the Federal University of Maranhão, Pinheiro Campus. These data were compared with records from automatic stations operated by the National Water and Basic Sanitation Agency (ANA) to generate precipitation time series for the period from January to August 2025, following the protocols of the GLOBE Program. The results showed high daily precipitation variability, with an approximate mean of 9.1 mm day⁻¹, characterized by dry days interspersed with high-intensity rainfall events. The results also indicated greater agreement between the conventional rain gauge and the automatic stations.

Keywords: Rainfall measurement; Climate monitoring; Citizen science; Climate variability

Research Question

Hypothesis: The conventional rain gauge, when properly installed and operated according to standardized protocols, produces reliable data that are comparable to records from automatic stations. It is further assumed that agreement between the datasets is higher when stations are located under similar microclimatic conditions, making local monitoring an effective complementary tool for analyzing regional precipitation variability.

Considering the high variability of precipitation in the municipality of Pinheiro, Maranhão, and the limited coverage of official weather stations at the local level, this study aimed to investigate the reliability and applicability of different rainfall data sources for local climate monitoring. Accordingly, the study addresses the following research questions:

Question: How do precipitation data obtained from a conventional rain gauge compare with records from the automatic stations operated by the National Water and Basic Sanitation Agency (ANA)?

How does the daily and seasonal variability of precipitation manifest in the municipality of Pinheiro, Maranhão?

To what extent can local rainfall monitoring complement official climate observation networks?

Introduction

Content Knowledge

The climate exhibits natural variability in time and space and is influenced by physical, biological, and anthropogenic factors, as well as by interactions among them. The analysis of historical climate time series allows the identification of trends and patterns that contribute to understanding regional climate dynamics and assessing risks associated with extreme events. According to Hersbach et al. (2020)

Rainfall is a fundamental atmospheric variable for climate and environmental studies, as it directly influences natural processes and human activities. Its variability, both at local and regional scales, reinforces the need for continuous monitoring, especially in areas subject to impacts resulting from excess or scarcity of rainfall (Anjos et al., 2020). Long-term studies, such as flood simulations and hydraulic infrastructure design, depend on reliable historical precipitation series (Mateus, 2006; Paz, 2010).

The use of conventional rain gauges is a viable alternative for collecting rainfall data at the local scale, especially in contexts where the official monitoring network is limited. In addition to providing relevant data, participatory monitoring contributes to scientific training, community awareness, and the strengthening of citizen science, broadening the understanding of the local climate and supporting public adaptation and mitigation policies. In this sense, the present study aims to statistically analyze precipitation in the municipality of Pinheiro, Maranhão, by comparing official data with measurements obtained from conventional rain gauges, in order to deepen the understanding of local climate variability.

Research Methods

Planning Investigations

Study area

The study area is located in the municipality of Pinheiro (Figure 1), within the Baixada Maranhense microregion, and is characterized by climatic conditions typical of tropical regions, with a hot and humid tropical climate classified as Aw according to the Köppen–Geiger system (Lima et al., 2024). This climatic pattern, predominant in the state of Maranhão, is characterized by high temperatures throughout the year and pronounced rainfall seasonality, with the highest precipitation occurring in the first months of the year and a reduction in rainfall during the second half of the year.

Figure #1

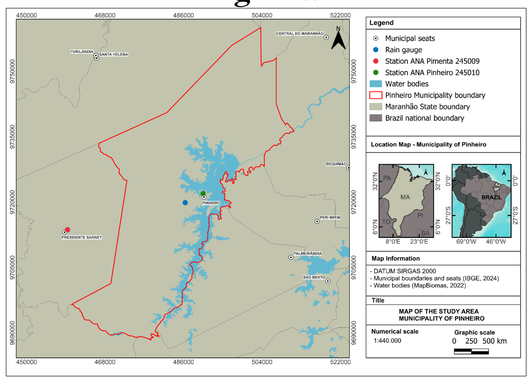
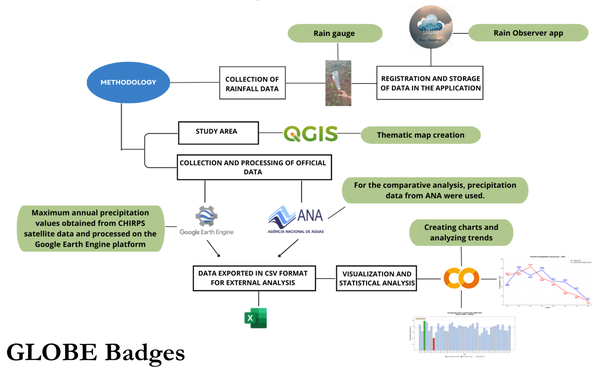


Figure #2

Methodological workflow of the study.



