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BOLETIM DE CONJUNTURA

BOCA

Ano VI | Volume 18 | Nº 54 | Boa Vista | 2024

http://www.ioles.com.br/boca

ISSN: 2675-1488

https://doi.org/10.5281/zenodo.12589547

BOLETIM DE CONJUNTURA

www.ioles.com.br/boca

EVALUATION OF URBAN DRAINAGE SYSTEMS AND FLOOD IMPACTS IN THE CITY OF GOIÂNIA (GO), BRAZIL

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Abstract

This study addresses the challenges and solutions for urban drainage and flood systems in Goiânia, focusing on the critical importance of effective urban planning and the implementation of sustainable management strategies. Using descriptive, documentary and case study methods, the research identifies a direct relationship between inadequate maintenance of drainage systems and the city's growing vulnerability to extreme weather events, which lead to frequent flooding, especially in densely populated areas. The results highlight the need for innovation and sustainable practices to strengthen urban resilience, suggesting the integration of compensatory techniques and the formulation of effective public policies. Significant contributions are made to understanding the socioeconomic and environmental impacts of floods, offering valuable guidance for future planning and the transformation of Goiânia into becoming a reference for sustainable water management.

Keywords: Flooding; Sustainable Management; Urban Drainage; Urban Planning; Urban Resilience.

Resumo

Este estudo aborda os desafios e soluções para sistemas de drenagem urbana e inundações em Goiânia, enfocando a importância crítica de um planejamento urbano eficaz e da implementação de estratégias de gestão sustentável. Utilizando métodos descritivos, documentais e de estudo de caso, a pesquisa identifica uma relação direta entre a manutenção inadequada dos sistemas de drenagem e a crescente vulnerabilidade da cidade a eventos climáticos extremos, levando a inundações frequentes, especialmente em áreas densamente povoadas. Os resultados destacam a necessidade de inovações e práticas sustentáveis para fortalecer a resiliência urbana, sugerindo a integração de técnicas compensatórias e a formulação de políticas públicas eficazes. Contribuições significativas são feitas para a compreensão dos impactos socioeconômicos e ambientais das enchentes, oferecendo orientações valiosas para o planejamento futuro e para a transformação de Goiânia em referência para a gestão sustentável da água.

Palavras-chave: Drenagem Urbana; Gestão Sustentável; Inundações; Planejamento Urbano; Resiliência Urbana.

INTRODUCTION

Goiânia is one of the epicenters of the Brazilian Midwest. Accelerated population growth and continuous territorial expansion have shaped the capital, transforming it into a scenario full of challenges, characteristic of the urbanization process. This reality underlines the need to understand and address the intricate interactions between natural and anthropogenic factors in the management of the situations arising from rainfall events in the developing city.

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It is important to highlight that the maintenance of the elements composing the urban drainage systems in Goiânia is deficient. This lack of maintenance compromises the effectiveness of drainage systems, negatively affecting urban resilience in the face of extreme weather events. Drainage system failures are crucial urban challenges, and it is essential to distinguish flooding from overflowing and inundation. Goiânia faces the challenges arising from accelerated urbanization, with frequent flooding resulting from the combination of soil sealing and inadequate drainage systems.

Faced with this reality, professionals and managers are recognizing the need for sustainable solutions and one of the hypotheses is the adoption of compensatory techniques, which effectively mitigate local impacts, harmonizing urbanization and the environment. Silveira (2018, p. 72) emphasizes that urban drainage is essential to ensure the comfort and safety of the population from occurrences of intense rainfall, avoiding inconveniences for pedestrians, drivers and residents.

In Goiânia, despite the monitoring by the Municipal Coordination of Protection and Civil Defense indicating multiple flooding points, a gap persists in policies and investments for effective drainage infrastructure. While other global cities strengthen resilience to climate and urban challenges, Goiânia seeks to align the diagnosis of critical points with pragmatic infrastructure strategies. This complex cycle has contributed to the intensification of the challenges associated with flooding, highlighting the urgent need for a comprehensive and integrated approach in the management of these issues.

Research on drainage in Goiânia is vital, since flooding brings economic consequences, degrades infrastructure and impacts on residents. With projections of climate change, robust drainage systems have become essential. Goiânia, as a reference in Goiás, has the potential to be a model for other cities.

