# Chapter 5
# Water-Sensitive Urban Design in Porto Velho

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**Abstract** This chapter focuses on the capital of the state of Rondônia, Porto Velho, in the Amazon region, to develop solutions for the water system. Through green and blue infrastructure, it aims to address urban flood adaptation measures. To this end, water-sensitive urban design solutions have been developed to meet the needs of the different zones. Due to its proximity to the Madeira River, the city faces increasing risk of flooding, as climate change increases. This chapter analyses different adaptation strategies to reduce the impact of urban flooding. The methodological framework includes literature review, mapping, and analysis through the use of remote sensing technology and design tools. The strategies include improving urban design and creating flood-resilient construction, early warning systems, sustainable drainage, and community involvement programmes. By implementing a comprehensive flood adaptation policy, Porto Velho aims to increase its resilience, protects vulnerable social groups, and promotes sustainable urban growth in the face of increasing flood risks.

**Keywords** Porto Velho · Urban floods · Climate change · Sustainable drainage · Floodplain management

## 5.1 Introduction

The Amazon River Basin is a dynamic ecosystem, and much scientific research is being done in order to understand its water cycles (Paca et al., 2020; Tian et al., 2021; Giffard et al., 2019).

It is quite evident that climate change and land use changes, such as deforestation and the expansion of agriculture and cattle ranching, are affecting the ecosystem (Figueiredo et al., 2020). The Amazon River Basin affects the hydrological cycle at

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regional and global scales, as it is considered to be the world's largest river system, covering ~40% of South America. The hydrological cycle of the rainforest affects the total global terrestrial evapotranspiration as well as the global moisture air mass fluxes (Vergopolan & Fisher, 2016; Field et al., 1998; Tian et al., 2021). Floods are also particularly relevant in this changing scenario. Research has shown that extreme droughts are becoming more frequent and intense. Urban areas are particularly affected by climate hazards such as flooding and sanitation.

The Amazon River has the largest river by volume in the world, contributing about 17% of the world's river discharge to the major oceans (Giffard et al., 2019). The Madeira River is the largest tributary of the Amazon River, representing 23% of the Amazon basin watershed. It flows northward, in a total of 3352 km from Bolivia to Brazil. It also was the largest water volume and sediment flow among its tributaries, counting about 50% of the Amazon River's sediment (Li et al., 2020).

The state of Rondônia is located in the Amazon region in the northern part of Brazil. The region of Rondônia was the land of several indigenous groups until the arrival of the colonizers. This territory was first part of other states, such as the State of Amazonas and the State of Mato Grosso. It was the result of a political agreement between Brazil and Bolivia for the construction of the Madeira-Mamoré Railroad (Petrópolis Agreement, 1903), which was also related to the history of its capital, Porto Velho. It was only in 1943 that the state region was transformed into its own territory, named Guaporé Territory. In 1956, the name was changed to Rondônia, in honour of the marshal Cândido Rondon, who explored the region (IBGE, 2023).

The capital of Rondônia state, Porto Velho, is the major city in the Madeira watershed. It has a population estimated at 519,531 inhabitants for the year 2019, and in 2000 the population was 334,661 (IBGE, 2023). It has an area of 34,096 $km^2$—the largest Brazilian capital in territorial size. The History of the Madeira Mamoré Railway and the rubber production are interlinked, that is why it was chosen as the site for the construction of the port, which was also a hub for transporting the rubber extracted in the forest areas to be sent to international markets, such as the USA and Europe.

The water supply in Porto Velho began with the construction of three reservoirs to supply water to the families of the workers of the Madeira-Mamoré Railway. The first reservoir was built in 1910, and the other two in 1912. The capacity of each reservoir was 200,000 L, which supplied water to the capital by gravity until 1957 (STRM Data). Two recently constructed run-of-the-river dams (Santo Antônio and Jirau), along the Madeira River in Brazil, have been controversial due to their large unquantified impacts on (1) land use and land cover (LULC) and (2) on the area that would be flooded (Emilio Moran, MDPI).

