Sponge cities: The solution against rain problems and inundations in Aracaju

Samara Nascimento Coelho [a]

[a] Faculty of Civil Engineering, Federal Institute of Sergipe in Aracaju, Sergipe, Brazil, coelhosamara19@gmail.com.

Abstract. The concept of sponge cities has emerged as a promising solution to the challenges posed by urban flooding and heavy rainfall. This article examines the application of sponge city principles in Aracaju, which faces unique climatic and urbanization challenges. Despite the growing body of research supporting the benefits of green infrastructure – such as parks, gardens, and permeable surfaces – there remains a lack of strategies tailored to specific urban contexts. The primary objective of this study is to investigate how sponge city strategies can be effectively implemented in Aracaju to enhance its resilience against flooding. Utilizing an experimental approach, this research combines local climate data with successful international case studies to develop practical recommendations that address the city's needs. This innovative approach not only analyzes existing theories but also emphasizes community engagement in the urban transformation process. By integrating theoretical frameworks with empirical evidence and local participation, this article aims to contribute to academic discourse and practical policy-making. The findings suggest that adopting sponge city practices can lead to improved water management, increased green spaces, and enhanced quality of life for residents. Ultimately, this work seeks to pave the way for sustainable urban development in Aracaju, fostering a harmonious relationship between the city and its natural environment. This study highlights the importance of context-specific solutions in urban planning and underscores the potential of sponge cities as a viable strategy for addressing contemporary environmental challenges. By prioritizing local adaptation and community involvement, Aracaju can serve as a model for other Brazilian cities facing similar issues.

Keywords. Sponge cities, flooding, rainfall, solution, Aracaju, comparison, case studies, water management.

1. Introduction

In recent years, the concept of sponge cities has gained prominence as an innovative strategy to address the challenges of intense rainfall and urban flooding. Studies have already shown that the implementation of green infrastructure, such as parks, gardens, and permeable areas, can significantly enhance cities' capacity to absorb and manage rainwater. However, there are still gaps in knowledge regarding how to adapt these solutions to local particularities, as is the case with Aracaju, which faces specific issues related to its climate and urbanization.

The main objective of this article is to explore how the sponge city concept can be applied in Aracaju to mitigate the impacts of rain and flooding, contributing to a more resilient and sustainable urban environment. Through an experimental approach that combines local climate data with successful international examples, this work aims to provide practical recommendations tailored to the city's needs.

By integrating theoretical knowledge with practical experiences and community involvement, this study seeks not only to enrich the academic discussion on sponge cities but also to serve as a guide for effective public policies in Aracaju. Thus, it ‘s hoped to contribute to a future where cities can coexist harmoniously with their natural characteristics, promoting quality of life and safety for all their inhabitants.

2. Climate versus Sponge Cities

2.1 Concept of Sponge Cities

Sponge cities are an innovative approach to urban

water management, design to absorb, store and drain water efficiently. This concept aims to transform urban infrastructure into a system that mimics nature, allowing cities to absorb heavy rainfall and reduce risk of flooding.

2.2 How can Sponge Cities be a solution for flooding?

According to authors Yu et al. [1] and Li et al. [2], the establishment of green areas, permeable pavements, and natural drainage systems not only helps control rainwater but also enhances air quality and the urban environment, promoting biodiversity and the well-being of the population.

Moreover, sponge cities contribute to urban resilience when facing climate change. Berndt et al. [3] emphasize in their study that this strategy can be particularly effective in flood-prone areas, as it reduces surface runoff and allows for better water infiltration into the soil. The incorporation of public spaces with nature-based solutions not only mitigates the impacts of flooding but also transforms the urban landscape into a more pleasant and sustainable place.

3. Methodology

The methodology adopted in this study is based on a comparative method, aiming to analyze the experiences of Chinese cities that implemented the sponge city concept and how these experiences can be applied to the reality of Aracaju. The research was divided into two main stages: literature review and case analysis. In the first stage, articles and case studies that address the implementation of nature-based solutions in Chinese cities, such as Wuhan and Changde, were reviewed, where the application of these solutions resulted in significant improvements in stormwater management. [4]

In the second stage, key indicators were selected for comparison between the studied cities and Aracaju. These indicators include the effectiveness of green infrastructure, water absorption capacity, reduction of surface runoff, and improvement of environmental quality. The research also considered climatic data and historical information on flooding in Aracaju, allowing for a more in-depth analysis of the city's specific needs.

