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BRUNO JOSÉ DE OLIVEIRA SOUSA

Stormwater best management practices (BMPs) in Brazil: citizen viewpoints, construction costs, and ecosystem services

Versão corrigida

São Carlos - SP

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Master thesis presented at São Carlos School of Engineering, University of São Paulo, in partial fulfillment of the requirements for obtaining the Degree of Master in Science.

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ABSTRACT

Sousa, B. J. de O. (2021). *Stormwater best management practices (BMPs) in Brazil: citizen viewpoints, construction costs and ecosystem services*. (Master Thesis). São Carlos School of Engineering, University of São Paulo, São Carlos.

Stormwater Best Management Practices (BMPs) may be a way to reduce the impacts of climate and land use and land cover change. However, there is a lack of studies regarding their application considering citizen viewpoints, their construction costs, and the reduction of flood risk. Therefore, the objective of this study is to understand how people see the use of stormwater BMPs as a form of adaptation and evaluate construction costs and runoff reduction. The first part consisted of analyzing if public participation may improve the application of stormwater BMPs. This was done by creating an online survey to investigate Brazilian citizens' opinions about the use of stormwater BMPs and evaluating the data graphically and statistically concerning the participants' socioeconomic characteristics. Then, the second part was an evaluation of stormwater BMPs' construction costs and the attenuation of floods they may provide. The costs were accessed through the Brazilian National Research System of Construction Costs and Indices (SINAPI). Flood reduction, on the other hand, were analyzed in terms of runoff reduction and treatment of the impervious area. Most of the respondents supported public investment in stormwater BMPs and some socioeconomic characteristics influenced their perception. Furthermore, most of the respondents showed a willingness to apply these practices in lot scale, even if they found infrastructural techniques to be more efficient. Regarding the construction cost analysis, the values determined varied for the seven scenarios considered. The higher cost did not mean more reduction in runoff, and an infrastructure technique may be more expensive with the same efficiency as large-scale use of individual techniques. The data here provided may help the decision-making for the creation of plans to implement or incentive stormwater BMPs. In addition, it may serve as a framework for future studies.

Keywords: stormwater management, citizen engagement, BMP cost benefit analysis, urban drainage.

RESUMO

Sousa, B. J. de O. (2021). *Técnicas compensatórias de drenagem no Brasil: dados cidadãos, custo de construção e serviços ecossistêmicos.* (Dissertação de Mestrado). Escola de Engenharia de São Carlos, Universidade de São Paulo, São Carlos.

Técnicas compensatórias de drenagem podem são uma forma de reduzir os impactos das mudanças climáticas e de uso e ocupação do solo. No entanto, faltam estudos a aplicação de técnicas compensatórias de drenagem (TCs) considerando dados cidadãos, custos de construção e a recuperação de serviços ecossistêmicos por essas técnicas. Portanto, o objetivo deste estudo é compreender os pontos de vista da população em relação às técnicas compensatórias de drenagem como uma forma de adaptação além de avaliar os custos de construção e os serviços ecossistêmicos recuperados por essas práticas. A primeira parte do estudo consistiu em analisar como a participação pública pode melhorar a aplicação de técnicas compensatórias de drenagem. Isso foi feito criando uma pesquisa online para investigar as opiniões dos cidadãos brasileiros sobre o uso de TCs. Primeiro, dados foram avaliados de forma gráfica e análise estatística em relação às características socioeconômicas dos participantes. Em seguida, uma análise dos custos de construção das TCs escolhidas seguido da avaliação dos serviços ecossistêmicos que eles podem fornecer. Os custos foram computados usando o Sistema Nacional de Pesquisa de Custos e Índices da Construção (SINAPI). Já os serviços ecossistêmicos foram analisados em termos de redução do escoamento e do tratamento de áreas impermeáveis. A maioria dos entrevistados apoiou o investimento público em BMPs de águas pluviais e algumas características socioeconômicas influenciaram sua percepção. Além disso, a maioria dos respondentes demonstrou disposição em aplicar essas práticas em escala de lote, mesmo que as técnicas de infraestrutura foram consideradas mais eficientes. Em relação à análise do custo de construção, os valores apurados variaram para os sete cenários assumidos que incluíam trincheiras de infiltração, pavimento permeável e coleta de água da chuva em diferentes proporções. Os resultados mostraram que custo mais alto não significa a recuperação de mais serviços ecossistêmicos, e uma técnica de infraestrutura pode ser mais cara com a mesma ou menos eficiência do que o uso em larga escala de técnicas individuais. Os dados aqui fornecidos podem auxiliar na tomada de decisão para a criação de planos de implantação ou incentivo de TCs e servir de base para estudos futuros.

Palavras chave: gestão da drenagem urbana, dados cidadãos, análise de custo-benefício, técnicas compensatórias de drenagem.

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1 GENERAL INTRODUCTION

Changes in land use, such as deforestation for urban or agricultural development, population and economic growth, and climate change destabilize the water balance, causing extreme events and many places are unable to absorb these changes (ANA, 2019). In Brazil, floods represented 34.9% of disasters that happened between 2000 and 2015 (DE FREITAS et al., 2020). In addition, they cause high socioeconomic destruction and human losses. Therefore, stormwater BMPs may be an option to mitigate the effects of urban flash floods caused by rivers or stormwater channels that overflow, when stormwater cannot infiltrate in the soil or go to a water body, accumulating on the street, or when the water moves with high energy carrying objects such as cars on the streets, they usually happen at places with steep topography. As they are the most affected by these events, the population should also be engaged in stormwater management.

BMPs (Best Management Practices) are used to reduce peak flow and water speed in high precipitation events, thereby reducing erosion (KRAUZE; WAGNER, 2019). It also includes the recovery of areas that have undergone Land Use and Land Cover Change (LULC) or the addition of land-use practices in agriculture, for example (MAES; JACOBS, 2017). They promote infiltration, serving as an option to increase water levels in the soil (ECKART; MCPHEE; BOLISETTI, 2017), which is in line with one of the dimensions of resilience of the Brazilian National Plan for Water Security, providing soil water storage (AGÊNCIA NACIONAL DE ÁGUAS, 2019). In addition, BMPs can reduce pollution carried by surface flow and decrease the entry of fertilizers into rivers (LAFORTEZZA et al., 2018). All these characteristics contribute to improving the environment and people's ability to absorb climate change and adapt to future climatic and LULC conditions, increasing their resilience (SIMONOVIC, 2016).

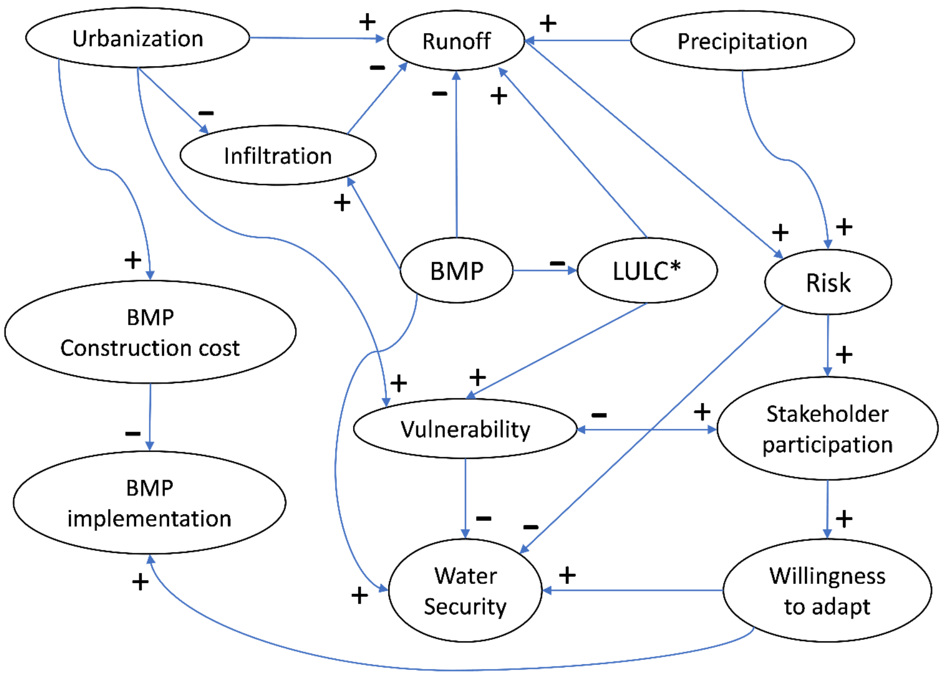
Stakeholder engagement should be promoted in data collection or consultation, which increases the likelihood that they will accept and apply changes, increasing their sense of ownership and responsibility (MCKINLEY et al., 2017; NJUE et al., 2019). For this purpose, citizen science is a non-traditional way to gather data that has been used in many areas, including urban hydrology, generating data with good quality (FAVA et al., 2018; FRITZ et al., 2019). Thus, it may help the promotion and implementation of stormwater BMPs.

People also need to know the construction and maintenance costs and the benefits generated by these practices. Therefore, BMPs may be evaluated the benefits in terms of runoff reduction in comparison to the budget necessary to build them. This analysis is an option to incentive-decision makers to implement these practices, incentive the use of such practices by citizens and gather the support of the population. Runoff reduction is considered an ecosystem service of regulation of extreme events (BRAZIL, 2021; TEEB, 2011). The costs can be computed in Brazil using the National Research System of Construction Costs and Indices (SINAPI, 2021) which is based on the costs of materials and labor in the different states of the country.

The causal loop diagram on figure 1 relates stormwater BMPs with the other variables and justifies this research. The intensification of extreme precipitation events produces more runoff, which is influenced negatively by the land's capacity of infiltration that has been being reduced by urbanization. In this context, various BMPs are valuable tools to reduce the runoff, increase infiltration, and capture sediments. On the other hand, LULC and Demography increase runoff, which is one of the factors that increase the risk of floods. In this context, it is expected that Stakeholders' engagement grows with vulnerability and risk. Therefore, increasing their willingness to adapt, improving the levels of water security and the chances of implementation of stormwater BMPs. However, construction cost is also a crucial characteristic when considering a public investment.

This dissertation is organized as follows. The first chapter consists of a general introduction to the study. It includes the hypothesis tested and the general and specific objectives of the study. In chapter 2 it was assessed whether a series of socioeconomic factors and the history of floods influenced the choices of citizens and the acceptance of BMPs. The citizens' Willingness to Adapt (WTA) implementing BMPs on their properties and their Willingness to Pay (WTP) to build and maintain such structures as a way of adapting to the changes caused by climate change and land use and cover is also explored. In chapter 3 the construction costs of stormwater BMPs, as well as the return they may provide, are evaluated in an urban watershed in Campo Grande, Mato Grosso do Sul, Brazil. As BMP construction costs increase proportionally with urbanization, its optimization may increase implementation of these practices. At last, chapter 4 brings the general conclusions of this study and recommendations for future works.

Figure 1 - Relationship between hydrological and social variables and stormwater BMPs. They indirectly reduce risk and increase water security as a form of planned adaptation to the effects of changes in land use and occupation and climate.