Porto Velho rainfall regime is defined by a rainy period from November to April and a dry period from June to September, with May and October considered as transitional months (Bezerra et al., 2010).

Brazil in general has a very vast geography and a very irregular development pattern, therefore urban planning has to be planned for each specific situation. The urban issues in Rondônia cities area related to the diversified and uneven distribution of resources, and it also leads to unplanned growth of the city, resulting in rapid urbanization.

In Rondônia, the specific reasons for the rapid urbanization were the enormous increase in the migrant population, which led to an increase in the need for infrastructure and employment opportunities, as well as the need to convert forest land to agricultural land and build additional houses (Moran, 1993), which were direct results of the Brazilian colonization programme implemented in Rondônia since 1964. This increased deforestation and forest fires, disturbing the ecological balance in the rainforest (REUTERS, Jake Spring). Agriculture expansion in the Brazilian Amazon has been driven not only by large-scale agriculture and cattle ranching, both of which have put considerable pressure on remaining forests and their watersheds.

## 5.2 Historical Background

Porto Velho has deep historical roots, dating back to the monumental construction of the Madeira-Mamoré railway in the year 1907. It was this ambitious project that set the stage for the city's development, a transformation that would shape its identity and trajectory. Although Porto Velho was not officially recognized until 1914, the seeds of its establishment as a major urban centre had already been sown (Britannica, Amy Tikkan).

The pivotal year of 1934 brought about a significant change, as Porto Velho assumed the prestigious position of being designated as the capital city of Guaporé. This strategic transition marked a turning point in the city's course, consolidating its administrative importance and putting it on the regional stage. However, it was the year 1987 that cast a long shadow over the city's environmental equilibrium. The initiation of large-scale deforestation activities triggered a domino effect that had far-reaching consequences for both the city and its surrounding ecosystem. The effects of this decision would reverberate through time, reshaping landscapes and ecological dynamics (ESA, Lars From).

The early 1990s ushered in a new wave of change for Porto Velho—this time driven by an influx of immigrants seeking opportunities and a better quality of life. This population surge put Porto Velho in the spotlight as an emerging urban centre, requiring a comprehensive reassessment of its infrastructure, services, and urban planning strategies. The city found itself at a critical juncture—how to accommodate this population boom while respecting the environment and striving for sustainable growth.

In essence, Porto Velho's journey from its origins during the monumental construction of the Madeira-Mamoré Railway to its current position as a recognized urban entity is a story of adaptation, resilience, and profound transformation. The city's historical timeline is a testament to the complex interplay between human ambitions and the delicate balance of the environment.

## 5.3 Research Question

Our study began with an in-depth study of the urban area of Porto Velho, with a focus on understanding the water-related issues. The analysis allowed the formulation of seven research questions, each one revealing new levels of challenges to guide possible solutions to improve the urban water problems. The research questions are:

1. What are the main needs to manage urban flooding in the case of Porto Velho?
2. Who are the main actors involved in the city of Porto Velho?
3. How can flood adaptation measures be implemented in cities?
4. What are the opportunities associated with adaptation strategies for flood management?
5. Depending on the context, which measures dealing with urban flooding can be considered the most effective to manage floods in Brazil?
6. What are the main advantages and limitations of these solutions?
7. How can these measures be applied in the spatial planning of concrete areas of the city of Porto Velho? What about the recommendations to implement these measures in Master Plans and other land policy plans?

Flood mitigation is a crucial front in the conflict over growing climate-related issues. Our study carefully examined the range of tactics used around the world and analysed how they could be modified to meet the needs of places like Porto Velho. In order to tailor adaptation strategies to the city's specific characteristics, we attempted to create a comprehensive roadmap that included everything from nature-based solutions to infrastructural fortifications.

Opportunities often emerge in the midst of difficulties, so our research delved into the realm of opportunities associated with adaptation strategy. These opportunities lie within the scope of flood management and mix with broader urban development goals. Our study sought to uncover the hidden opportunities that emerge when adaptation techniques serve as proactive, rather than simply reactive, growth engines for the whole person.