Based on the panorama presented above, the objective was to understand the vulnerabilities of the existing infrastructure along the main flood points registered and monitored by the Municipal Coordination of Protection and Civil Defense, which are part of the drainage system of the municipality of Goiânia. The methodology involved data collection that supported the analysis.

This study offers *insights into* territorial planning, seeking harmony between urbanization, the environment and citizens, and guides policies and investments for a metropolis more structured in water discipline, thereby reducing negative impacts.

The structure of the article is composed of an introduction, which exposes the theme, topic, problem, hypothesis, and objective. The literature review is where the search for authors on the subject is deepened. The methodology with the research procedures. The results and discussion from an analysis of the data obtained. Finally, the conclusion and references.

LITERATURE REVIEW

This literature review segment focuses on the city of Goiânia, deeply exploring its infrastructure's weaknesses, especially in critical flood sites monitored by the Municipal Coordination of Protection and Civil Defense.

Integrating these areas into the city's urban drainage system, the article investigates how academic research can direct urban planning, focusing on drainage systems and the impacts of floods. In addition, the concepts of urban drainage, floods and inundations are discussed in detail, based on international academic literature.

This approach not only broadens the local understanding of these critical phenomena but also incorporates global perspectives that can enhance the strategies and preventive measures adopted in Goiânia, aiming to transform the city into a more resilient and safe space.

GOIÂNIA: RAINWATER LIST

Goiânia, the capital of the state of Goiás, faces significant challenges in stormwater management due to accelerated urbanization and inadequate planning. Disorderly urban sprawl and high soil sealing aggravate flooding, negatively affecting infrastructure and quality of life. Urban planning instruments of the Master Plan, such as Areas of Special Programs of Social Interest, seek to mitigate these problems, but the uncontrolled creation of new subdivisions continues to drive away poorer populations (VALLE JÚNIOR; PASQUALETTO, 2014).

Stormwater management in Goiânia requires an integrated approach, considering environmental and socioeconomic issues. The city has geographical characteristics that influence drainage and flood control. Sustainable practices, such as permeable pavements and green areas, can minimize the impact of heavy rains. The soil occupation analysis reveals problems such as the suppression of PPAs and insufficient drainage, affecting environmental processes. Adequate public policies and conservation of preservation areas are essential to reduce risks of urban erosion (SANTOS; SANTOS, 2018).

Founded in the 1930s, Goiânia faced rapid urban expansion, especially in the Southwest Region, where the Ribeirão Anicuns Basin is of significance. The Master Plan is crucial for spatial planning, but disorderly urbanization impacts stormwater management. In the Ribeirão Anicuns Basin, policies and practices to mitigate flooding are analyzed, aiming for a harmonious coexistence with the rainfall regime (DUARTE, 2024).

SUSTAINABLE URBAN DRAINS

Sustainable urban drainage systems go beyond water quantity control, integrating aspects such as runoff quality, visual convenience, recreational value and ecological protection. Unlike conventional drainage, which uses point and decentralized solutions, these systems mitigate diffuse pollution in urban areas, promoting a more holistic and sustainable approach to stormwater management.

Sustainable drainage is a multidisciplinary approach that requires the collaboration of experts from different areas for its effective development. This system aims not only to avoid flooding and inundation problems but also to bring environmental and social benefits, becoming an effective tool for water management in urban areas (POCHODYŁA *et al*., 2021).

Increasingly frequent extreme rainfall events test the capacity of urban drainage systems. Obsolete and poorly maintained networks can lead to flooding, urban flooding and environmental pollution. During the rains, the runoff is complex, and conditioned by the urban configuration and the drainage network. Understanding and simulating these flows are essential to assess flood risk and propose actions to mitigate against them (CEA; COSTABILE, 2022).

The management of a Sustainable Urban Drainage System (SUD) requires extensive knowledge about precipitation regime, hydrological and hydraulic characteristics, as well as the use of water by the population. Modern systems integrate ecological and social aspects, promoting solutions that mitigate against the risks and improve urban resilience. Effective development and implementation of SUDs are essential to address climate change challenges and promote sustainability (CEA; COSTABILE, 2022).

Carvalho *et al*. (2024) discuss strategies to regenerate decaying urban areas, proposing advanced urban drainage systems that help flood management and promote economic and cultural revitalization. Applying these ideas in Goiânia, flood-prone areas could be transformed into revitalized zones, improving the quality of urban life. Sustainable Drainage Systems (SuDS) are essential for this implementation, restoring soil permeability and promoting circular resource management, with multiple ecological and social benefits.