GLOBE Badges

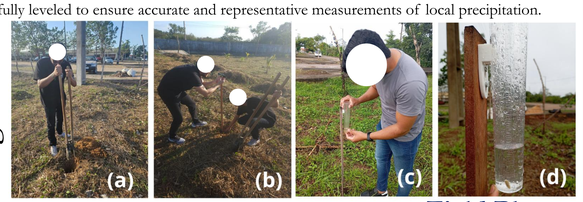
Be a **Collaborator:** The research was developed with the participation of undergraduate students from the Federal University of Maranhão, who collaborated in local rainfall monitoring, data organization, and comparative analysis between different sources of climate information. The application of standardized GLOBE Atmosphere protocols allowed the collection of consistent records at the local scale, highlighting the potential of participatory monitoring as a complement to official observation networks. In addition to contributing to the understanding of the spatiotemporal variability of precipitation in the municipality of Pinheiro, the initiative strengthened scientific collaboration and demonstrated the relevance of citizen science as a tool to support environmental planning and water resource management in the region.

Be a **Data Scientist:** The project involved the collection and organization of rainfall data in the municipality of Pinheiro, Maranhão, obtained through daily field measurements using a rain gauge, following standardized observation procedures. These records enabled the construction of a structured database on precipitation variability in the study area. The data were analyzed to identify temporal rainfall patterns in the region, allowing the interpretation of the local rainfall regime. Considering the limitations of the collection period and the spatial scale of the measurements, the study demonstrated the systematic application of environmental monitoring methods to understand Earth system phenomena at the local scale.

Be an **impact maker:** The project arose from the need to understand precipitation variability in the municipality of Pinheiro, Maranhão, given the scarcity of systematic rainfall data at the local scale. This context highlighted the importance of continuous rainfall monitoring, establishing links between a specific territorial demand and broader challenges related to climate monitoring, water resource management, and the occurrence of extreme events. The initiative contributed to strengthening environmental monitoring by demonstrating that locally collected rainfall data, obtained in a systematic and standardized manner, can be organized into a structured and reliable database that complements official datasets. In addition to expanding the availability of climate information for the municipality, the results provide support for territorial planning and water management, while promoting student engagement in citizen science practices and strengthening scientific and socio-environmental education, with impacts at local and regional scales.

Based on these protocols, precipitation monitoring was conducted from January to August using a conventional rain gauge (Incoterm, 150 mm model) installed at the Federal University of Maranhão, Pinheiro Campus (Figure 3). The instrument was positioned 1.5 m above the ground, with the orifice located 5 cm above the mounting rod and approximately 50 cm from the buried support structure, ensuring greater stability. The installation site was selected to minimize interference from wind and physical obstacles, and the instrument was carefully leveled to ensure accurate and representative measurements of local precipitation.

Figure #3



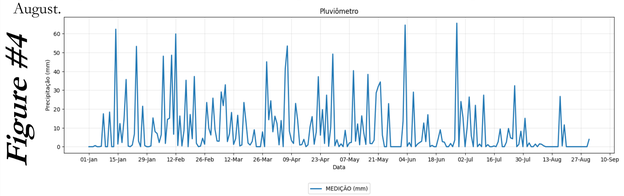
Field Photos

Results

Analyzing Data

The graph of average daily precipitation recorded by the Incoterm rain gauge (Figure 4) shows marked variability in rainfall values over the analyzed period, with an approximate mean of 9.1 mm day⁻¹. This pattern indicates the predominance of numerous days without rainfall or with negligible precipitation, interspersed with a few rainfall events. The highest accumulations occurred between January and April, a period corresponding to the regional rainfall peak and accounting for a substantial portion of the annual total. In May and June, rainfall was still observed, although with reduced frequency and intensity. From July onward, a decline in precipitation was observed, with a predominance of dry days, particularly in July and August.