Our study began as an academic quest to sort through the maze of problems related to urban flooding in Porto Velho. Through methodical research, it was possible not only to answer these questions but also to tie them all together into a cohesive story. This story acts as a compass to guide Porto Velho towards a more flood-resilient future by highlighting the needs, stakeholders, solutions, opportunities, and constraints. More information on the methodological approach is provided below.

## 5.4 Process and Methods

This study utilized a combination of quantitative and qualitative research methods to gain an understanding of the research topic. The aim was to triangulate findings from sources and perspectives ensuring a rounded analysis.

Both qualitative and quantitative data were thematically analysed. The transcripts underwent coding using both deductive approaches. Through a process of data immersion, categorization and constant comparison, themes, and patterns were identified.

The methodology employed analysis and mapping tools. The former played a role in understanding the city, its region, history, local legislation, and current challenges. Additionally bibliographic research helped uncover indicators related to sanitation in Porto Velho as well as economic factors such as the Gross Domestic Product (GDP) of the municipality for a specific year. With this information at hand, the following steps were undertaken;

Analysis of how basic sanitation rankings corresponded to indicators.

Description of issues within water supply, sewerage systems, urban drainage, and solid waste management.

Projection analysis based on required investments, for universalizing services alongside current investment trends.

To further explore and analyse the city and its surroundings we utilized mapping as a tool. We incorporated layers of data, including water bodies, green spaces, topography and transportation infrastructure, such as roads and railways using McHarg (1969) landscape analysis technique.

Spatial syntax and morphological analysis have also been applied in order to provide a comprehensive approach to urban reality. This methodological journey helped in concluding the solutions for the drainage problems in the city, for that there was synergizing multiple layers of understanding into a cohesive strategy.

Thereafter, space syntax method was adopted, a method that considers the analysis of the cityscape. Paths, corridors, "axial lines," "convex spaces" are considered in this approach. These axial lines, like arteries of movement, reveal the primary routes that dictate the flow of the city. Meanwhile, the "convex spaces" offer a glimpse into the central hubs and places where the convergence of axial lines creates a nexus of activity. This perceptive analysis forms the basis of our subsequent strategies. The morphology analysis method was used for the understanding of the city's past and present urban form, urban structure, land use, and patterns.

Some of the analyses resulting from the research methodology are detailed below.

## 5.5 General Analysis

### 5.5.1 Topography

Porto Velho's topography is predominantly flat, with gentle slopes and occasional low hills. The topography is largely shaped by the presence of rivers, streams, and wetlands, which contribute to the region's rich biodiversity and ecological importance. However, the flat terrain and the city's location in a flood-prone area also pose challenges for urban planning and infrastructure development, particularly in mitigating the risks associated with annual flooding events. Inundation hazards are caused by seasonal rainfall and river flooding. Levees, drainage systems, and urban design are among methods used to mitigate the effects of flooding. Resilience strategies are critical to safeguard the city from disasters.

### 5.5.2 Water and Dam

The city of Porto Velho is surrounded by the Amazon River and Madeira River. Important Dams in Porto Velho are Jirau and Santo Antonio. These are the two important structures which help in flood control in the city and also acts as a major source of transport and economic activities. Furthermore, these are the two major barriers which help in flood control. This important body of water supports a variety of habitats in addition to facilitating transit. However, these two dams have a huge impact on the biodiversity and the social groups, there have been also serious threats and flooding due to the construction of these two dams, which resulted into social and environmental problems. Furthermore, the energy produced through these dams does not satay in the region and is being sold out, which is why the regions suffers from energy instability. See (Fig. 5.1) for the placement of the Dams and the river flowing through the region.

### 5.5.3 Urban Growth

Socio spatial formation of the city of Porto Velho, the period between 1980 and 2010 played a big role in realizing the Urban Reality of Rondônia, Carlos Santos, Maurício Silva Published 29 June 2012). As we see in Fig. 5.2. Over the years people started moving on the outskirts of the city in search of better opportunities, which created an Urban arch where there are clusters of settlements of people. The municipality has experienced cycles of deforestation and the construction of projects, roads and dams, which have altered social conditions and land use. Since 2000, Porto Velho has undergone a particularly dramatic transformation due to the construction of two hydroelectric power stations (HPS) along the Madeira River.