To address urban flooding and inundation, it is crucial to assess how much water can be managed within the system, considering seepage, soil storage, and transport through drainage systems. The absence of hybrid urban sanitation policies that integrate technical and socioeconomic aspects is a significant challenge (PAPPALARDO; LA ROSA, 2020). These policies are essential to creating more effective and resilient drainage systems, promoting holistic and sustainable stormwater management in urban areas.

Anacleto and Silva (2023) address public policy challenges in rural contexts, but their insights into legislative barriers apply to urban flood management in Goiânia. Recognizing these barriers, the city can adapt its policies to overcome local disparities and improve urban resilience. Although the studies do not focus directly on Goiânia, their methodologies offer a valuable basis for refining urban planning strategies, ensuring comprehensive approaches that are appropriate to the specific needs of the city (ANACLETO; SILVA, 2023).

HYDROLOGICAL IMPACTS

One of the main environmental problems in Brazilian cities is the occurrence of floods, which take on a hydrological risk character in underdeveloped countries. Flooding and inundation are natural events that occur periodically in watercourses, often resulting from intense and rapid or long-lasting rains. These hydrometeorological events significantly affect urban infrastructure and community life, requiring effective management and mitigation strategies.

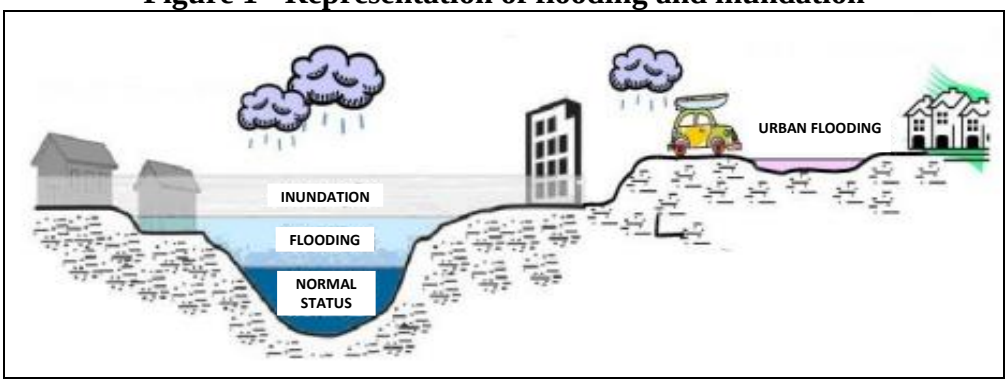
Urbanization significantly threatens natural hydrology, transforming permeable surfaces into impermeable ones, which prevents rain infiltration and increases runoff. In urban areas, storage in soils and depressions is limited, reducing surface runoff attenuation. Natural drainage is replaced by artificial systems that capture and accelerate the transport of runoff from developed areas, exacerbating the risk of flooding (MILLER *et al*., 2023).

Freshwater, vital for living beings, is becoming scarce due to consumption habits and human interference with ecosystems. Sustainable management practices are essential to mitigate the hydrological impacts of changes in land use and land cover on the water balance of river basins. The effectiveness of these practices, however, varies from case to case, highlighting the need for customized approaches for each scenario (KACHHOLZ; TRANCKNER, 2021).

Funasa (2015) defines these terms as:

> **Flood:** "represents the phenomenon of increased flows with the overflow of a drainage channel".
>
> **Flooding**: "represents the overflow of the flood phenomenon. Therefore, a flood may or may not cause flooding; however, it is commonly observed that these terms are used synonymously".
>
> **Inundation:** "accumulation of water in the streets and urban perimeters due to drainage problems".

Figure 1 - Representation of flooding and inundation



Source: FUNASA (2015).

Flooding

The modern trend of urbanization has transformed landscapes, creating cities that face increased risk of flooding due to climate change. Factors such as rapid urbanization, altered land use patterns, and insufficient stormwater management infrastructure complicate the connection between climate change and urban flooding. Non-absorbent surfaces and inadequate drainage systems increase the risk of flooding, which has caused loss of life and economic damage in several urban areas, including Goiânia (DHARMARATHNE *et al*., 2024).