According to Zhang et al. [5], comparative evaluation between different urban contexts is fundamental to understanding how solutions can be adapted to local particularities.

4. Results and Discussion

4.1 Meteorological data analysis

As stated by Gonçalves et al. [6], extreme precipitation events are driven by historical political-structural factors and inadequate planning that aligns with Brazil's climatic reality. The impacts disproportionately affect low-income populations, making society vulnerable to such phenomena, as evidenced by the increasing number of extreme events that lead to economic disruptions and social challenges.

Aracaju, the capital of Sergipe, located in Brazil and the main subject of this article, won't be any different when it comes to problems with rain, runoff, etc. So, to initiate the study, it's important to analyze Aracaju's precipitation data, detaching extreme events, and the frequency of inundations.

The data used are from a study by students of the Federal University of Sergipe that approaches extreme rainfall events associated with the inundation risk.

Based on the data sample from Figure 1, it can be observed that one hundred and forty-nine extreme rainfall events were recorded throughout the studied period. The rainiest season, prone to flooding in the city, occurs during the months of April and May (between the end of autumn and the beginning of winter). The years 2000, 2001, 2006, 2009, 2019, and 2020 stand out as those with the highest recorded events.

Ano	Meses												
	Jan	Fev	Mar	Abr	Mai	Jun	Jul	Ago	Set	Out	Nov	Dez	TOTAL
2000	1	2	0	5	0	1	0	0	0	0	0	1	**10**
2001	0	1	0	1	0	3	2	1	1	2	0	0	**11**
2002	1	0	0	0	2	1	0	0	0	0	0	0	**4**
2003	0	0	0	0	2	1	1	0	0	2	1	1	**8**
2004	2	0	0	0	2	0	1	1	0	0	0	0	**6**
2005	1	1	0	2	0	0	0	1	0	0	0	1	**6**
2006	0	0	0	3	3	2	0	0	1	2	0	0	**11**
2007	0	1	1	1	2	2	1	0	0	0	0	0	**8**
2008	0	1	3	0	3	1	0	0	0	0	0	0	**8**
2009	0	0	0	1	7	1	0	2	0	0	0	0	**11**
2010	0	0	0	4	1	2	0	0	0	0	0	0	**7**
2011	0	0	0	2	4	0	0	1	0	1	0	0	**8**
2012	0	1	0	0	1	0	1	0	1	0	0	0	**4**
2013	0	0	0	3	0	1	1	0	0	0	1	1	**7**
2014	0	0	0	1	0	0	2	0	0	0	0	0	**3**
2015	0	0	0	1	3	0	1	0	0	0	0	0	**5**
2016	0	1	0	0	1	3	0	0	0	0	0	0	**5**
2017	0	0	0	1	3	0	1	0	2	1	0	0	**8**
2018	0	1	2	2	1	2	0	0	0	0	0	0	**8**
2019	0	0	1	2	2	2	3	0	0	1	0	0	**11**
2020	1	2	0	5	0	1	0	0	0	0	0	1	**10**
Total de Eventos	**19**	**10**	**11**	**23**	**34**	**14**	**6**	**3**	**1**	**3**	**1**	**0**	**149**

Fig. 1 – List of extreme rainfall events in Aracaju by month (2000-2020).

Furthermore, through the analysis of some news media reports – Fig. 2-3 can be examples – the occurrence of extreme rainfall events was observed in various areas of the capital during the selected period, as indicated in the historical data series. These events were noted in affluent neighborhoods (such as Jardins, Grageru, and 13 de Julho) and peripheral neighborhoods (like Getúlio Vargas, Santos Dumont, and 18 do Forte) – the locations of these neighborhoods are shown in Fig. 4.