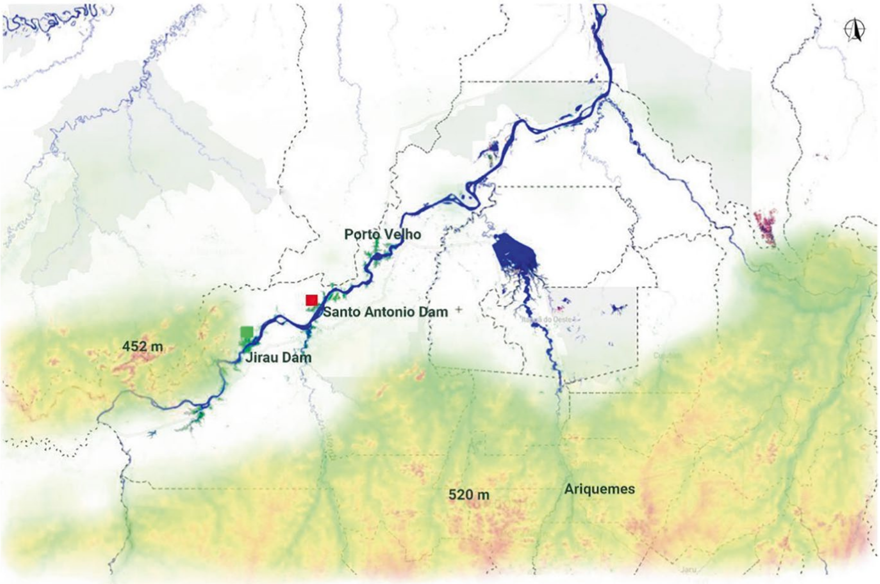


**Fig. 5.1** Porto Velho's Water body and dams. (Source: Elaborated by Singla and Aktürk, based on data from Mapbiomas (2021) and IGBE)