According to the Brazilian Classification and Codification of Disasters (COBRADE), flooding is the extrapolation of the runoff capacity of urban drainage systems, resulting in the accumulation of water in low areas, such as streets and sidewalks, due to intense rainfall. This phenomenon is directly related to urbanization, which promotes the channelling of rivers and overloads the galleries with surface runoff. The Southeast, Northeast and South regions of Brazil are the most affected by these events (COBRADE, 2012).

Based on the study by Oliveira (2022), this topic addresses the importance of an efficient drainage system for Goiânia, highlighting the challenges brought by urbanization and soil sealing. The high density of housing and the extensive waterproofed area exacerbate flooding in Goiânia. Evaluating the waterproofed area coefficient (AI), it is proposed to adapt drainage strategies to minimize the environmental, economic and social impacts of rainfall, using international practices as a reference to improve urban resilience and stormwater management in the city.

The study by Rego and Barros (2014) analyzes the effects of climate change on precipitation, offering relevant insights on how these phenomena can influence the frequency and intensity of floods in Goiânia. Although it does not focus specifically on this city, the methodology and conclusions can be

applied to the local context, assisting in the identification of vulnerable areas and the formulation of mitigation strategies.

A study by Soares (2021) on this topic discusses the relationship between the densification and verticalization of Goiânia, especially in Jardim Goiás, and the increase in occurrences of flooding and inundation. The analysis suggests that soil sealing, resulting from accelerated urban development, exacerbates drainage problems. It is important to adopt and reinforce urban planning policies, such as the master drainage plan and laws that promote sustainability, to mitigate the impacts of floods, aligning Goiânia with international rainwater management standards and sustainable urbanism.

Urban Flooding

According to the Brazilian Classification and Coding of Disasters (COBRADE), flooding is the submergence of areas outside the normal limits of a watercourse in areas that are not normally submerged. Overflow occurs gradually, usually caused by prolonged rains in the river basin. Historical data from the Brazilian Atlas of Natural Disasters show that the Southeast, Northeast and Southern macro-regions of Brazil are the most affected by floods, especially in lowland areas, where surface runoff is insufficient to absorb large volumes of water (COBRADE, 2012).

Urban flooding causes major disruptions, significantly affecting people, the economy and the environment. These impacts are exacerbated by climate and socioeconomic change. Resilience has become essential for urban managers in dealing with these risks. Flood-resilient cities are less affected by extreme events, so professionals must understand these impacts to build more prepared cities.

In urban areas, with limited infiltration, heavy rainfall can cause rapid water rises. Urbanization and severe weather events increase the frequency and intensity of flooding, resulting in mortality, injuries, and structural damage (AGONAFIR *et al*., 2023).

The growing risk of urban flooding confronts managers with new challenges for prevention and hinders the sustainable development of urban ecosystems. Incorporating the future impacts of climate change into flood risk assessment and management is crucial. Flood risk assessment is essential for sustainable management, especially with the intensification of climate effects.

The lack of quantitative records on the occurrence and magnitude of urban flooding, in response to extreme precipitation events, is a challenge. Assessing future trends in probabilistic flood risk can improve the estimation of risk around uncertainty produced because of climate change. Probabilistic flood risk was quantified based on surface runoff risk thresholds and analysed under historical conditions and climatic scenarios (ROSENZWEIG *et al*., 2018).

Urban Floods

Urbanization and population growth require investments in infrastructure to ensure quality housing, sanitation and rainwater drainage. Cities with extensive impermeable areas, such as asphalt and concrete, make it difficult for water to seep into the ground, aggravating flooding and inundation. The lack of social urban planning is evident in large cities, where disorderly urbanization irreversibly alters the landscape and ecosystem. Modern solutions aim to slow flows and reduce maximum flows, using retention and detention basins to mitigate floods (MARECO; TERENZI, 2024).

Urban floods have been exacerbated by extreme rainfall and river flooding challenges, cities' flood control systems and drainage capacity. When these events occur simultaneously, the high level of river waters can severely compromise drainage, increasing the risk of overflow and threatening urban security. Research on urban floods, control and protection has been intense, seeking effective solutions to mitigate these risks (CHEN *et al*., 2023).