Source: Prepared by the author (2021)

1.1 OBJECTIVES

Assess whether the use of citizen science improves the decision-making process regarding the creation of flood adaptation plans using stormwater best management practices.

Hypothesis 1: The population's participation improves the decision-making process for the application of compensatory drainage techniques.

- Identify if the population knows what drainage BMPs are;

- Determine the selection criteria used by the population and if the population is willing to adopt compensatory drainage techniques as a long-term adaptation to floods.;
- Analyze whether there is a relationship between their criteria and socioeconomic factors;

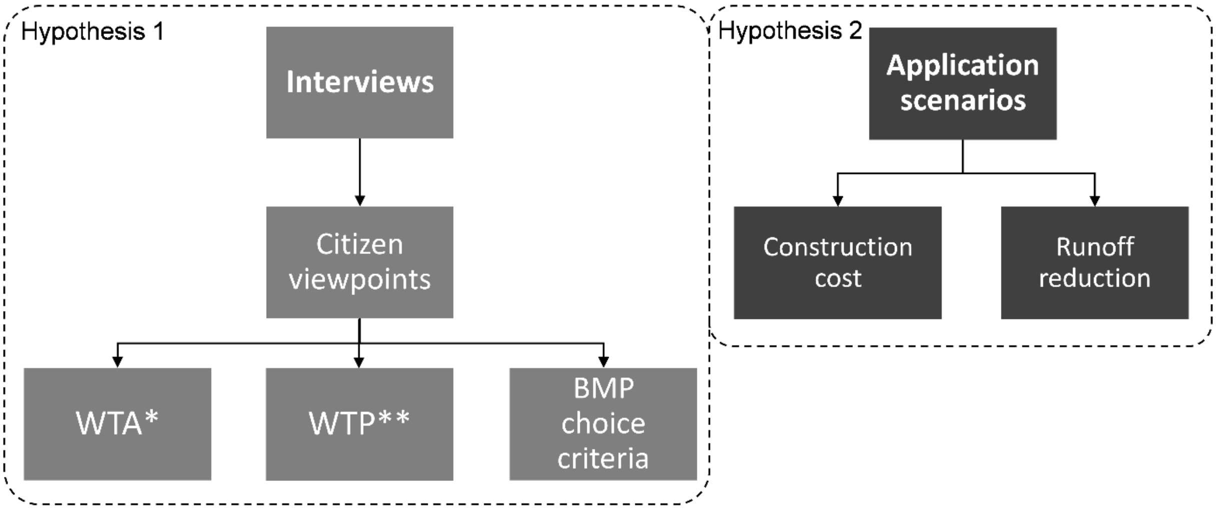
Hypothesis 2: The evaluation of stormwater BMPs' construction costs and ecosystem services may help the choice of techniques to apply.

- Evaluate the construction costs of different stormwater BMP application scenarios;
- Analyze how these scenarios differ in terms of providing ecosystem services.

1.2 DELINEATION OF THE STUDY

The study is divided into two stages, one for assessing social perception concerning compensatory techniques and the other for cost analysis of the application of these techniques in urban basins. Thus, Figure 2 below explains the steps of this research. The interviews were be used to assess the population's criteria for choosing compensatory techniques. The second part consists of a comparison among the construction cost of BMP application scenarios in an urban basin in Campo Grande, Mato Grosso do Sul.

Figure 2 - Delineation of the study. *Willingness to Adapt; **Willingness to Pay.



Source: Prepared by the author (2021).

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2 CITIZENS’ VIEWPOINTS ON STORMWATER BEST MANAGEMENT PRACTICES (BMPS) IN BRAZIL

A modified version of this chapter was submitted as: SOUSA, B. J. DE O.; FIALHO, H. C. P.; TAFFARELLO, D.; SOUZA, F. A. A.; HASSANZADEH, E.; MENDIONDO, E. M.; DE OLIVEIRA, P. T. S. Citizens’ viewpoints on stormwater Best Management Practices (BMPs) in Brazil. Journal of cleaner Production.

Abstract: Stormwater Best Management Practices (BMPs) are a set of strategies to reduce urban floods and their damages by capturing surface runoff and promoting infiltration. Engagement of citizens in BMP selection can facilitate the decision-making process and increase the chance of adopting these practices. Here, we explore Brazilian citizens’ viewpoints on a set of structural stormwater BMPs in relation to their socioeconomic profiles. For this purpose, online surveys were used to access wide and diverse groups of citizens from different ages, level of education and income, as well as geographical locations. The questions and description of BMPs were prepared in an accessible language. We received 1017 responses from 26 Brazilian states. Our results show that the respondents found the retention and detention basins, as well as permeable pavement as the most efficient BMPs. Considering the small-scale practices, although they found lot related BMPs are less efficient, they are willing to use green roof, bioretention, and rain barrel in their houses or properties. In addition, most of the respondents support public investment on stormwater BMPs. We found that participants’ age and level of education such as their knowledge of stormwater BMPs, willingness to pay, and public investments in BMP infrastructure statistically influenced their responses. In addition, we found that the socioeconomic profile of the respondents also affected their BMP efficiency perception. These results can help decision makers choose relevant BMPs that match with the viewpoints of Brazilian citizens.

Keywords: stormwater, Best Management Practices, BMP, flood, Brazilian citizen’s viewpoints.

2.1 INTRODUCTION

Frequent and intense extreme rainfall events over impervious surfaces have caused formation of severe floods in various cities across the globe, increasing human and material losses (Blöschl et al., 2019). In Brazil, floods have caused high socioeconomic destructions and human losses. Specifically, 34.9% of disastrous events between 2000 and 2015 in Brazil are related to floods (de Freitas et al., 2020). More recently, in the state of minas Gerais, for example, floods caused losses of approximately 230 million dollars in January 2020, making around 90 thousand people have to temporarily leave their houses. This shows the country's vulnerability to flash floods has been increasing. Therefore, with the increasing population in the cities, it is critical to implement strategies to mitigate the effects of urban flooding.

Stormwater Best Management Practices (BMPs) under two categories of structural and non-structural strategies are commonly used worldwide to reduce urban flooding (Kuller et al., 2019). Non-structural strategies use watershed characteristics to reduce floods. Some examples include protecting the riparian buffer, stormwater disconnection, and improving flood warning systems (Fava et al., 2020; Meyer et al., 2012; Shakibamanesh, 2011). Structural strategies, on the other hand, require interventions and investments (Priest et al., 2011), e.g., use of permeable pavement, construction of retention and detention basins, infiltration trenches, swales. These practices are also called Low Impact Development (LID), Sustainable Urban Design (SUD), or Water Sensitive Urban Design (WSUD) (Krauze and Wagner, 2019; Lafortezza et al., 2018; Macedo et al., 2017; Maes and Jacobs, 2017).

The structural-based BMPs have been widely used in urban areas to reduce runoff, peak flows and water velocity, and thereby reduce soil erosion and flooding, as well as improve water quality (Lafortezza et al., 2018; Li et al., 2018; Locatelli et al., 2017; Seo et al., 2017; Sungji et al., 2020). Therefore, implementing these practices can increase the cities' ability to adapt to changing climate and land use and land cover conditions (Simonovic, 2016). For instance, an experiment conducted in an urbanized area in Italy showed that covering only 30% of the available buildings with green roof, and 30% of the impervious surfaces with permeable pavement would reduce 25% of the runoff generated in the area (Palermo et al., 2020). In another study, permeable pavement was effective in removing more than 85% copper and 65% zinc from synthetic rainfall samples (Turco et al., 2020). The performance of stormwater BMPs can vary from a region to another depending on their number or combination, intensity of rainfall, density and distribution of houses (Liu et al., 2016; Pirouz et al., 2020; Rodrigues et al., 2021). De Macedo et al. (2019) found that a bioretention system in São Carlos, São Paulo, Brazil had a 75% runoff reduction efficiency and showed that the water stored in the practice could be used for non-potable purposes. Most of these practices can be implemented in lot scale or neighboring areas, promoting stormwater disconnection; however, we depend on the citizens' willingness to accept these practices. In addition, their runoff and pollution reduction efficiencies can reduce over time and they will need maintenance (de Macedo et al., 2017; Sungji et al., 2020). This highlights the co-responsibility between the governments and citizens to implement and maintain such practices. Hence, citizen viewpoints can also become a variable into stormwater management.

Despite the rich body of literature on the efficiency of stormwater BMPs in reducing floods and diffuse pollution (Ahiablame et al., 2012; Dietz, 2007; Eckart et al., 2017; Fach et al., 2011), the influence of local citizens and their willingness to adopt these practices is not well established (Nardi et al., 2020). However, it is commonly known that the social engagements allow understanding stakeholders' experience and knowledge, as well as co-development of action plans that are in line with public viewpoints (Hassanzadeh et al., 2019; Zammali et al., 2021). Moreover, it is often mentioned that stakeholder engagement can increase their sense of ownership and responsibility, which can lead to successful implementation and promotion of BMPs (Bradford et al., 2020; Degrossi, 2014; McKinley et al., 2017). In the context of cities, social studies show that the residents often have diverse opinions regarding the BMPs (Kaplowitz and Lupi, 2012; Qiu et al., 2014). Therefore, participation of local residents can lead to better understanding their viewpoints, requirements, and feasibility of practices, which can facilitate decision-making processes (Ugolini et al., 2015).

Kaplowitz and Lupi (2012) used a choice experiment, where programs or scenarios and their characteristics are presented to the participants so that they chose their favorite one. The authors found that it is important to investigate preferences of stakeholders and identify their priorities to choose BMP for stormwater management. Interestingly, in the same community, while some stakeholders may prioritize economic benefits, others care more about the environmental consequences (Du et al., 2019). This highlights the importance of stakeholder consultation to meet their needs. Cadavid (2013) also used a choice experiment to study stormwater management and found that impact of policies is not equal on all stakeholders but in general citizens are willing to engage in implementation and maintenance of stormwater BMPs.

In this study, we also evaluate the participants availability to pay for the construction of stormwater BMPs in lot scale (Willingness To Pay – WTP), and their acceptance of these practices (Willingness To Accept - WTA). Both of these concepts can be related to social factors such as age, income and, in terms of stormwater BMPs, individual experiences with flood (Entorf and Jensen, 2020; Viscusi and Huber, 2012; Wang et al., 2017, 2020).

The objective of this study is to investigate the citizens' viewpoints on stormwater BMPs and their implementation with a greater goal of proposing adaptation plans to manage urban floods in Brazil. For this purpose, we evaluated whether a series of socioeconomic factors and the history of flooding influenced the citizens' choices and acceptance of the BMPs. The survey was applied online, and we received 1017 answers from 26 Brazilian states. The outcomes of this study can improve the use of stormwater BMPs through affordable information from and to citizens in compliance with the Brazilian New Framework of Sanitation (Brazil, 2020).

2.2 MATERIALS AND METHODS

A combination of quantitative and qualitative methods was used to understand citizens' perception about stormwater BMPs and their applications, as well as WTP and WTA in long-term. In addition, since socioeconomic variables such as income, education, and age might influence the choice or priorities of people (Qiu et al., 2014; Tassi et al., 2016), we aimed to understand the relationships between the viewpoints of citizens and these factors. Therefore, we can better understand the differences among the needs of different classes of society and how they influence the selection of BMPs (Venkataramanan et al., 2020).