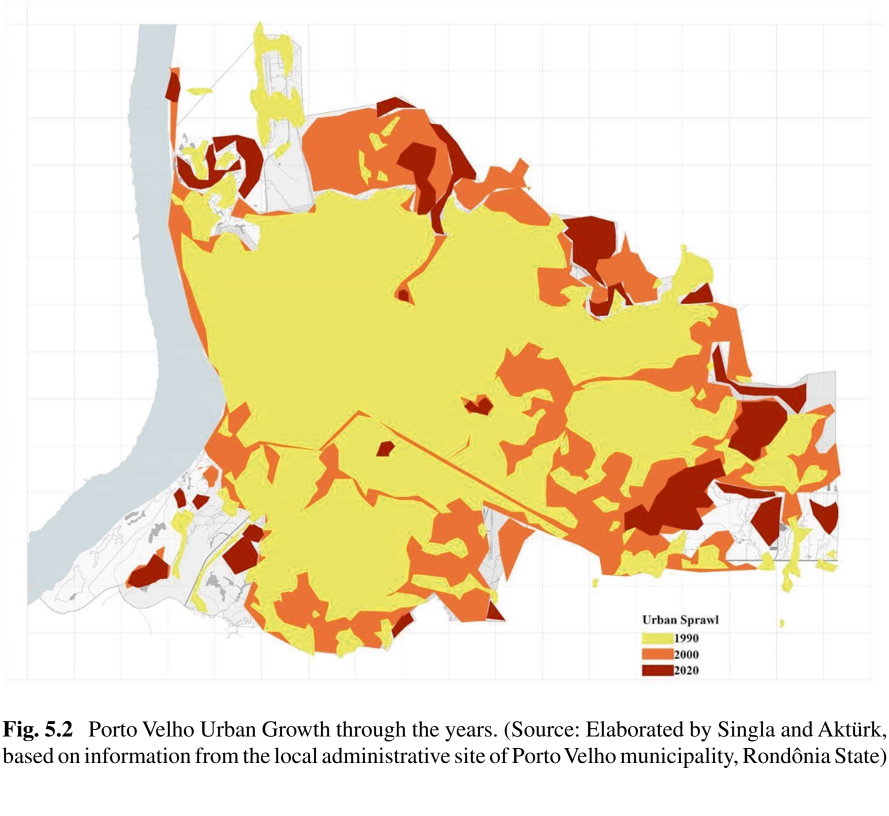


**Fig. 5.2** Porto Velho Urban Growth through the years. (Source: Elaborated by Singla and Aktürk, based on information from the local administrative site of Porto Velho municipality, Rondônia State)

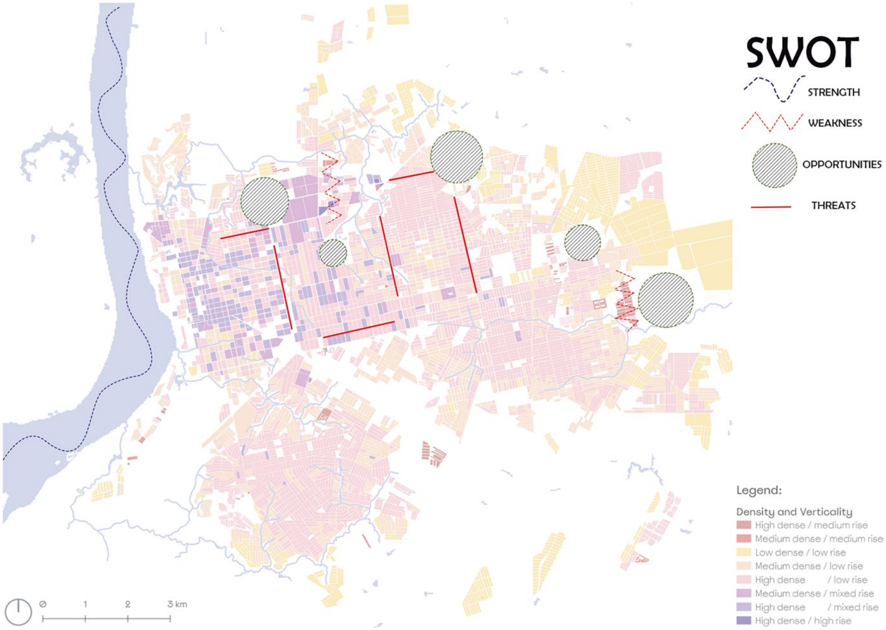


**Fig. 5.3** Swot Analysis of Porto Velho. (Source: Elaborated by Singla and Aktürk with the support of Denis Eke)

### *5.5.4 SWOT and Challenges*

A SWOT analysis is a strategic planning tool used to assess the area strengths, weaknesses, opportunities, and threats of an area. The SWOT analysis of Porto Velho showed the strength of the river, which acts as a source of important activities for trade, commerce, transportation, and leisure. On the other hand, the weakness is the poor urban planning and the lack of quality of streets, which leads to road congestion and drainage issues. There is also a lot of vacant land for further expansion, which is definitely an opportunity.

There are undoubtedly additional issues related to the safety of people, due to the high crime index.[1] Also, the city has very precarious basic sanitation services, aggravated by the fact that part of the water distributed to the population comes from deep tubes wells and, to a lesser extent, from the Madeira River (IJEARS, Kleber Borges).

Part of the population gets water from the Amazonian system as well, which collects water from the shallowest part of the water table. This water is usually contaminated and the situation is exacerbated when floods occur, such as the one in 2014. Irregular urban occupation and difficulties in implementing public policies make the population even more vulnerable to urban flooding (WWF Report, Kricher 1997). See Fig. 5.3 for a clearer understanding of the SWOT analysis.

[1] The homicide rate in Porto Velho was 27.38 for the year 2019. For comparison, São Paulo had a rate of 3.71 for the same year (IPEA, 2019).