Impacts on the environmental resources of urban watersheds, such as deforestation of slopes, occupation of soils subject to flooding and increased waterproofing, significantly alter hydrological phenomena, aggravating the formation of floods. These events can be considered some of the most impactful consequences of the dynamics of natural systems on the earth's surface. Interdisciplinary approaches are essential in understanding and preventing or reducing these phenomena, promoting more sustainable and resilient urban management (WOLLMANN, 2015).

METHODOLOGY

This study adopts an analytical-descriptive methodological approach to evaluate urban drainage systems and the impacts of floods in the city of Goiânia. It is structured in three interconnected phases, which include characterization of the target area, bibliographic and legal research, as well as field research.

Through the design of the proposed methodology, we sought to analyse the steps of the methodological proposition. Thus, Phase 1 - characterization of the target area we make the location of the study area, Goiânia, GO. In Phase 2 – we present the definition of bibliographic and legal research metrics. In Phase 3 – field research, with (Step 01 - Precipitation Data Collection), then (Step 02 - Flood Data Collection) and (Step 03 - Flood Mapping).

The present study on urban drainage systems and the impacts of flooding in Goiânia followed a rigorous methodology, structured in three interconnected phases. Initially, a detailed characterization of the study area was carried out, using secondary data collected from IBGE and SEMAD to map the administrative regions of the city and its drainage infrastructures. Then, a comprehensive bibliographic and legal research was conducted, analysing relevant studies and technical documents provided by COMPDEC. This phase was fundamental in understanding the history and frequency of flooding events in Goiânia, based on secondary data collected from various academic and institutional sources.

The field research complemented these steps with the collection of primary data on rainfall and flooding, carried out at different periods of the year to capture seasonal variability. These primary data were obtained through direct measurements and historical records from the Center for Meteorological and Hydrological Information of the State of Goiás (CIMEHGO). Primary data collection involved technical visits and on-site measurements to ensure the accuracy and relevance of the information.

The collected data, both primary and secondary, were analysed quantitatively, using descriptive statistics and geoprocessing tools (ArcGIS) to map the most affected areas. Correlation analysis helped to identify significant patterns between rainfall data and flooding events, while a comparative analysis allowed us to evaluate the effectiveness of Goiânia's drainage systems concerning international best practices.