Before launching the real survey, we conducted a survey pilot to improve the description of the BMPs and ensure the clarity of the questions. For this purpose, we shared an initial version of the questionnaire using social media platforms with people from various ages and backgrounds within our network, and with laboratory colleagues. The wording of questionnaire was then refined based on the feedbacks received, e.g., on utilized terminologies, to make the language more accessible to people from any region or level of education.

The modified questionnaires were virtually shared with potential participants such as university students and professors from different states, researchers, government sectors such as city councils and civil defense and the general public. We used an adaptation of the snowball sampling method to spread the questionnaires by asking the participants to distribute the same invitation letter among their network (families, friends, relatives, colleagues, etc), then each respondent would distribute the invitation to another group of possible participants (Edgar and Manz, 2017). The invitations were disseminated through multiple social media platforms, mobile text messages and email. Using this approach, we could reach individuals from multiple regions, with different levels of education and age in a short period of time. In total, 1017 responses were recorded between June 23 and July 31, 2020.

2.2.1 Stormwater BMPs

Stormwater BMPs that were considered in this study are retention and detention basins (R/DP); infiltration trenches (IT); swales (SW); rain barrel (RB); bioretention (BR); permeable pavement (PP); as well as green roof (GR). These practices were chosen based on their popularity and the fact that they are commonly used in other studies and in Brazilian applications (Aceves and Fuamba, 2016; de Macedo et al., 2019; Dietz, 2007; Eckart et al., 2017). The questionnaire also contains explanations of these BMPs with a plain language (see Table 1). Similar to the survey questions, these definitions were validated with random people to ensure their transparency.

Table 1 - Descriptions of seven BMPs included in the survey.

Name	Description
Retention and detention basins	Tanks built to store part of the rainwater so that it does not go all at once to the drainage system, channel, or river.
Infiltration Trenches	Open channels that slowly decrease water velocity, and transport it to other techniques or channels and rivers. They allow water to penetrate the soil through a layer of gravel that filter rainwater and reduce the pollution that goes into the rivers.
Swales	Open channels with plants or grass that slow down the water, transport it to other techniques or channels and rivers, and allow it to penetrate the soil and the plants reduce the pollution that goes into the rivers.
Rain Barrel	Collection of water that comes from residential or industrial roofs for indoor use. It decreases the amount of water that goes to the street.
Bioretention (rain garden)	Small reservoirs with layers of soil, sand and gravel that store and filter water and allow it to penetrate the soil. The top of the soil layer has plants that also help to reduce water pollution.
Permeable pavement	Material for building streets and avenues that allow water to penetrate the soil, reducing the amount of water that goes into channels and rivers or accumulates in the streets.
Green roof	Plants placed on the tops of buildings or roofs of houses to reduce the amount of water that goes from the lots to the streets.

Source: Prepared by the author (2021)

2.2.2 Questions and variables

Our survey included different types of questions. First, a few questions were related to participants' socio-economic profile such as age, income, profession, level of education, and being a rural or urban residence (Wang et al., 2020). These questions were classified as independent variables. Then, 9 specific questions related to urban flooding and BMPs, shown in Table 2, were posed. In brief, in question 1, participants were asked if they had been affected by floods in the past to understand whether their experiences can influence their knowledge and viewpoints about floods or not. Questions 2 to 7 were about people’s knowledge about the BMPs, usage of these practices, willingness to adopt as well as WTP for their construction and maintenance. Questions 8 and 9 were posed using 5-Point Likert Scale (Preedy and Watson, 2010) and were related to support for public investment on BMPs as well as the efficiency of practices. For these questions, participants could choose an option based on their attitude towards the efficiency of each stormwater BMP (Ajzen, 1991; Chen, 2016).

Table 2 - Survey questions used in the web forms along with their possible answers.

	Questions	Answer options
1	Have you been affected by floods?	Yes No
2	Do you know what stormwater BMPs are?	Yes No
3	Do you know any of the BMPs listed?	Retention and detention basins Infiltration Trenches Swales Rain Barrel Bioretention (rain garden) Permeable pavement Green roof None
4	Do you have any of these BMPs in your house/property?	Same BMP options as before
5	Would you use any of these BMPs in your house/property?	Same BMP options as before
6	Have you seen any of these BMPs in you the city where you live?	Same BMP options as before
7	Would you pay to build and maintain BMPs in your house/property?	Yes No Yes, if I received public incentive
8	Do you support public investment on BMPs to reduce floods?	Support strongly Support Neutral Against Totally against
9	Which of these practices do you think are more efficient? (Sort the practices based on their efficiency).	Very efficient Efficient Neutral Inefficient Totally inefficient

Source: Prepared by the author (2021).

2.2.3 Data analysis

The data analyses were divided into descriptive and statistical evaluation, for which we used bar charts and chi-squared tests. As previously noted more than 1000 answer sheets were received for our survey, which were then archived, organized, and analyzed. We also organized the tables using the percentage of answers to the questions. Chi-squared tests are usually applied to investigate there is a significant statistical relationship between two categorical variables (Du et al., 2019).

In questions 3, 4, 5 and 6 the participants were asked about their knowledge of the BMPs considered, if they had or were available to have these techniques in their properties, and their perception of these techniques in their cities. With that information we could know what of these BMPs have been used in the country, according to citizens, both in lot and city scales. Moreover, the results could show what BMPs the respondents are more willing to apply in the lot scale.

The responses to Questions 1, 2, 7 and 8 were separated by the categories of age, education, income, and if the participant were affected by floods or not in the past to assess the implication of these parameters in the public opinion and experience. The data was organized in tables containing the number of responses for each group. Consider the example of question 1, the columns in the tables represented the age groups and the rows represented the answer yes or no, therefore we knew how many times respondents in age group 1 answered yes or no and so on. Then, the Chi-square statistical test applied to verify if an individual category was statistically related to the answers. To apply the Chi-squared tests, the categorized results were transferred to Past software, version 4.01 (Hammer et al., 2001). We considered the following hypothesis: the null hypothesis (H0) meant that the answers to questions 1, 2, 7, and 8 are statistically independent from the considered socioeconomic variables. Thus, considering a significance level of 95%, if p was above 0.05, H0 was accepted. If p was smaller than 0.05, H0 was rejected, meaning that the analyzed socioeconomic factor may have influenced the provided response. The results of these analyses can help to adapt BMP implementation plans to the regions depending on the relationship found between the answers and their socioeconomic characteristics. If a region or group of stakeholders have limited knowledge about the practices or flood management in general, the results can also help to promote awareness campaigns.

The correlation between citizens' opinions on the efficiency of the stormwater BMPs and the other factors was also verified. For this purpose, in Question 9 participants were asked to sort the BMPs based on their performance as totally inefficient, inefficient, neutral, efficient, and very efficient. To analyze these answers, we transferred the ratings into numbers, ranging from 1 to 5, based on 5-Point Likert Scale. We then calculated a weighted average of these answers using Equation 1 (Du et al., 2019).

$$T = \sum x \times p \tag{1}$$

where T is the total score (between 1 and 5), x is the value attributed to each of the five possible answers, and p is the percentage of people that selected each option.

In addition, we transformed qualitative data into numbers to quantitatively analyze them. The groups of age, level of education, income, geographic region, being affected by floods or not, knowledge of BMPs and WTP were transformed into the numbers. Then, we could produce the frequency of each answer given in 5-Point Likert Scale to each of the seven practices considered for each different group. For example, how many times respondents in age group 1 assigned score 1 to bioretention in question 9. At last, we produced seven tables for each characteristic with the 5-Point Likert Scale on the side and groups on the top. These tables were also transferred to Past software and tested using Chi-squared tests following the hypothesis: the null hypothesis (H0) is that there is not a statistically significant relationship between answers from 5-Point Likert Scale questions and the other variables (age, level of education, income, geographic region, being affected by floods, knowledge of BMPs and WTP). Therefore, considering a significance level of 95%, if $p > 0.05$, H0 was accepted. If $p < 0.05$, H0 was rejected, meaning that the variable may have a statistical relationship with the viewpoints regarding the efficiency of the stormwater BMPs.

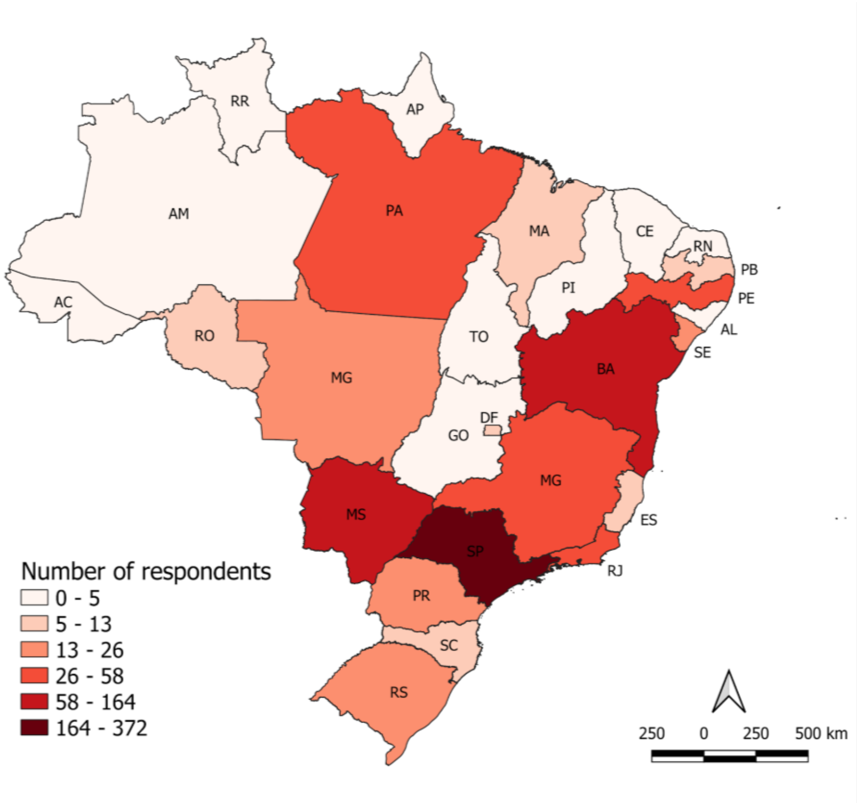
If one category presented a significant statistical relationship with the opinion of the population regarding most of the BMPs considered, a detailed graph using the score for each BMPs was made to show the answers of each group.

2.3 RESULTS

2.3.1 Socioeconomic characteristics of respondents

Regarding the spatial distribution of the respondents in the country (Figure 3), from the 1017 respondents in 26 Brazilian states, 36.6% were from the state of São Paulo in the Southeast, 16.1% were from the state of Mato Grosso do Sul in the central-west and 12.9% were from Bahia in the Northeast region. The rest of the respondents (34.4%) were from other states of the country. Such spatial distribution of respondents seems to be logical as the dissemination of the questionnaire started at the University of São Paulo and Federal University of Mato Grosso do Sul. In addition, most of the country's population is concentrated in the Southeast region. The state of São Paulo, for example holds more than 21% of the Brazilian population (IBGE, 2021). At the same time, it is interesting to see how far in the country the questionnaires have gone, which imply the effectiveness of utilized dissemination approaches.