## 5.6 Plan of Action

In the initial phase of our project, we conducted a morphological analysis that included the classification of various building typologies and their surroundings. This revealed a notable prevalence of high-rise and mixed-use buildings in the urban landscape. This observation also highlighted the emerging pattern of clustering, which contributes to the creation of open spaces. Unfortunately, these open spaces have yet to reach their full potential and remain underutilized. This presents an exciting opportunity for innovative interventions that could revitalize these spaces and transform them into vibrant community spaces.

Our focus then shifted to a comprehensive review of the flood risk plan for the area. This strategic approach provided valuable insights into the different flood-prone zones in the region, allowing the formulation of strategies to improve the resilience and preparedness of these specific zones in anticipation of potential flood events.

The flood risk analysis revealed a number of challenges and vulnerabilities that required immediate attention. Identifying these critical issues allowed us to determine the precise actions needed to effectively strengthen flood mitigation and adaptation efforts. With an informed approach, we set out to design tailored solutions that not only address existing vulnerabilities, but also lay the foundation for a more sustainable and secure urban environment.

We then transitioned to the creation of a comprehensive Vision Plan, meticulously tailored to the unique needs of each designated zone. This plan embodied our commitment to holistic urban development and served as the blueprint for a systematic implementation strategy, integrating existing infrastructure, land use patterns, and drainage systems.

In summary, our exploration with the categorization of building typologies and spatial configurations, revealing the trend of clustering and latent open spaces. This discovery prompted a closer examination of the flood risk plan, decoding the specific flood-prone zones and their immediate fortification needs. The next step was the creation of the Vision Plan, positioning us at the threshold of a transformative journey towards urban improvement.

Some water-sensitive regions were selected as implementation zones in the structure plan we developed for the city centre of Porto Velho. Zones A, B, C, D, and E were recognized in Fig. 5.4 as being significant based on several criteria. Some factors considered for selecting these areas included prior floodplains, infrastructure, and closeness to the city core. In the structural plan, three different street kinds were chosen: low density A type streets, which are coloured blue, medium density B type streets, which are coloured green, and high-density C type streets, which are coloured red (Fig. 5.4).

In the plan, the igarape (waterways) in the region was another determining factor in the zone selection. The distance or closeness of the igarape to high-density areas was taken into consideration as it would affect the sustainable solutions planned.

Various evaluations were done, including distribution of public spaces, utilization characteristics of the regions, such as whether they are used for residential or industrial purposes, and green-oriented zones within the zones.

Another feature that distinguishes the selected regions from the others is that they have different requirements and are important against the risk of flooding. In the upcoming years, other regions will join these ones in contributing to the designs for the new master plans. Regions that have different needs and are guiding are chosen as examples for future designs.

For instance, zone C is situated near the Madeira River and features a moderately dense green area. This area contrasts with zone A, which has more intense urbanization and a drain that runs through it. Although these two places have very different demands, the flood danger is about the same. The specifics of our studies have gone in this direction, as you can see. Details of these regions is found in the following section (Implementation zones).