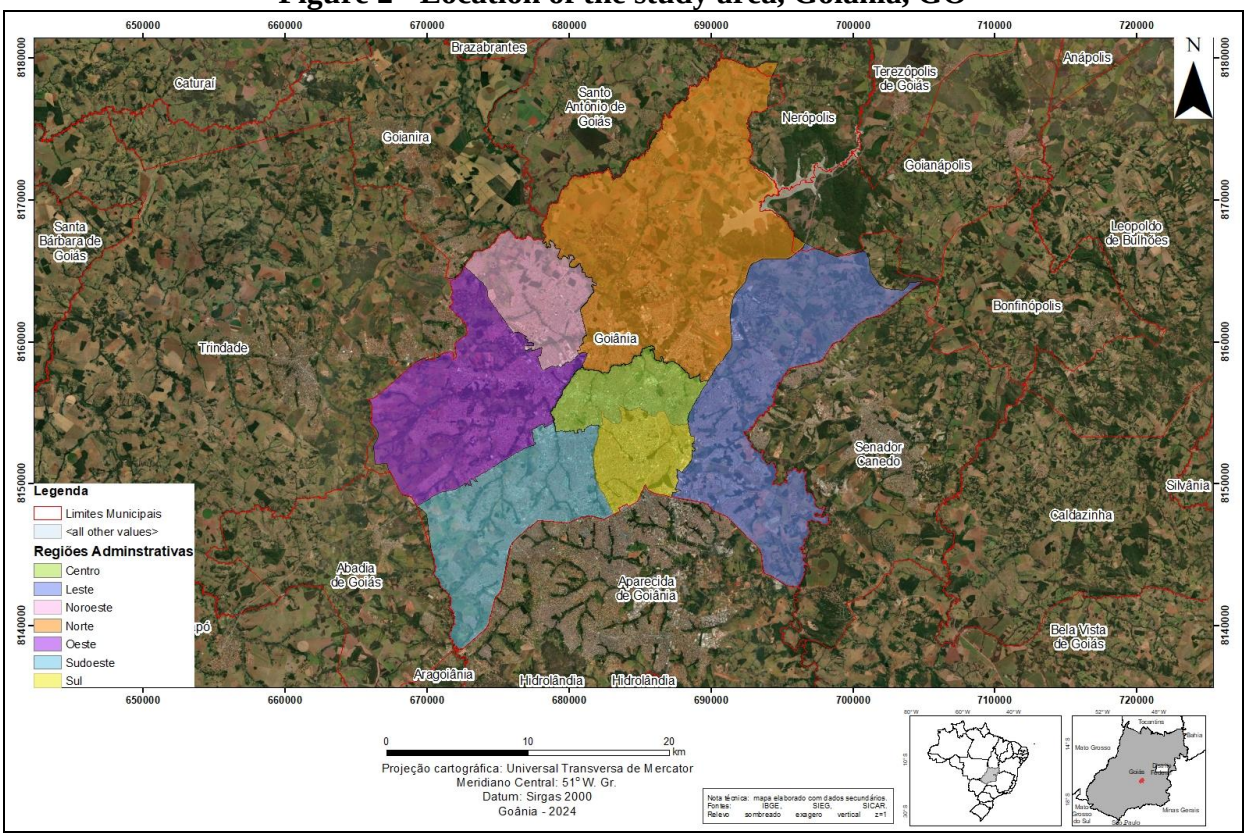
Characterizations of the Target Area

This initial phase focuses on detailing the study site, with an emphasis on Goiânia. It explores administrative regions, discusses the relevance of these areas in local and broader contexts and addresses challenges related to irregular occupations and urban planning issues.

Goiânia, the capital of Goiás, initially a planned city, is located in the middle course of the Meia Ponte river basin, integrating the Goiano Center. With an area of approximately 729.296 km², the city is segmented into seven administrative regions (Figure 2).

It has a population of 1,437,237 residents, according to IBGE (2022). In its geographical contours, Goiânia is limited to the north with the municipalities of Goianira, Nerópolis and Goianápolis, to the south with Aparecida de Goiânia and to the east, it extends to Senador Canedo and Bela Vista de Goiás and to the west with the municipality of Trindade.

Figure 2 - Location of the study area, Goiânia, GO



Source: Self elaboration.

Bibliographic and Legal Research

Conducted extensively on Urban Drainage Systems and Flooding Impacts, this phase includes a detailed analysis of current technologies in the field, employing a critical reading of academic literature. The research was enriched through consultations with specialized databases included in Google Scholar, significantly expanding the scope and diversity of the academic sources used.

In this study, a historical and descriptive approach was adopted, based on bibliographic and legal research methods. The bibliographic research was carried out from indexed scientific articles, which bring a theoretical and contextual overview to the subject. As such Reis *et al.* (2020), carried out an analysis of academic publications and technical literature, detailing the instruments conventionally adopted in water management.

Within the scope of this research, the principles, systems, devices and regulations that guide the drainage and management of rainwater were surveyed. This examination was based on specialized literature, with a bibliographic review based on scientific articles in addition to data and information collected from IBGE, SNIS and ABNT standards (ABNT, 2015). Following Parra and Teixeira (2020),

to contextualize the study, the typical organizational structure of the municipalities related to rainwater management was outlined.

In parallel, legal research was carried out, which made it possible to go deeper with the data, these being official documents and records from the Municipal Coordination of Civil Defense and Protection – COMPDEC, made available by the government.

Field Surveys

The field research, central to this study, covered the entire perimeter of the administrative regions of Goiânia and was carried out in three stages: rainfall data collection, flooding occurrences and mapping of these areas. Daily rainfall data were collected from INMET's rainfall station, covering thirteen years (2010-2023), focusing on extreme rainfall and validating data quality. Historical records from the Municipal Coordination of Protection and Civil Defense provided information on floods, while the use of ArcGIS allowed the mapping of and spatial analyses of the affected areas, identifying crucial patterns for public policies.

For the selection of data collection sites, we adopted specific criteria: administrative segmentation, flooding history and geographical distribution. The seven administrative regions of Goiânia were considered to ensure full representativeness of the urban conditions. Data collection was continuous and systematic, with daily rainfall data and flood records, allowing a detailed analysis of weather patterns and their consequences. The combination of qualitative and quantitative approaches enabled an in-depth understanding of the interactions between urban planning and stormwater management, crucial to mitigating the adverse effects of floods.