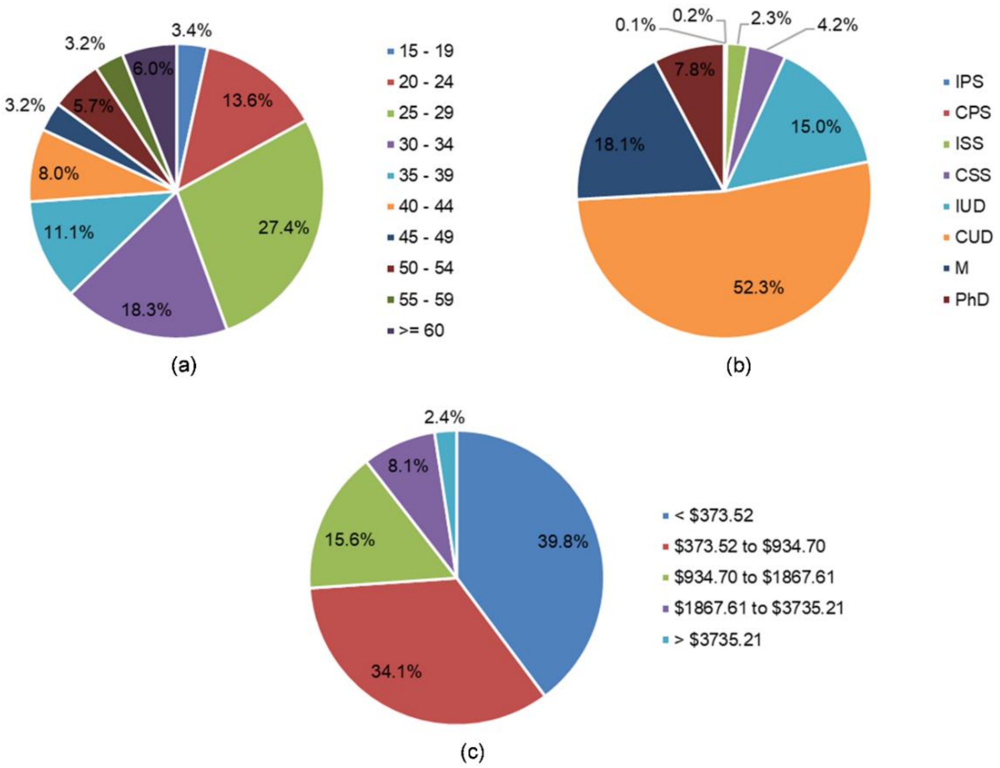
Figure 3 - Distribution of the respondents throughout the country, separated by states.



Source: Prepared by the author (2021).

Figure 4 shows the distribution of socioeconomic specification, e.g., age, education, and income of the respondents. We had the highest participation from the age group of 25–29 years old followed by the group between 30–34 years old. Most of the respondents had a middle to higher monthly income. In fact, 73.9% of respondents' income ranged from less than 373.52 to 934.70 USD and only 36,1% of them had a monthly income higher than 934.70 USD. It should be noted that during the time of survey one USD was equal to 5.59 BRL on August 24th, 2020.

Figure 4 - Socioeconomic profile of the 1017 respondents. a) age, b) level of education, c) income. IPS: Incomplete Primary School; CPS: Complete Primary School; ISS: Incomplete Secondary School; CSS: Complete Secondary School; IUD: Incomplete Undergraduate Degree; CUD: Complete Undergraduate Degree; M: Master. ($1,00 = R$5.59 24/08/2020 https://www.bcb.gov.br/)



Source: Prepared by the author (2021).

More than half of the respondents had an undergraduate degree. A few respondents did not finish secondary school (2.6%) and, in the other extreme, 79 of the participants (7.8%) had a doctorate degree. In fact, the percentages of respondents that have bachelor, master's, and doctorate degrees in this study are above the national average. In 2010, people at master's and doctorate levels represented 0.4% and 0.1% of the total Brazilian population, respectively (CGEE, 2015; CGEE, 2019). Moreover, the percentage of people equal or above 25 years old that completed secondary school was 15.5% in 2018 (IBGE, 2019), which is closer to the percentages in our survey.

As noted previously, the relationships between participants' socioeconomic characteristics and their responses to the questions were analyzed statistically by applying the Chi-squared test (see Table 3). The results show a significant relationship between participant's age and level of education and their knowledge of BMPs, WTP and support for public investments on the practices (null hypothesis was rejected, see p-values < 0.05 in Table 3). Therefore, age and level of education may have affected the responses to questions 2, 7 and 9. Moreover, the relationship between people's knowledge of BMPs and their geographic region was significant too as the null hypothesis was rejected, showing the influence of this factor in answering question 2. Interestingly, no significant relationship was found between people's level of income or past experiences with flood and their knowledge of BMPs or willingness to pay or even support of public investments for stormwater management practices.

Table 3 - Results of Chi-squared test, showing the correlation between three decisive variables, the socioeconomic profile of the respondents, and their experience with floods. P values lower than 0.05 show statistically significant correlations.

	Age	**Level of education**	**Monthly income**	**Geographic Region**	**Was affected by floods?**
Do you know what stormwater BMPs are?	1.06×10^{-9}*	2.486×10^{-6}*	0.17	1.08×10^{-8}*	0.646
WTP	0.01*	2.098×10^{-8}*	0.485	0.198	0.644
Support for public investments on BMPs as infrastructure	0.001*	2.094×10^{-10}*	0.69	0.503	0.222

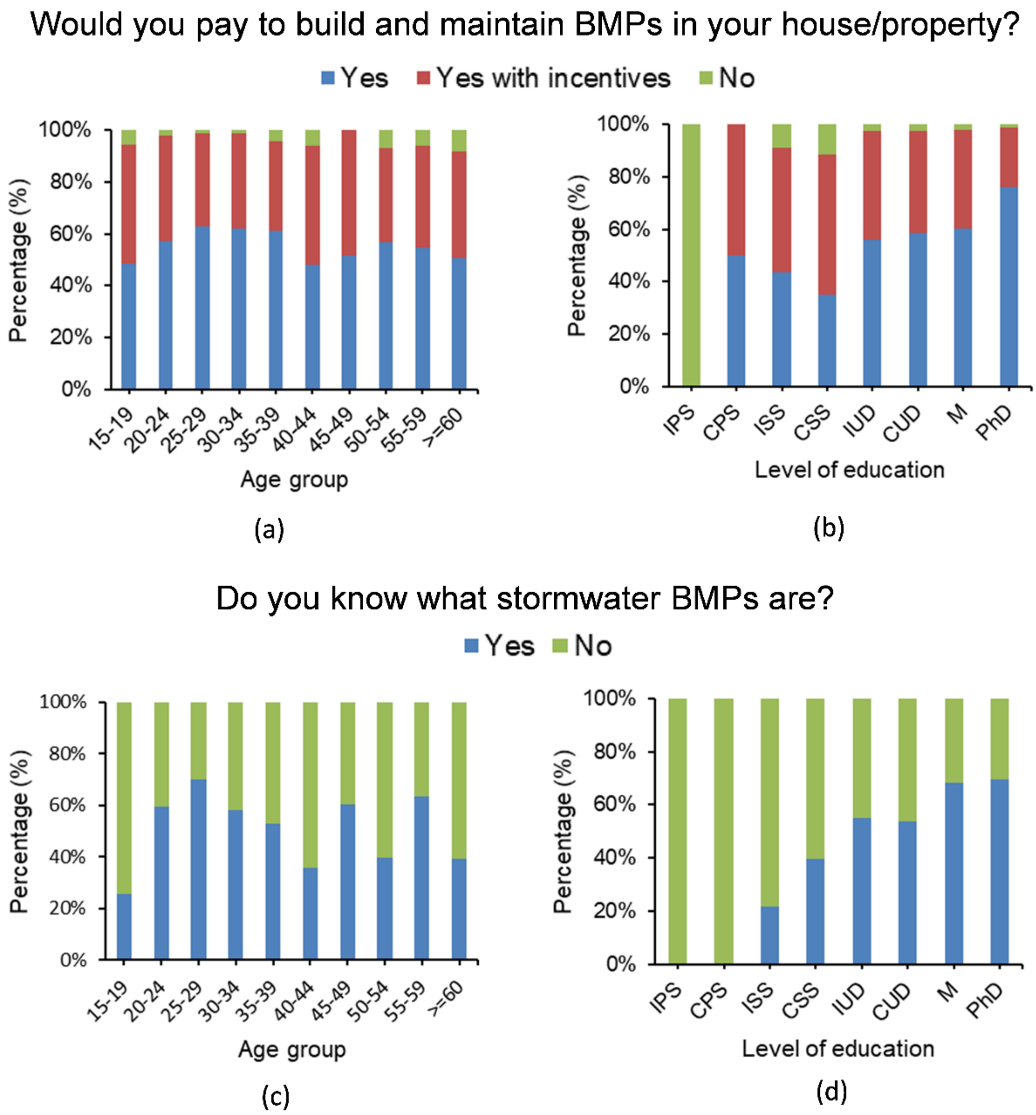
*significance level of 0.05

Source: Prepared by the author (2021)

2.3.2 Participants' level of knowledge and support of BMPs

Regarding the WTP, Figure 5a shows that receiving public incentives to implement BMPs was more favorable for respondents older than 40 years. However, participants over 50 years old do not support such as strongly as the other groups (Figure 5e). We also found that in total 52.2% of participants had some priori knowledge about stormwater BMPs, from whom about 60% belonged to the age group of 20–39 years old. Then these numbers vary from 40% to 60% for respondents older than 40 years old (Figure 5c).

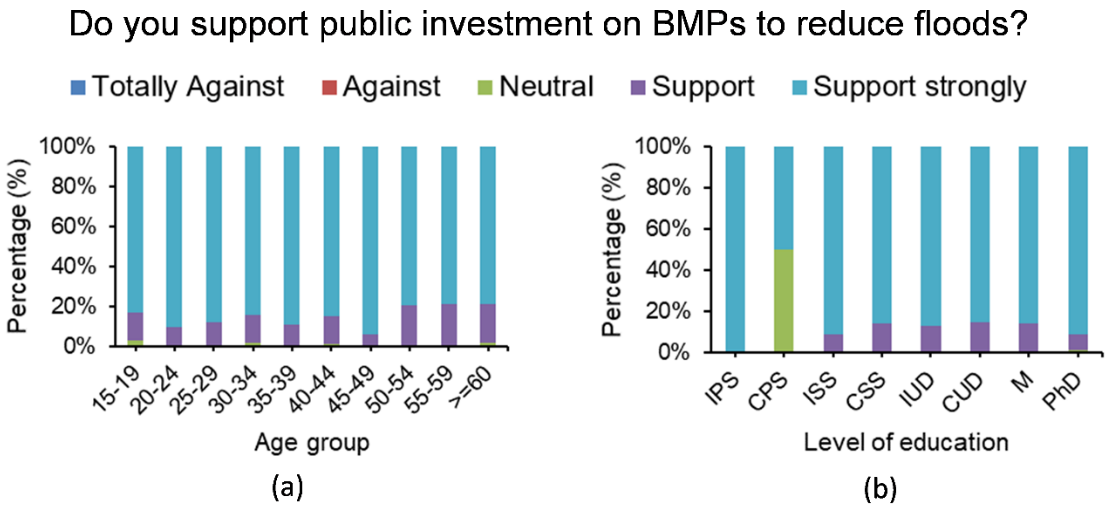
Figure 5 - Relation between people's WTP (top row) and knowledge of BMPs (bottom row) with age group (a and c) and level of education (b and d). IPS: Incomplete Primary School; CPS: Complete Primary School; ISS: Incomplete Secondary School; CSS: Complete Secondary School; IUD: Incomplete Undergraduate Degree; CUD: Complete Undergraduate Degree; M: Master.