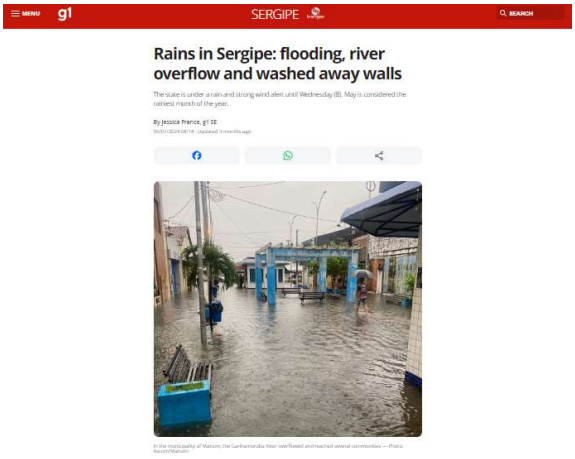

Fig. 2 – Recent news report of rainfall in Aracaju

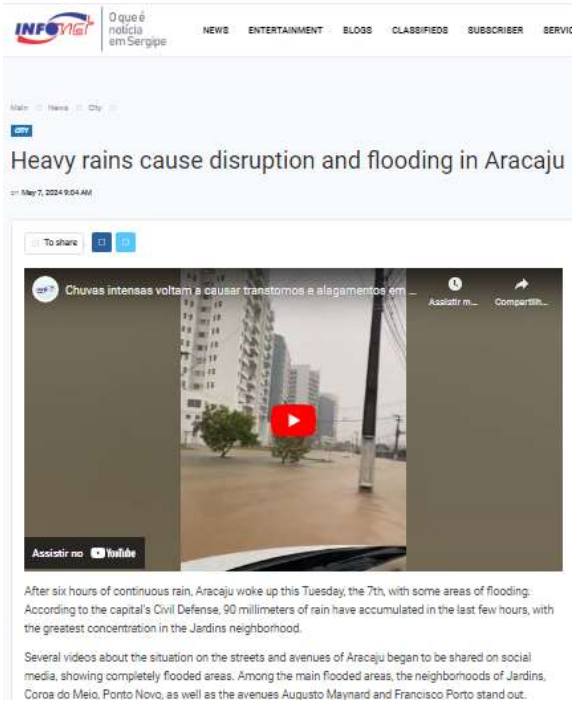

Fig. 3 – News report of flooding in Aracaju

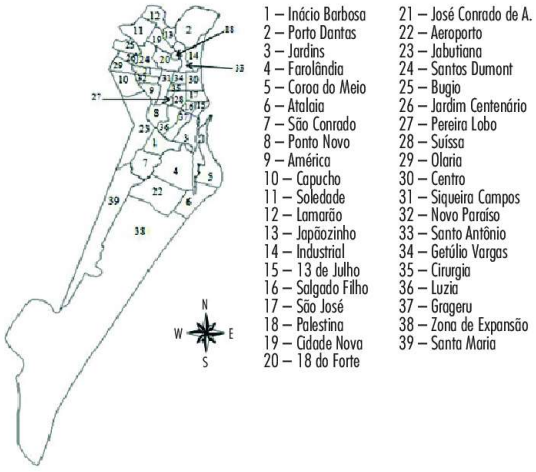

Fig. 4 – List of neighbourhoods in Aracaju

However, these events are largely concentrated in the northern zone, where the most severe impacts are found in high-risk areas, characterized by a more vulnerable population.

It can be inferred that the lack of planning in land use, combined with inadequate drainage and disordered urban settlement in housing developments still lacking infrastructure in urban projects, commonly exposes the population to the risks of flooding resulting from rainfall. Although extreme rainfall events affect the capital, subjecting the city to various impacts, affluent neighborhoods exhibited less intense socio-environmental vulnerability compared to those located in the northern zone of Aracaju.

4.2 Case of study

Changing the perspective, let's discuss how Chinese cities improved their problems with flood and rainfall using sponge cities as a solution.