First Stage - Rainfall

In the process of evaluating urban drainage systems and the impacts resulting from flooding in Goiânia, one of the main inputs is daily precipitation data. These data were obtained from the Secretariat of Environment and Sustainable Development (SEMAD), specifically through the Center for Meteorological and Hydrological Information of the State of Goiás (CIMEHGO), whose access is made possible through the official website.

There was a robust focus on rainfall data collection, particularly on the analysis of trends related to daily extreme rainfall over thirteen years (2010-2023). To ensure the accuracy and relevance of the information, verification was carried out, validating its quality and reliability. The subsequent analysis

provided insight into trends, patterns and possible climate anomalies, illustrating the behavior of precipitation in Goiânia.

The choice of monthly total rainfall records for Goiânia was conducted based on well-defined criteria, which are:

a) Time series with at least 15 years of records.

b) Consistency in the data, meaning uninterrupted series over the years or, in the case of interruptions, that these are minimal. This rigor is justified by the challenge of replacing daily precipitation values, given the substantial spatial and temporal variation, especially for medium and low-frequency events (BERTONI; TUCCI, 2001).

c) Representativeness in relation to the spatial distribution of the seven administrative regions of Goiânia. This data visualization is facilitated by a map prepared with ArcGIS software, supported by the georeferenced databases provided by ANA.

As described by Capozzoli *et al*. (2018) the Goiânia rainfall station, identified by codes 01649013 (Ana) and 83423 (WMO), is located in the municipality of Goiânia. Its specific location is at latitude 16°40'25" S and longitude 49°15'50" W, about 2 km from the state headquarters. Figure 3 illustrates the geographical layout of both the municipality and the rainfall station in question. In operation since 1937, INMET – National Institute of Meteorology manages the station.

Figure 3 - Location of the municipality of Goiânia and the rainfall station

Source: Self elaboration.

Second stage – Occurrence of flooding

It focused on the collection of data related to floods, constituting an essential component for further analysis. Primary information on floods in Goiânia was gathered, allowing both the frequency and intensity of these events to be understood in the different municipal administrative regions.

Moving forward, the investigation benefited from the collection of reports and historical records of 13-year floods, all monitored and documented by the Municipal Coordination of Protection and Civil Defense.

Third Stage – Flood Mapping

Attention was directed to the mapping of areas frequently affected by floods. With the help of geoprocessing tools and geographic information systems, it was possible to discern the regions most susceptible to flooding, facilitating the spatial analysis of the most affected points.

It focuses on the confrontation and interpretation of the data collected in the previous phases. It began with a preliminary analysis of the occurrences of flooding, to understand the amplitude and patterns of the events recorded. This analysis served as a basis for comparison with the rainfall data previously studied, to identify possible correlations and causes between extreme rainfall and subsequent flooding in the city of Goiânia.

RESULTS AND DISCUSSION

Rainfall

This topic addresses the historical averages of rainfall between 2010-2022 in the municipality of Goiânia/GO, for the design of the Annual Rainfall Chart. It was possible to elaborate and demonstrate the peculiar distribution over the 13 years analysed. The month of December 2013 stands out as the period of greatest precipitation, registering 530.5 mm, while May 2010 was characterized by the total absence of precipitation, marking 0 mm.

When analysing the historical series, the considerable variation in annual rainfall totals over the years is evident, presenting remarkable seasonality. Months such as January, February and December generally have higher values, in contrast to May, June and July, which tend to have lower precipitation.

The month of December 2013 was identified as the wettest (530.5 mm), while 2019 was characterized as the driest year, with several months registering low rainfall (1277.6 mm).

This analysis reveals a marked alternation in the historical series, highlighting the importance of variation between periods of low rainfall intensity and phases of high concentration to maintain equilibrium. As observed by Muthoni *et al*. (2019), the annotation of the spatio-temporal patterns of rainfall variability is fundamental for the creation of new projects and adaptive strategies appropriate to a given locality.

Interventions are strongly encouraged in highly urbanized areas, which suffer from impermeable surfaces and increased extreme precipitation events due to urbanization and climate change. In these areas, the natural water balance is disturbed, as little precipitation infiltrates or allows evapotranspiration. In addition, wastewater discharges and poor-quality runoff increase, even when drinking water is imported to meet urban demands. Case studies in Genoa and Milan, with similar climatic conditions, were used for testing (RAIMONDI *et al*., 2023).