Source: Prepared by the author (2021).

Roughly more than 50% of participants with prior knowledge of BMPs had secondary school or higher education (Figure 5d). This variation confirms the influence of education on their knowledge of BMPs, which was shown by the statistical analyses as well. In addition, WTP is higher for people that are at undergraduate, master's or doctorate levels. However, more than 70% of the respondents with PhD reveal that they would pay for construction and maintenance of BMPs without necessarily receiving public incentives. Considering the WTA, more than 80% of respondents support public investment in the BMPs (Figure 6). The graphs that compare the relationship between knowledge of BMPs, WTP and support for public investments on BMPs (WTA) and socioeconomic characteristics and experiences with floods are available in Appendix A.

Figure 6 - Relation between people's support for public investments on BMPs as infrastructure with age group (a) and level of education (b). IPS: Incomplete Primary School; CPS: Complete Primary School; ISS: Incomplete Secondary School; CSS: Complete Secondary School; IUD: Incomplete Undergraduate Degree; CUD: Complete Undergraduate Degree; M: Master.

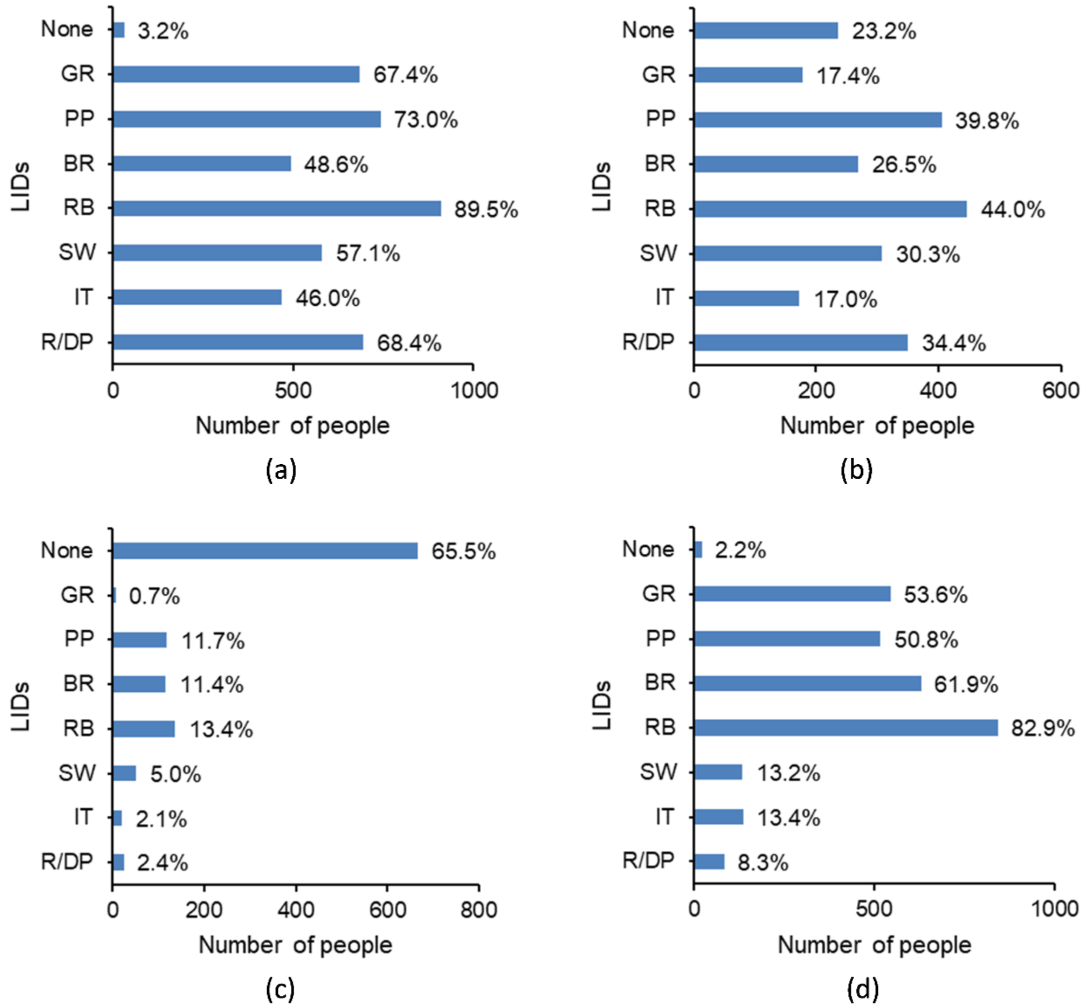


Source: Prepared by the author (2021).

2.3.3 Application and preferences of stormwater BMPs

Figure 7 shows the participants' perception of stormwater BMPs and their preferences at the lot scale. Our analyses show that almost 97% of the participants had some priori knowledge about some of these presented BMPs. While the rain barrel was known for most participants (89.5%), bioretention and infiltration trenches were the least known BMPs (46% and 48.6%). The most seen BMPs were the rain barrel (44%) followed by permeable pavement (39.8%) (Figure 7b). On the other hand, the least seen BMPs were green roof and infiltration trenches (17.4% and 17% respectively), and 23.2% of the respondents have never seen any of these techniques in their cities. Furthermore, among the seven BMPs, permeable pavement, rain barrels and bioretention have been mostly used by participants in their properties. However, 65% of the respondents have never used any of these practices yet. According to the answers, green roof is the BMP that the respondents have least applied in their houses or properties (Figure 7c). Regarding their willingness to apply stormwater BMPs at lot scale, 82.9% of participants answered that they would use rain barrels, 61.9% would use bioretention, 53.6% would use green roof and 50.8% would implement permeable pavement. Interestingly, only 2.2% of participants did not choose any of the proposed BMPs for future adaptations.

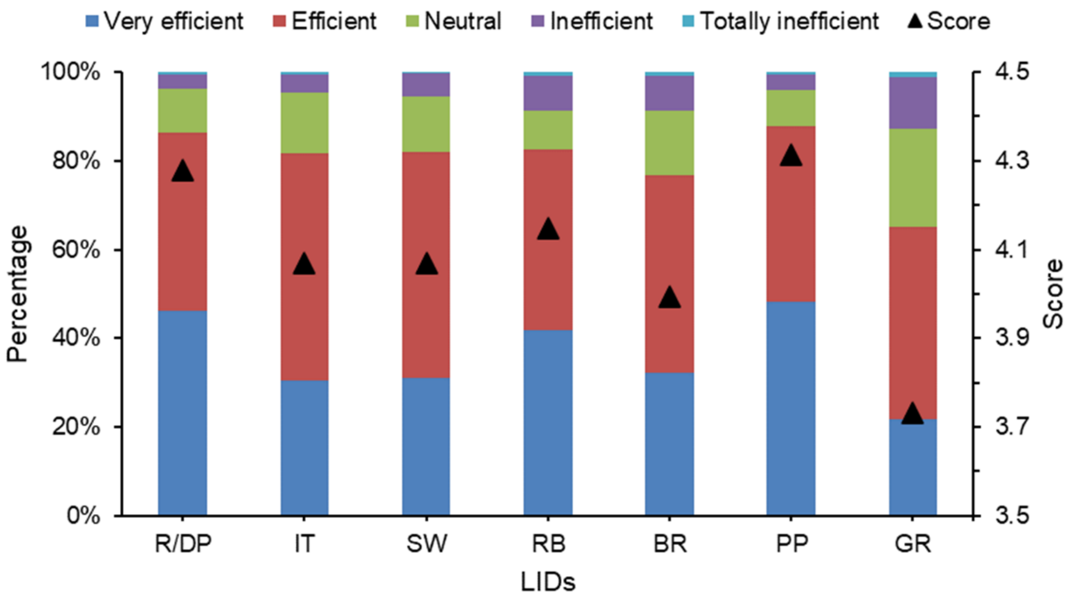
Figure 7 - Peoples' perception on BMPs and their preference for lot scale: a) Do you know any of the BMPs listed? b) Have you seen any of these BMPs in the city where you live?; c) Do you have any of these LIDs in your house/property?; d) Would you use any of these BMPs in your house/property? (WTA). R/DP: Retention basin/Pond; IT: Infiltration Trench; SW: Swale; RB: Rain Barrel; BR: biorretention; PP: Permeable Pavement; GR: Green roof.



Source: Prepared by the author (2021).

Figure 8 presents the respondents' viewpoints on the efficiency of each BMP, independent of the scale considered to reduce floods. Retention and detention basins as well as permeable pavements received the highest scores (T = 4.28 and 4.31, respectively) and more answers for very efficient BMP (more than 40%). Rain barrel was in the fourth place with T = 4.14, and infiltration trench, swale, and bioretention received scores close to 4. Green roof, on the other hand, received the lowest score, 3.73. This was the only BMP that more than 10% of the respondents found inefficient (11.41%). On the contrary, detention and retention ponds were the options that received less answers for inefficient (3.15%). 45% of the respondents believed that infiltration trenches and swales are efficient practices.

Figure 8 - Opinions on the efficiency of the types of stormwater BMPs. The bars represent the percentage of people, voted on each of the options, while the triangles show the score of each of the BMPs (T). Each bar and triangle represent the answers of 1017 people. Retention or detention basins and permeable pavement had the highest scores. They both received more answers for “very efficient” and “efficient”. R/DP: Retention basin/Pond; IT: Infiltration Trench; SW: Swale; RB: Rain Barrel; bioretention (BR); PP: Permeable Pavement; GR: Green roof.



Source: Prepared by the author (2021).

The results from the chi-square test applied to the 5-Point Likert Scale questions are shown in Table 4, where $p < 0.05$ means that the null hypothesis (H0) was rejected and there is a statistically significant relationship between the scores given by the responders for the efficiency of the BMPs and the variable.

Table 4 - Results of Chi-squared tests, showing the correlation between the respondents' socio-economic profile, and their opinions on the efficiency of the stormwater BMPs. P-values lower than 0.05 represent statistically significant correlations.