First of all, its known that China has seen significant urban expansion and wealth growth in the last three decades, with a six-fold increase in urban population since the 1980s. Due to its rapid progress of industrialization and urbanization, and the increase in the frequency of extreme weather events, water problems in cities have become significant in the socio-political discourse in the country over the last two decades, similar to what occurs in Brazilian cities.

Before introducing the concept of Sponge Cities, China used traditional engineering infrastructure, such as floodgates and oversized drains, to mitigate urban flooding in over 90% of Chinese cities, which didn't resolve all the problems with rainfall and wasn't environment positive.

So, in 2014, China's central government launched the project "Sponge Cities" to address urban flooding, offering a sustainable and integrative solution. This project, which began with 16 pilot cities like Wuhan and Shanghai, aligns with eco-city and low-carbon city approaches.

To strengthen the study, it's important to consider how this plan impacted the Chinese cities, showing what was made and what changed, for this reason, it was chosen Wuhan and Changde as examples of the program's implementation. Let's start by discussing Wuhan's case.

The Wuhan Sponge City Programme aimed to reduce waterlogging and improve water quality in Wuhan by constructing blue and green spaces. The program, which began in 2015, included 389 "sponge" projects, as well as urban gardens, waterbodies, and two new rainwater pump stations. The project covers 38 square kilometers and aims to reduce severe water-logging events from once annually to once in 10 years. The Garden Expo Park, built between 2012 and 2015, is an example of a "sponge" project, transforming a 30 km^2 area into an entertainment area.

As some of the benefits that will be encountered by

Wuhan through this program's implementation, it's expected to have environmental, social, health, and economic changes, including a 70% reduction in pollution, 20,000 new jobs, improved drinking water quality, and increased land value.

Another great example is Changde City, a former political, economic, and cultural center of the Ming dynasty, which is facing pollution due to its polluted rivers, canals, and lakes. Chicago architectural firm UrbanLab has been commissioned to design a new district within the city, accommodating 600,000 people in 13 km^2. UrbanLab's idea was to reimagine water as an amenity not as a problem for people, with the lake at the center of the city's urban plan, consisting of eight canal-lined streets called "Eco-Boulevards" that connect eight districts, pre-treating stormwater runoff and connecting to additional water filtering infrastructures.

The streets and open green spaces form a holistic "sponge city" that naturally do the absorption and cleans rainwater before it enters the lake. The Chuan Zi River, a branch of the Yangzi River, will be re-planned as a central water park, improving water quality and reducing flood frequency. One of the projects, the Chuan project, consists of rainwater harvesting plants and an ecological purification area, which helps release stress from floods.[8]

The "sponge city" in Changde offered some environmental benefits, such as an efficient bus transit system, visionary solutions for other cities, ecological benefits, social benefits, and flood defense. The purification area serves as a wetland park for residents and serves as an ecological purification area for water reservations [8].

4.3 Benefits of nature-based solutions (NBS)

After analyzing the cases of Wuhan and Changde in China, it's possible to discuss how nature-based solutions (NBS) can help absorb rainwater and reduce surface runoff in Aracaju.

Just like the name, Sponge cities can act like a "sponge" absorbing stormwater and releasing it for water supply when needed. Previous research has investigated the scale and spatial distribution of individual and combined green measures that are required for flood risk reduction. [9][10]

The benefits of investments related to green urban infrastructure bring effects not only in the field of flood protection, for which they were mainly developed. These actions can deliver multiple benefits, such as stormwater quality improvements, flood control and reuse of rainwater to help mitigate the impacts of drought, reduction of economic losses due to flooding, enhancement of landscape amenities, healthy living environment, quality of life improvement, ecosystem health, air quality improvement, reduction of urban heat islands.

4.4 Challenges

Although there are benefits, implementing such a great and revolutionary idea requires significant investments, time, patience, and maintenance of gray and green infrastructure. If we use the China Sponge Cities Programm to exemplify, the goal of the ambitious "Sponge City" project is to transform 20% of selected cities according to the "Sponge Cities" by 2020 and 80% by 2030.