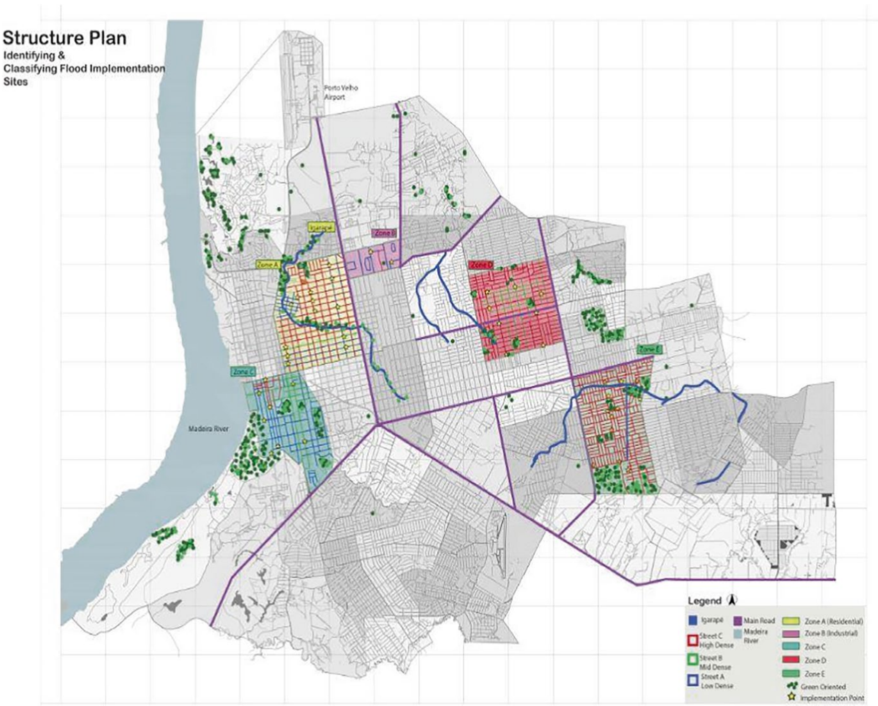


**Fig. 5.4** Structural Plan: identifying and classifying flood implementation areas. (Source: Elaborated by Singla and Aktürk. Created using QGIS 3.28.0 version)

## 5.7 Implementation Zones

In our comprehensive implementation strategy, we have defined different typologies for each zone, taking into account various factors that influence their functionality and vulnerability to flooding. Using a standardized scale ranging from 1 to 10, the vulnerability to flooding was assessed for each zone, allowing for prioritization of zones.

In addition, a density analysis was conducted for each zone to assess the concentration of infrastructure, buildings, and population within the boundaries of the zone. This density assessment serves as a critical determinant in the design of solutions, guiding the allocation of resources and the implementation of measures that address the unique needs of each zone.

The classification of the zones was based on their respective land uses. This segmentation ensures that the solutions are tailored to the specific functions and activities that take place within each zone, optimizing the impact of the interventions.

In addition, the street selection process aimed to identify key thoroughfares within each zone where innovative solutions could be applied. These streets serve as vital conduits for connectivity and accessibility, and by focusing our efforts here, we aim to create a ripple effect that extends the benefits of our interventions throughout the entire zone. For a more detailed representation of the characteristics and intricacies of each zone, see Fig. 5.5. This illustrative representation reunites the essence of our zoning framework and visually conveys the nuanced attributes that have informed our implementation strategy.

If we examine the specifics of the chosen zones, they are:

Zone A (Sao Joao Bosco): This zone includes the big igarape and high-rise buildings. The big residential and commercial area can cause high risk of damage due to flood. Flood risk in this area is 8/10. Also the Flood in 2014, damaged this area. Density in this area according to the google maps site view is 7 out of 10. Defining this zones type is residential and commercial. Most of the governmental buildings and the economic activities are going in this zone and this cause a big movement of people and density.

Zone B (R. Cipriano Gurgel): This is an industrial zone of our structure plan. Choosing this area may lead us the different needs of an industrial zones. In industrial zones, transportation issues and density are different from other zones. Flood risk in this area is 8/10. Flood risk will affect the low-rise depot stores in this zone. In order to prevent new problems in industrial zones specified sustainable drainage systems are needed. Density in this area according to the google maps site view is 5 out of 10.

Zone C (Santa Barbara): This zone is the closest to the Madeira River. It includes green zones and it has dense residential area. Flood risk in this area is 9/10. According to the analaysis locating the end of the igarapes or closest to the water areas may cause higher damage for residential buildings. Density in this area according to the google maps site view is 8 out of 10.


**Fig. 5.5** Implementation zones and classifications. (Source: Elaborated by Singla and Aktürk, based on Google maps)

Zone D (Esperança da Comunidade): This zone includes highest populated neighbourhood area. High dense neighbourhoods are important to consider as daily life flood problems such as backyard water drainages, car park drainage areas or walking paths. Density in this area according to the google maps site view is 9 out of 10. Flood risk in this area is 7/10. Brazilian neighbourhood designs are the key factor in the solution making.