	Age	**Level of education**	**Monthly income**	**Geographic region**	**Affected by floods**	**Knew the BMPs**	**WTP**
R/DP	0.665	8.889×10^{-11}*	0.051	0.322	0.956	0.0022*	0.449
IT	0.657	2.569×10^{-14}*	0.818	0.324	0.024*	0.1065	0.122
SW	0.263	0.529	0.353	0.090	0.155	0.1266	0.025*
RB	0.137	1.593×10^{-10}*	0.037*	0.508	0.138	0.0427	0.530
BR	0.216	3.877×10^{-5}*	0.277	0.021*	0.945	0.0575	0.006*
PP	0.648	3.108×10^{-12}*	0.276	0.123	0.690	0.8570	0.630
GR	0.004*	2.283×10^{-10}*	0.029*	0.436	0.198	0.0002*	0.589

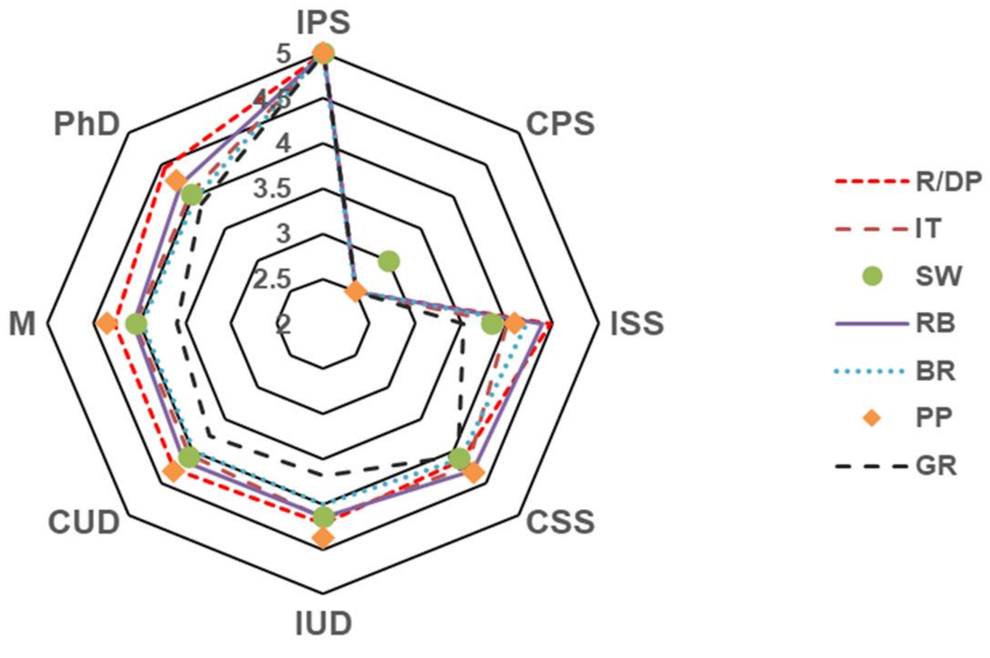
*significance level of 0.05

Source: Prepared by the author (2021).

The p-values show that the null hypothesis was rejected for the relationships between various factors and the scores given to the BMPs, such as level of education and all of the practices except the swale. In brief, the analyses showed a statistically significant relationship between the viewpoints on the retention and detention ponds and respondents' level of education and knowledge of BMPs. In fact, the respondents that had higher educational levels and prior knowledge of BMPs gave slightly higher scores to these practices. The classification of the infiltration trench was influenced by level of education and the experience of the respondents with floods. For instance, the respondents at the complete primary school level found this practice inefficient. Interestingly, the respondents' scores for swales were related to their WTP for such practices as they accept either to implement this practice with public incentives or simply do not support it. The choice of using rain barrels was influenced by respondents' level of education, and monthly income. Respondents with monthly income between 1867.61 and 3735.21 USD gave lower scores for this practice. Similar to swales, the choice of bioretention cells was affected by participants' level of education, geographic region and WTP. Most of the respondents with incomplete secondary school until PhD levels and from all regions considered this practice efficient (score 4). However, people that were not willing to pay for construction and maintenance of these techniques gave lower scores to this practice. The respondents' opinion about green roof was the most influenced, depending on the age, level of education, monthly income, and knowledge of BMPs ($p < 0.05$). Generally, the group of people from 30 to 49 years old believe that this BMP has a low efficiency. The same viewpoint was observed in the group of participants with complete primary and incomplete secondary school levels. Similar to the rain barrel, people with an income between 1867.61 and 3735.21 USD gave a low score for the green roof. Knowledge of BMPs also influenced the responses regarding the green roof. For example, people who knew the techniques believed that this kind of BMP was less effective.

The relationships between the respondents' level of education and the scores obtained for each BMP are shown in Figure 9. Considering all levels of education, the scores ranged from 3.5 to 4.5.However, only green roof received a score less than 4 (not considering people with complete primary school which gave scores below 3 for all the BMPs). Therefore, it was the BMP that received the lowest score. The scores for retention and detention ponds increased with the level of education, varying between 4 and 4.5. Permeable pavement received the highest scores from complete secondary school to master's level. It means that the participants at these levels of education think this is the most efficient practice. People with most of the levels of education scored close to 4 for infiltration trenches and rain barrel.

Figure 9 - Scores obtained by each BMP depending on the respondents' level of education. IPS: Incomplete Primary School; CPS: Complete Primary School; ISS: Incomplete Secondary School; CSS: Complete Secondary School; IUD: Incomplete Undergraduate Degree; CUD: Co mplete Undergraduate Degree; M: Master. R/DP: Retention basin/Pond; IT: Infiltration Trench; SW: Swale; RB: Rain Barrel; bioretention (BR); PP: Permeable Pavement; GR: Green roof.



Source: prepared by the author (2021).

2.4 DISCUSSIONS

Among the 1017 respondents, most of them were between 20 and 44 years old, with undergraduate and graduate degrees. As for income, people with all levels were represented, but the majority received a monthly income of less than1867.61 USD. As this survey was pursued online, the barriers of face-to-face interviews may have been removed, such as time availability. This way, the survey reached almost every state of the country, with representativeness from various age and income groups.

The percentages of people at master's and Ph.D. levels in Brazil are lower than the ones from the answers for this survey. Therefore, even if the survey was not directed to a specific public, most of the answers came from a group with a higher educational level. This may also explain the statistical relationship found between the answers to most questions and level of education.

The results also imply that older adults expect to receive incentives to apply BMPs. This might be related to the fact that some young adults still do not work for their living, the age group from 14 to 24 years old has been the most affected by unemployment in Brazil (IBGE, 2021). On the other hand, older and more mature people perhaps find it difficult to invest in the infrastructure that would not bring any direct revenue to them at least in a short period. Nevertheless, these strategies provide ecosystem services, and can potentially reduce the risk of flooding and damages (Liu et al., 2015; Nordman et al., 2018; Scholz et al., 2013); therefore, their implementation can be useful. In this study, although people over 50 years old supported public investments on the structural BMPs, they did not support them as strongly as other age groups. Du et al. (2019) found that people between 45 and 60 years old from a rural watershed in China are less concerned with water pollution and would accept government decisions. They reported that the higher the level of education, the more people will engage in public participation. Such results corroborate with our study that shows the statistically significant relationship between the level of education, knowledge of stormwater BMPs and WTP. Level of education also influenced the choices of BMPs; as the score given to these practices varied between uneducated and educated individuals.

A paradox is observed when more than 40% of the respondents said they have no knowledge about drainage BMPs, yet when they were asked about each technique individually, they knew most of them. Most of the participants have not implemented these practices in their properties yet; however, most of them were willing to adopt rain barrels, bioretention, permeable pavement and green roofs at lot scale in the future. Although green roof has received the lowest score in terms of people's viewpoints on its efficiency, it received more than 50% of acceptance to be used in their properties. Green roofs are effective to control small storms in highly urbanized areas and have better results when used in a combination of techniques (Carter and Jackson, 2007). Due to their acceptability, they can be considered as one of the options to reduce stormwater in Brazil, obviously after comprehensively analyzing their effectiveness. In addition, based on the respondents' preferences, new projects at lot scale should include BMPs such as bioretention, rain barrels, and permeable pavement.

Also, while 54.8% of the participants were willing to pay to implement stormwater BMPS in their properties, but 38.5% of them would only adopt them if they receive government incentives. No statistical relationship was found between the participants' experience with floods and their WTP. In contrast, in a study in in Champaign-Urbana, Illinois, in the USA, Cadavid and Ando (2013) found that depending on the location two types of situation may happen, people may be more willing to pay if they are suffering from floods, or worry less about flooding because they got used to it. In the city of São Carlos, for example, the shopkeepers in a historical flood prone area have a sense of belonging to the place and are not willing to relocate (Marotti et al., 2014; Mendes and Mendiondo, 2007). This information can help decision makers to offer public incentives to implement stormwater BMPs at small or lot scales. Moreover, citizen awareness campaigns can be held about other stormwater management practices if they are also efficient to increase public knowledge, and their chance of adoption and WTP (Wang et al., 2020).

Similar to the study by Kaplowitz and Lupi (2012), the most preferred BMPs were the ones that people had a higher level of knowledge about them such as the retention and detention basins. The results showed that the general perception is that the detention and retention ponds, as well as permeable pavement are more efficient than the rest of the practices. Moreover, it was found that the respondents' preferences vary with their level of education. As it was shown in Figure 6, the detention-based techniques (retention/detention ponds and rain barrel), and permeable pavement received higher scores from respondents at higher levels of education.

In general, it seems that people find BMPs with large infrastructure more efficient than lot scale techniques. Moreover, these practices are applied by government investments, which means no direct budget from individuals are often needed. Due to the lack of space in the cities, the construction of some infrastructure BMPs such as large retention and detention ponds may not be feasible. On the other hand, small scale practices such as bioretention, green roof, and rain barrels have been reported to reduce runoff and pollution (De Macedo et al., 2019; Palermo et al., 2020; Sungji et al., 2020). Therefore, lot scale techniques should also be promoted to incentive property owners to construct them. Due to their various advantages, incentives may only be needed to launch the project, as 99.3% of the respondents were in favor of public investment on this type of technique.

For instance, a policy used in some cities in the state of São Paulo called IPTU verde promotes the use of practices such as green area, and the use of rain barrels in the properties in exchange the reduction of territorial taxes (Guarulhos, 2010; Jahnke et al., 2013). This policy can be adapted by including stormwater BMPs in the list of practices that can be used to reduce property taxes.

2.4.1 Study implications

This work brings practical and theoretical contribution, and initial findings may influence and support public policies. One the one hand, the hypotheses here adopted may be the first step to thrive a pool of bottom-up mechanisms and procedures to warrant affordable information from and to citizens in compliance with the Brazilian New Framework of Sanitation (Brazil, 2020). On the other hand, and also considering this Brazilian Act, this paper considers social engagement and accountability for technical representation and participation in policy-making processes, as well in the planning and evaluation of sanitation services.

Discovery of initial patterns from citizens' perceptions here presented can help governmental bodies to make decisions about the adoption and promotion of BMPs.

They can use the information to produce stormwater BMP implementation plans based on the region where the plan is being adopted. If a plan includes co-participation from the government in the construction costs, for example, the BMPs to be applied can be chosen among the ones the respondents are more willing to apply and pay, considering their socioeconomic characteristics. As infrastructure techniques are considered more efficient, they should also be included to increase acceptance.