Figure #4



The monthly comparative analysis between the conventional rain gauge and the ANA Pimenta Automatic Station (Figure 5) throughout 2025 revealed marked differences in precipitation records, with a variation in the pattern over the year. In the first months (January to March), the automatic station consistently recorded higher volumes, with March showing the greatest discrepancy between the instruments. From April onward, this behavior was reversed, with the rain gauge recording higher values, especially in June and July, when the differences were most pronounced. This seasonal pattern of discrepancies suggests the combined influence of climatic factors, instrumental limitations, methodological differences in measurement, and the spatial separation between the monitoring points, affecting the records differently throughout the annual hydrological cycle.

Figure #5

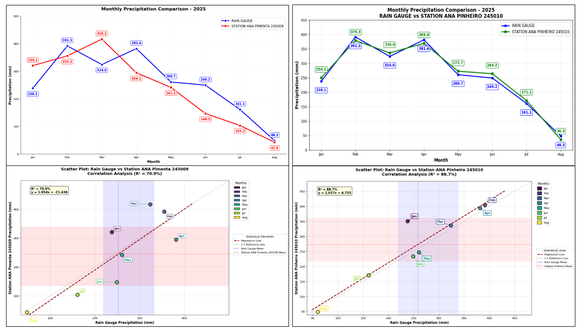


Figure #6

The comparison between the records from the conventional rain gauge and the ANA Pinheiro Automatic Station (Figure 6) shows high agreement throughout the analyzed period. Both datasets consistently reproduce the seasonal pattern of precipitation in the region, with higher volumes concentrated in the rainiest months and a progressive reduction in the subsequent months. The observed monthly differences remain relatively low and homogeneous, with no significant discrepancies in specific months. This similarity suggests that the rain gauge and the ANA Pinheiro Station are influenced by similar microclimatic conditions, due to the short distance between the monitoring sites

Discussion

Interpreting Data

The variation in average daily precipitation observed in Figure 5 is consistent with the typical behavior of humid tropical regions, where short-duration, high-intensity rainfall events predominate. According to the World Meteorological Organization, daily precipitation shows strong spatial and temporal heterogeneity, even in geographically close areas, which limits the representativeness of point measurements and requires caution in interpreting this type of data (WMO, 2022). Thus, the pattern identified in this study reflects the intermittent nature of rainfall, without indicating anomalies in the local rainfall regime. As highlighted by the Intergovernmental Panel on Climate Change (IPCC), annual fluctuations in total precipitation are associated with natural climate variability, resulting from the interaction between large-scale atmospheric and oceanic systems (IPCC, 2021). Thus, the analysis of extensive historical series is essential for a correct understanding of regional climate behavior and to avoid interpretations based on short periods.

The differences identified in the comparison between local rain gauge data and ANA Pimenta station data, as illustrated in Figure 4, can be explained by the high spatial variability of precipitation, especially in environments dominated by convective rainfall. Studies show that the correlation between rainfall records decreases significantly with increasing distance between stations, even at small spatial scales, reflecting the highly localized nature of rainfall events (Ochoa-Rodríguez et al., 2015). In this sense, occasional discrepancies between series do not necessarily indicate inconsistencies in the data, but rather the influence of spatial and environmental factors. In contrast, the greater agreement observed between the local rain gauge and ANA Pinheiro station records, shown in Figure 6, highlights the importance of spatial proximity and similarity of physiographic conditions for the consistency of rainfall measurements. According to technical guidelines from the National Water and Basic Sanitation Agency, stations located in similar environmental contexts tend to show greater consistency in the totals recorded, especially when operated under standardized observation protocols (ANA, 2020). This result reinforces the reliability of local monitoring as a complement to official hydrometeorological observation networks.

Conclusions

The implementation of the GLOBE protocols for rainfall monitoring in Pinheiro, Maranhão, proved to be a viable tool for producing local precipitation data. The results revealed the spatiotemporal variability characteristic of the Baixada Maranhense region, with rainfall concentrated in intense events between January and April and significant interannual variation.

The comparison between the conventional rain gauge and the ANA automatic stations revealed different levels of agreement, with the highest agreement observed for the Pinheiro 245010 station. This suggests that factors such as geographical proximity and similar microclimatic conditions are decisive for data consistency, reinforcing the importance of methodological standardization.

This initiative validated citizen science as an essential complement to official monitoring networks, especially in regions with limited coverage. In addition to generating relevant data for water planning and climate risk management, the program promoted environmental education and community engagement. Therefore, the integration of participatory methodologies such as GLOBE with official and remote sensing data represents an effective strategy for improving the understanding of regional climate variability and supporting public adaptation policies in the Amazon region of Maranhão.

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