Zone E (Tancredo Reves): This zone has the second big igarapé and huge public spaces. Density in this area according to the google maps site view is 8 out of 10. Public spaces main needs should be defined by residents and decision makers in the zone. Flood risk in this area is 7/10.

To sum up, there is a correlation between zone density and a higher risk of flooding. In conclusion, Porto Velho‘s classification of these five zones offers important insights into the different degrees of flood risk and urban features found in each area. It is clear that each zone requires unique techniques, from targeted urban design concerns in densely populated neighbourhoods to sustainable drainage systems in industrial areas. Urban planners and authorities can develop specialized solutions to improve flood resilience and protect the well-being of Porto Velho‘s residents by knowing the distinctive characteristics and dangers associated with these zones.

## 5.8 Conclusion

Addressing urban flooding in Porto Velho requires a multi-faceted approach that considers the city's unique needs and challenges. To conclude, in order to manage the urban floods, preparing a new structural plan according to the city's needs is important and also analysing the flood risk areas according to different criterias plays a vital role.

The main needs for managing urban flooding in Porto Velho include improving drainage systems, enhancing flood monitoring and early warning systems, and implementing sustainable land use planning. Preparing a new structural plan with using zoning framework will help the water-sensitive issues. Design positive structural plan will lead us to defining problematic areas quickly and easy to implement solutions.

Local government representatives, urban planners, civil engineers, environmental agencies, and community people are among the essential participants in this project. These parties must work closely together to create and put into action efficient flood adaptation strategies. Infrastructure improvements, land use restrictions, and community involvement programmes can all be used to carry out these measures. Increased resilience, better urban planning, and potential financial gains are advantages linked with adaptation measures for flood management. The development of green infrastructure, the adoption of construction rules that are flood resistant, and zoning laws that protect floodplains could represent the most successful strategies in the Brazilian setting. These solutions have benefits like increased public health and decreased property damage but they also have drawbacks like high costs and difficult implementation.

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## References

Field, C. B., et al. (1998). Primary production of the biosphere: Integrating terrestrial and oceanic components. *Science, 281*(5374), 237–240. https://doi.org/10.1126/science.281.5374.237

Figueiredo, R. D. O., Cak, A., & Markewitz, D. (2020). Agricultural impacts on hydro biogeochemical cycling in the Amazon: Is there any solution? *Water, 12*, 763. https://doi.org/10.3390/w12030763

Giffard, P., Llovel, W., Jouanno, J., Morvan, G., & Decharme, B. (2019). Contribution of the Amazon River discharge to Regional Sea level in the tropical Atlantic Ocean. *Water, 11*, 2348. https://doi.org/10.3390/w11112348

IBGE. (2023). *Brazilian Institute of Geography and Statistics*. Retrieved September 1, 2023

IPEA. (2019). *Atlas da violência*. Retrieved September 1, 2023, from https://www.ipea.gov.br/atlasviolencia/dados-series/20

Li, D., Lu, D., Moran, E., & da Silva, R. F. B. (2020). Examining water area changes accompanying dam construction in the Madeira River in the Brazilian Amazon. *Water, 12*, 1921. https://doi.org/10.3390/w12071921

McHarg, I. L. (1969). *Design with nature*. Doubleday/Natural History Press.

Paca, V. H. D. M., Espinoza-Dávalos, G. E., Moreira, D. M., & Comair, G. (2020). Variability of trends in precipitation across the Amazon River basin determined from the CHIRPS precipitation product and from station records. *Water, 12*, 1244. https://doi.org/10.3390/w12051244

Tian, K., Wang, Z., Li, F., Gao, Y., Xiao, Y., & Liu, C. (2021). Drought events over the Amazon River basin (1993–2019) as detected by the climate-driven Total water storage change. *Remote Sensing, 13*, 1124. https://doi.org/10.3390/rs13061124

Vergopolan, N., & Fisher, J. B. (2016). The impact of deforestation on the hydrological cycle in Amazonia as observed from remote sensing. *International Journal of Remote Sensing, 37*, 5412–5430. https://doi.org/10.1080/01431161.2016.1232874