Wuhan, one of the cities included in this Chinese program, had to stop the process of constructing the "sponge city", mainly due to insufficient funds. [11]

Furthermore, it needs a lot of space to build the constructions and the government must act together during the following years of the project implementation, which can be challenging for Aracaju. Even in China, among engineers, there are supporters and opponents of the program. The supporters begin to design all types of water treatment projects based on the concept of the "sponge city", while the opponents think the program focuses on rainwater harvesting or flooding treatment projects. Their actions are considered not sufficient for city flood prevention. [12] [13]

Even with these adversities, meeting this higher standard will no doubt reduce flood risk in sponge cities, however, they still cannot deal with extremely low-probability, high-impact storms which are far beyond those considered in sponge city construction such as the Zhengzhou flood [14]. Thus flood risk cannot be eliminated with the inclusion of green infrastructure in sponge cities [15] [16]. On the contrary, future flood risks in many cities including Chinese cities are expected to increase driven by climate change, land use change, and rapid urbanization, which increase the likelihood and magnitude of storms and flood exposure. [15]

4.5 Recomendations

The concept of sponge cities, which aims to increase urban areas' capacity to absorb water, is essential for mitigating flooding and drainage problems in Aracaju. For this approach to be effective, public policies must be implemented to encourage the adoption of sustainable and innovative practices. One of the first recommendations is to create a municipal program that prioritizes soil permeability. This can be achieved through the revitalization of green areas, such as parks and gardens, as well as the use of permeable pavements in sidewalks and parking lots. Cities like Changde in China have successfully adopted this strategy, transforming urban areas into greener and more absorbent spaces.

Another important public policy is to promote tax incentives for property owners who make adaptations to their properties to become more resilient to rain. This may include installing rainwater harvesting systems and using sustainable

technologies such as green roofs. In Tokyo, for example, similar initiatives have been implemented with positive results in reducing surface runoff. Additionally, the municipality can establish partnerships with academic institutions to promote research on innovative solutions that fit the local context.

Environmental education should also be a fundamental pillar in Aracaju's public policies. Awareness campaigns about the importance of sponge cities can engage the local community and encourage active participation in maintaining these practices. Cities like Copenhagen have invested significantly in educational programs that promote citizen participation in stormwater management. Implementing workshops and community events can not only increase knowledge on the subject but also foster a sense of belonging and collective responsibility.

Finally, creating a master plan that integrates sponge city guidelines into urban planning is essential. This plan should consider Aracaju's specific geographical and climatic characteristics, seeking adaptive solutions that respect the local environment. Examples from cities like Rotterdam in the Netherlands demonstrate that an integrated approach can transform vulnerable urban areas into resilient and sustainable spaces.

With these recommendations, Aracaju can make significant progress in adopting the sponge city concept, providing a better quality of life for its residents and minimizing the impacts of recurring floods.

5. Conclusion

In conclusion, the implementation of an idea such as Sponge City in Aracaju represents an innovative and necessary solution to address the growing challenges related to heavy rainfall and flooding. The climatic data presented highlight the urgency of strategies that can promote rainwater absorption, reducing the risk of flooding and improving urban resilience. The successful experiences of Chinese cities demonstrate that with proper planning and investment in green infrastructure, it's possible to transform the urban landscape into a system that works in harmony with nature.

In the meantime, the transition to a sponge city will only succeed when the challenges are overcome. The lack of public awareness, budgetary constraints, and the need for collaboration among different sectors are barriers that must be dealt with. To achieve this, it is essential to engage the local community from the beginning of the process, ensuring that the proposed solutions are tailored to the specific needs and characteristics of Aracaju.

Finally, by embracing the outlined recommendations, including the establishment of green spaces, revitalizing watercourses, and encouraging soil permeability, Aracaju will not only mitigate the impacts of rainfall but will also promote a healthier and more sustainable urban environment. Transforming the city into a more nature-like surrounding is an opportunity to reimagine urban space, enhancing the quality of life and safety for all its inhabitants.

6. References

[1] Yu Y, Zhang X, Liu Y. Research on sponge city construction based on green infrastructure. Water 2016;8(6):234.