Our study showed that people with minimum education did not know about stormwater BMPs and were less available to pay for their construction and maintenance. Therefore, there is a need to promote these strategies in every level of education to enhance their acceptance. Holding such awareness workshops is in line with the objective of Brazilian Act of Environmental Education (Brazil, 1999).

The Brazilian Act of Basic Sanitation and Urban Waters (Brazil, 2007) has also established opportunities for adopting BMPs. Thus, the Art.8, part II of this act, states inter-municipality sanitation consortia aim to exclusively set up BMPs for water utilities on water supply, sewage systems, stormwater management and solid management. In summary, under the Brazilian legislation, social engagement is one fundamental in which participatory procedures and governance are derived from and conducted with local citizens' and their perceptions. Moreover, our research methodology and findings adopt viable backgrounds for BMPs by using citizens' perceptions (Brelsford et al., 2020; Sarmento Buarque et al., 2020; Souza et al., 2021; Troy et al., 2015). We explore how local communities provide cultural and environmental values (Fornara et al., 2020; Peng et al., 2021; Scopelliti et al., 2019).

2.5 CONCLUSIONS

We carried out a virtual survey to understand the public’s viewpoints about a series of stormwater BMPs to manage urban flooding in Brazil. Using a series of statistical tests, we aimed to explore the relationships between participants’ socioeconomic profile such as age, and level of income and education, and their choice of practices and willingness to pay them. The results showed that large infrastructures such as detention and retention ponds and permeable pavement are the most favorable and efficient practices from the participants' perspectives. Although respondents find small scale practices such as green roof, bioretention and rain barrel less efficient, they are willing to implement them in their properties. Most of the participants showed support for public investment on stormwater BMPs as adaptation measures to flooding. We also found that there is a statistically significant relationship between participants' level of education and age and their perceptions about BMPs and willingness to pay for them. However, participants' level of income or geographic location were not significantly influencing their choices.

The results presented in this study may serve as a reference for Brazilian policy makers to implement stormwater BMPs and manage urban floods. They can base their plans on the citizen's viewpoints presented here or use the same methodology to replicate the study in other scales. Moreover, our research methodology could elicit initial patterns on citizens' perceptions on BMPs for future crowdsourcing-based approaches like 'citizen observatories' (Degrossi et al, 2014; Wehn et al, 2015). The use of citizen perceptions may bring a sense of trust and responsibility to stormwater management.

A limitation of this study was about not knowing the type of property (e.g., condo, house), in which participants resided and whether they owned this property to be able to apply the BMPs. Therefore, we recommend investigating property types and ownerships to enhance the results regarding the lot scale practices. In addition, there are other types of BMPs that can be included in future studies to expand the analysis and provide more options for the participants to evaluate.

Due to existence of different climate and land conditions as well as infrastructure and population densities in Brazil's cities, the findings of this study at the country level may not necessarily be valid at smaller scales. Therefore, similar research should be continued in different regions, states, cities, basins or even at neighborhood scales. This way, it will be possible to have a better understanding of citizen perceptions locally with more homogeneity. In this context, this study can be a framework for the evaluation of people's preferences on the application of BMPs as a form of adaptation to floods. For future studies, we indicate the development of methodologies to include this type of citizen data into stormwater modeling and into multiobjective optimization of stormwater BMP implementation.

This the first step to know what people think about these practices, what factors influence their way of thinking and even how much they are willingness to implement the practices without knowing their exact effectiveness. Nevertheless, to raise awareness, people also need to know the construction and maintenance costs and the benefits generated by these practices. Therefore, pilot projects should be held in Brazilian cities to evaluate the effectiveness of these BMPs and provide the citizens with ranges of their efficacy in reducing floods, depending on the basin, area or arrangement of BMPs.

2.6 ACKNOWLEDGEMENTS

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3 A CASE STUDY OF STORMWATER BMP'S SCENARIOS IN BRAZIL REGARDING CONSTRUCTION COSTS AND RUNOFF REDUCTION

A modified version of this chapter will be submitted as: SOUSA, B. J. DE O.; TAFFARELLO, D.; MATTOS, T. S.; MENDIONDO, E. M.; DE OLIVEIRA, P. T. S. Case study of stormwater BMP's scenarios in Brazil: construction costs and ecosystem services. Urban Water Journal: Urban Water Management in Developing Countries.

Abstract: Stormwater Best Management Practices have been used to reduce the impacts of floods, such as excessive surface runoff, and restore hydrological ecosystem services (e.g., water reservation in the soil and peak flows' damping). However, few studies have focused on their construction costs in relation to the mitigation of urbanization impacts. This article addresses the construction costs and the runoff reduction of the application of seven scenarios by different stormwater BMPs for a 32 km^2 basin located in Campo Grande, Midwestern Brazil. The BMPs considered were permeable pavement (PP), rainwater harvesting (RWH), and infiltration trenches (IT). Seven hypothetical stormwater BMP implementation scenarios (SC#) were assumed to apply the BMPs in different proportions concerning available public areas for PP and possible runoff retention by RWH and IT. The first three scenarios considered PP, RWH, and IT techniques, respectively, and the other four used different combinations of the three BMPs. The Brazilian National Research System of Construction Costs and Indices (SINAPI) was used for the regional cost analysis, and the benefits of the scenarios were evaluated regarding runoff reduction and impervious area treated. Scenario 3 (SC3) would require the lowest cost for the construction of its BMP units ($ 4,125,780), with a 19% runoff reduction for a storm of 10 years´ return period in the near future (2020-2045). The cost of Scenario 2 (SC2) was the closest to that of SC3 (15,993,563), but with a 13% higher runoff reduction. The cost of SC4 ($ 19,618,790), on the other hand, was moderately higher than that of SC2, but offering a diversity of techniques and treatments to more impervious areas. Such construction costs can be justified by both reduction in losses and disturbances caused by floods, and the ecosystem service provided (minimization of floods). These analyses can help in the identification of the balance between benefit and cost by local stakeholders for

the application of stormwater BMPs, and in the creation of new frameworks and policies for their implementation in Brazil using SINAPI.

Keywords: stormwater BMPs, floods, BMP cost-benefit analysis, runoff reduction.

3.1 INTRODUCTION

Stormwater management has been a challenge to urban planners due to the high maintenance costs of its systems (USEPA 2007), and climate change has become a threat with the increased intensity of extreme events that worsen the impacts of floods and intensify the unbalance between water demand and availability (Denise Taffarello et al. 2017; Gesualdo et al. 2019; Fava et al. 2020). Tanoue et al., (2021) found that floods in Brazil generates damages that can sum up to 0.05% of the country's Gross Domestic Product (GDP), which would be 722.5 million dollars in 2020 (THE WORLD BANK, 2021).

Stormwater Best Management Practices (BMPs) have been used to mimic ecosystem functions, such as infiltration and evaporation, reduce runoff, promote groundwater recharge, improve water quality, and, consequently, attenuate the impacts of floods (Lafortezza et al. 2018; Hoban 2018). They have been reported to promote infiltration, carbon sequestration, in case of vegetated BMPs, and pollution regulation (Moore and Hunt 2012; Scholz et al. 2013; Busch et al. 2012). Mattos et al. (2021) investigated the way three types of stormwater BMPs, namely permeable pavement (PP), rainwater harvesting (RWH), and infiltration trench (IT) can attenuate extreme events of precipitation. Liu et al. (2016) simulated the reduction of runoff, suspended solids, phosphorus, Kjeldahl Nitrogen Nitrate and Nitrite using permeable patio, grassed swale, green roof, bioretention, rain barrel, porous pavement, grass strip, wetland channel, wetland basin, retention and detention basins in the the Trail Creek basin in Indianapolis, USA. Regarding people1s acceptance of stormwater BMPs in Brazil, Sousa et al. 2021 reported a survey conducted in Brazil in 2020 which revealed more than 80% of the participants would use rainwater harvesting in their houses, and almost 55% would use permeable pavement.

Some studies have also considered economic benefits, construction and maintenance costs, and stakeholders´ choices in stormwater BMP modelling and planning (Bai et al. 2019; Raei et al. 2019), and others have evaluated the ecosystem services that can be recovered by those practices (Johnson and Geisendorf 2019). In a study conducted in an urban area in Italy, Palermo, Talarico, and Turco (2020) observed covering 30% of the available roofs with green roofs and 30% of the impervious surfaces with permeable pavement would reduce 25% of the stormwater runoff. Studying a flood-prone area in London, Ossa-Moreno et al. (2017) observed the most important benefits of stormwater BMPs would be flood risk reduction, rainwater harvesting, and amenity. Therefore, methodologies and frameworks for the evaluation of implementation costs of stormwater BMPs and recovery of ecosystem services should be created and tested in different places with different climate, soil, and land use and cover.

We considered three types of stormwater BMPs in this study: Permeable Pavement (PP) which is made of a paving material that enables water to penetrate and be stored in the sub-base and infiltrate in the soil (Woods Ballard et al. 2015); Infiltration Trench (IT) that reduces water velocity, promotes its infiltration in the soil, filters it through porous materials (such as gravel), stores part of it, thus reducing floods, and then lets it infiltrate in the soil. (Eckart, McPhee, and Bolisetti 2017); Rainwater Harvesting (RWH), which is a system to collect stormwater from roofs to be given in non-potable uses such as irrigation (Hoban 2018).

The economic analyses of stormwater BMPs can be conducted through Capital Cost Assessment (CCA), which considers construction costs and land purchase when necessary, and Benefit Cost Analysis (BCA), which also takes into account the benefits of BMP implementation (USEPA 2013). Some studies have applied BCA on a basin scale (Nordman et al. 2018; Liu et al. 2016a; Liu, Bralts, and Engel 2015; Joksimovic and Alam 2014). Stormwater BMPs can be evaluated in terms of regulation of extreme events, towards lessening the effects of environmental changes and maintaining the stability of ecosystem processes, such as minimization of floods and infiltration (Cardinale et al. 2012; Brazil 2021). This way they provide groundwater recharge, savings of drinking water through the reuse of rainwater harvesting and runoff reduction, which can be used by stakeholders in cost-benefit analyses (Johnson and Geisendorf 2019; D Taffarello et al. 2020; USEPA 2013). An example is the IPTU verde, a policy applied in many Brazilian cities that consists in reducing municipal property taxes if the owners use environmental conservation practices in their properties (e.g., water reuse, rainwater harvesting, solar water heat, green roof, and maintenance of permeable areas) (Jahnke, Willani, and De Araújo 2013; Guarulhos 2010).

In Brazil, the National System of Costs Survey and Indexes of Construction (SINAPI 2021) computes the costs of construction according to the prices of materials with suppliers and labour costs with companies in the sector. SINAPI produces a monthly series of costs (services and construction materials) and indexes that are publicly published. Every construction company contracted by the Brazilian government must consult SINAPI to prepare contracts and budgets. Since the system is separated by states, costs are adjusted to them, leading to a more accurate survey. However, investments in the stormwater infrastructure also demand analyses of the return to the society (Kwizera, Sebareze, and Murungu 2019).