Variation in rainfall intensity due to climate change is a crucial factor affecting the adequacy of the drainage network. Many drainage facilities are designed based on historical data, assuming a stationary climate. However, recent studies show the importance of using data that are more accurate and advanced techniques, such as data mining and machine learning, to improve precipitation forecasting and urban flood management. This study, conducted in the city of Robe, Ethiopia, highlights the need for rainfall data on hourly or sub-hourly scales for effective flood management (BIBI *et al*., 2023).

Garcia *et al*. (2018) associate extreme precipitation events with global warming. This understanding is critical for water resource management and risk assessment. Understanding the relationship between climate change and precipitation patterns is crucial for improving adaptation and mitigation strategies, and ensuring a sustainable approach to climate challenges.

Occurrences of flooding

According to the Civil Defense of Rio de Janeiro (2023), within the Brazilian Classification and Codification of Disasters - COBRADE, "floods" refer to the overload of urban drainage systems, causing water accumulation in urban infrastructures during intense rains.

Analyzing the annual flood balance, consistent patterns emerge. In 2010, there were 314mm floods, especially in January, February and December.

Considering the consequences of urban flooding, it is crucial to increase the capacity of cities to deal with climate disasters. Severe rains, resulting from global climate change, have drawn attention to urban resilience against flooding. Floods disrupt traffic networks, affecting residents' mobility and access. With accelerated urbanization and the increase in impermeable surfaces, these events have become more frequent. Understanding these disruptions is essential to improve emergency planning and urban resilience (KHODADAD *et al*., 2023).

In 2013, although less frequent, but with a sum of 372mm, it indicates a possible correlation between precipitation intensity and events. Years with higher rainfall, such as 2011 and 2017, show significant amounts of flooding, reinforcing the relationship.

This in-depth analysis of patterns is essential for developing adaptive strategies and risk management plans. Extreme precipitation events are studied internationally due to losses caused by excess or scarcity of rainfall (FLATO *et al*., 2017).

Flood mapping

The correlation between rainfall and flooding reveals relevant socioeconomic impacts. These events affect biodiversity, and agricultural and urban activities, resulting in flooding and increased temperatures.

The Municipal Coordination of Civil Protection and Defense (COMPDEC) of Goiânia identified and mapped the areas of vulnerability to flooding in the city, revealing weaknesses in the drainage system regardless of geographical location. This vulnerability affects social, economic and environmental aspects, requiring effective strategies to strengthen urban resilience (VEYRET, 2007).

The data, obtained through COMPDEC, show 4895 occurrences of flooding between 2010 and 2023. The spatial analysis shows that the southern region faces the highest number of events, requiring specific measures. The temporal analysis highlights important variations, such as the year 2022 with 540 occurrences and December as the month most prone to flooding.

The integration of rainfall data and flooding occurrences reveals striking correlations. Months such as December and January, with a high incidence, coincide with intense rains, highlighting the importance of the temporal and regional distribution of precipitation.

These data offered a detailed perspective on the trajectory of this phenomenon over the years. Based on this understanding, it was possible to classify floods based on their severity and frequency. This classification provided accurate insight into the areas most in need of immediate interventions in their drainage systems.

CONCLUSIONS

Throughout this research, the urban drainage systems in Goiânia were examined, considering precipitation, floods and their mapping in urban areas. The complexity of the challenge faced by the city in the management of rainwater is highlighted and the urgent need to improve existing systems is highlighted.

The data collected reveal that, although there are advances in urban drainage systems, the ability to respond to extreme events, such as heavy rains, still has limitations. Vulnerable areas were identified, and the frequency of flooding in these locations demonstrates the need for specific interventions.

In addition, it was observed that climate change could intensify the challenges faced by the urban drainage system of Goiânia. The increase in the frequency and intensity of rainfall requires a careful review of management strategies and the implementation of adaptive measures.

The interconnection between drainage infrastructure and other urban aspects such as real estate development and land use should be considered. Disorderly urbanization and excessive soil sealing contribute to the overload of the drainage system, aggravating the impacts of flooding.

In short, the comprehensive assessment of urban drainage systems in Goiânia points to the pressing need for investments in resilient infrastructure, adaptation to climate change and sustainable urban planning. This research serves as the basis for the formulation of effective policies and the implementation of concrete measures to address the challenges related to urban drainage, promoting a more resilient city prepared for future impacts.

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Ano VI | Volume 18 | Nº 54 | Boa Vista |2024

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