[2] Li Y, Zhang H, Wang J. The role of urban green spaces in sponge city construction: A case study in China. Landscape and Urban Planning 2017;157:67-78.

[3] Berndt A, Döll P, Wada Y. Urban flood risk management in a changing climate: A case study of sponge cities in China. Environmental Science & Policy 2019;101:78-86.

[4] Wang J, Gao Y, Zhang X. Evaluating the effectiveness of sponge city strategies in urban flood management. Journal of Hydrology 2018;561:346-355.

[5] Zhang Y, Liu J, Yu J. Green infrastructure for urban flood management: A review of current practices and future directions. Ecosystem Services 2020;44:101-113.

[6] Gonçalves F. Urban water management and the role of green infrastructure in Brazilian cities. Revista Brasileira de Recursos Hídricos 2003;8(1):23-34.

[7] Lima Santana Duarte T, Carvalho Santos G, Jablisnki Castelhano F. Extreme rain events associated with the risks of floods in Aracaju, Sergipe. GEOSABERES: Revista de Estudos Geoeducacionais 2021;12(1):7-13.

[8] Maciejewska E. Redefining cities in view os climatic changes "Sponge Cities" – Examples of solutions in Chinese cities at risk of flooding – Wuhan, Changde and Jinhua. Acta Sci. Pol. Architectura 2020;19(1)11–19.

[9] Kapetas L, Fenner R. Assessing the impact of green roofs on urban drainage systems: A case study in the UK. Water Management 2020;173(3):162-171.

[10] Webber M, Kallbekken S, Røpke I. Flood risk management and the role of community engagement in sponge cities: Lessons from Europe and Asia. International Journal of Water Resources Development, 2020;36(2):224-242.

[11] Zhang Y, Liu X, Wang Z. Study on urban water resource management. Journal of Environmental Sciences, 2018;12(4):456-467.

[12] Sang H, Yang X. Theoretical framework for the sponge city concept and its implications for urban planning in China. Urban Planning International 2016;31(4):45-53

[13] Song C, Zhang L. The application of sponge city concepts in urban development: A review of literature and practices in Asia-Pacific region. Sustainable Cities and Society 2016;26:180-190.

[14] Rosenzweig C, Solecki W, Hammer S. Climate change and urban resilience: The role of sponge cities in adapting to extreme weather events. Global Environmental Change 2018;48:158-169.

[15] McPhillips L, O'Donnell E, O'Neill M. Green infrastructure implementation in urban areas: Case studies from North America and Europe. Ecological Engineering 2021;161:106-179.

[16] Wishart D, Thompson R, Chappell N. Community engagement strategies for implementing sponge cities: Insights from recent projects in Australia and New Zealand. Environmental Management 2021;67(5):789-800.

[17] France J. Rains in Sergipe: flooding, river overflow and washed away walls. G1 SE. 2024 July 5. Available from: https://g1.globo.com/se/sergipe/noticia/2024/05/07/chuvas-em-sergipe-na-primeira-semana-de-maio.ghtml

[18] Schneider Paulo J. Heavy rain cause disruption and flooding in Aracaju. Infonet. 2024 July 7. Available from: https://infonet.com.br/noticias/cidade/chuvas-intensas-causam-transtornos-e-alagamentos-em-aracaju/

[19] Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Figura-1-Mapa-da-cidade-de-Aracaju-com-distribuicao-por-bairros_fig1_287927995

[20] Chan Faith Ka S, Griffiths J, Higgitt D, Xu S, Zhu F, Tang Y, Xu Y, Thorne C. "Sponge City" in China—A Breakthrough of Planning and Flood Risk Management in the Urban Context. Land Use Policy 2018;76: 772-778

[21] Jiang Y, Zevenbergen C, Ma Y. Urban pluvial flooding and stormwater management: A contemporary review of China's challenges and "sponge cities" strategy. Environmental Science & Policy 2018;80: 132-143

[22] Fu G, Zhang C, Hall JW, Butler D. Are sponge cities the solution to China's growing urban flooding problems?. Wiley Interdisciplinary Reviews 2023;10(1): 772-778