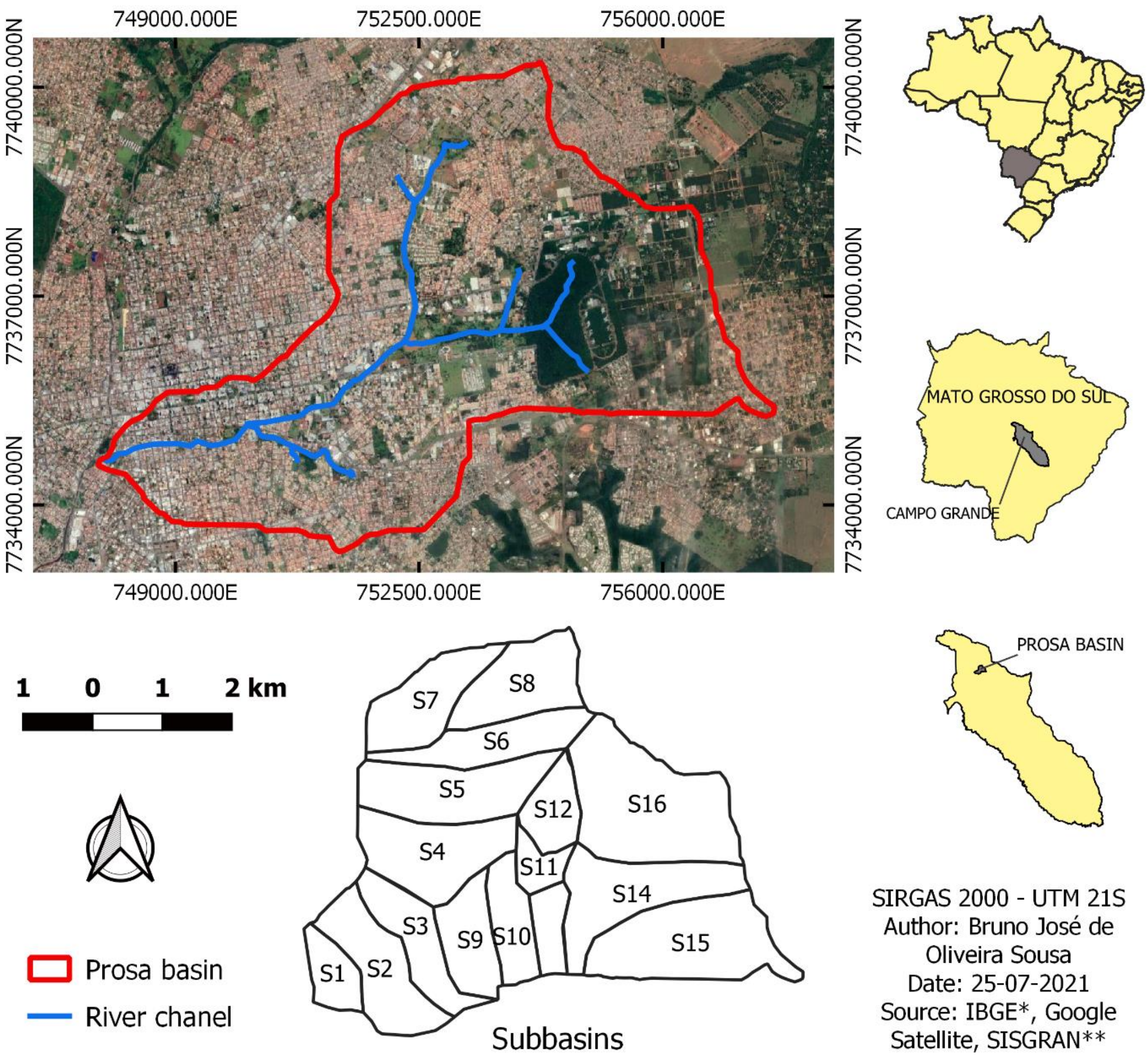
This study evaluated the construction costs of stormwater BMP application scenarios and the ecosystem services they provide in an urban area. Different methodologies applied to an urbanized basin in the city of Campo Grande, Mato Grosso do Sul, Brazil, identified the benefits and construction costs of stormwater BMPs in seven different hypothetical scenarios. Since the scenarios were hypothetical, only the construction costs were evaluated while those of project and maintenance were not considered. The costs were estimated calculating the services needed for the construction of each type of BMP and multiplying them by the unit costs available in SINAPI. The quantitative ecosystem services restored by BMPs were then evaluated according to two services of regulation of extreme events, namely stormwater runoff reduction and compensation of impervious areas.

3.2 MATERIALS AND METHODS

3.2.1 Study area

Prosa is an urban basin located in Campo Grande, Mato Grosso do Sul, Brazil (Figure 10). Its total drainage area is 32 km² with sixteen sub catchment areas, and its land use and land cover include 40% of commercial and residential areas, 10% of asphalt pavement, 24% of grass, 19% of forests, and 6% of bare soil (Mattos et al. 2021). Part of the basin became a state conservation unit in 2002 for protecting its natural ecosystems and two sources of Prosa creek, and promoting research and educational, and recreation activities (Brazil 2002; Mato Grosso do Sul 2002). One of its sources had a history of erosion processes, controlled after the establishment of the conservation unit (IMASUL 2011). However, erosive processes occur through the waterbody (de Lollo and Sena 2014). The annual rainfall in Campo Grande ranges from 1300 to 1600 mm and its climate is classified as Aw, i.e., tropical with dry winters and rainy summers, according to the Köppen climate classification (Alvares et al. 2013). The basin shows a predominance of latosols upstream and quartz sands downstream (Sobrinho 2015). Figure 10 also shows the 16 subbasins in which the study area was divided to perform the hydrologic simulation.

Figure 10 - Location of the Prosa basin. *Brazilian Institute of Geography and Statistics; **Municipal System of Georeferenced Indices to the Planning and Management of Campo Grande.



Source: Prepared by the author (2021)

3.2.2 Stormwater BMPs

This study considered three types of stormwater BMPs, namely permeable pavement, rainwater harvesting, and infiltration trench, and seven stormwater BMP hypothetical implementation scenarios were composed from their combination and according to different variables. Permeable pavement should be implemented only in public areas, within the basin and with no inclusion of main roads. The quantity of RWH and IT was assumed in terms of the amount of runoff produced by impermeable areas in the basin (Mattos et al. 2021). Therefore, each RWH or IT would retain part of the runoff during a precipitation event. The scenarios are identified in the text and in tables by SC# followed by a number from 1 to 7.

Each of the first three scenarios was designed using only one of the techniques. Scenario 1 (SC1) had 50% of available public areas covered only by PP; Scenario 2 (SC2) considered only RWH for application in the basin, absorbing 50% of the volume of runoff produced by the impermeable areas; and Scenario 3 considered only infiltration trenches and the number of units should be enough to absorb 50% of the runoff volume produced by the impermeable area in the basin. The other four scenarios were combinations of the three stormwater BMPs in different proportions by the same quantification method used in the first three scenarios, available public area for PP, and retention capacity for RWH and IT. Scenario 4 (SC4) assumed 25% of areas covered by PP and that the amount of RWH and IT would absorb 25% of the runoff each. Scenario 5 considered 50% PP application and, again, 25% retention for RWH and IT. Scenario 6 (SC6) was comprised of 50% PP use, 50% RWH retention, and 25% IT retention. Finally, Scenario 7 (SC7) assumed 50% PP use, 25% RWH retention, and 50% IT retention. The percentages of BMPs do not totalize 100% because they refer to different areas.

Table 5 shows a summary of the percentages, number of units of each BMP necessary for their achievement, and the runoff reduction caused by each scenario in the basin outlet in a 10-year return period storm. PP and IT occupied spaces outside the properties, while RWH were assumed be used in lot scale, collecting water from roofs.

Table 5 - Scenarios of Best Management Practices used. PP: Permeable Pavement; RWH: Rainwater Harvesting; IT: Infiltration Trenches. Scenarios are identified by SC#, and their number ranges from 1 to 7.

	SC1	**SC2**	**SC3**	**SC4**	**SC5**	**SC6**	**SC7**
PP	50%*			25%*	50%*	50%*	50%*
RWH		50%**		25%**	25%**	50%**	25%**
IT			50%**	25%**	25%**	25%**	50%**
Number of BMP units per scenario							
PP	4139	0	0	2069	4139	4139	4139
RWH	0	38727	0	19364	19364	38727	19364
IT	0	0	19455	9727	9727	9727	19455
Runoff reduction in the basin outlet per scenario for a 10-year return period storm (%)* **							
	10	14	31	28	30	40	35

*Percentage of roads or public areas that could receive permeable pavement; **Percentage of impervious area compensated by RWH and IT; ***Mattos et al. (2021) (considering the BMP's storage layer empty at the beginning of the storm).

Table 6 shows the dimensions and the characteristics of one unit of each BMP considered. One Permeable Pavement (PP) unit consists of an area of 300 m² covered by a layer of 10 cm high pavement, and a 15 cm high layer of gravel storage below this pavement. Each Infiltration Trench (IT) unit has an area of 10 m² and is 1m deep, totalizing 10 m³ volume, and a commercial tank of 5,000 L capacity was considered for the Rainwater Harvesting (RWH). The amount of construction service necessary to build each part of the BMPs was based on those dimensions. The services for the construction of the permeable pavement were execution of the pavement itself, soil movement, and drainage, including drains and geotextiles. Excavation, soil movement, and drainage (including drains and geotextiles) were also considered for the infiltration trenches. Regarding rainwater harvesting reservoirs, pipes and connections, apart from the reservoirs themselves, were included. A more detailed list is available in the supplementary material (Table 9, Table 10, and Table 11).

Table 6 - Dimensions of one unit of each Best Management Practice considered.

Permeable pavement		Inf. Trench		Rainwater Harvesting	
Area (m²)	300	Area (m²)	10	Area (m²)	3.14
Width (m)	6	Width (m)	2	Height (m)	1.6
Length (m)	50	Length (m)	5	Capacity (l)	5,000
Pavement height (cm)	10	Height (m)	1		
Storage height (cm)	15				

Source: Adapted from Mattos et al. (2021).

3.2.3 Cost estimation

The data base from National System of Costs Survey and Indexes of Construction (SINAPI 2021) and suppliers in the case of rainwater harvesting reservoirs were used for the estimation of the construction costs. The procedure consisted of searching for the construction services necessary to build each BMPs in the database and then multiplying their unit cost by the dimensions shown in Table 1, providing the total value for the construction of one unit of each BMP. Most services are classified by square and cubic meters or units. The result was then multiplied by the number of units in each scenario. No land purchase cost was considered, since permeable pavement and infiltration trenches would be constructed in public areas, and rainwater harvesting would be installed in the properties.

3.2.4 Regulation of extreme events

The moderation of extreme events was assessed in terms of the regulation provided by runoff reduction and percentage of impervious area treated (Scholz et al., 2013; TEEB, 2011), and runoff reduction and percentage of impervious area treated were previously analyzed by (Mattos et al. 2021). Concerning runoff reduction, it was obtained using the dynamic hydraulic-hydrology model PCSWMM considering a single precipitation event of 10 years´ return period. The basin was divided into 16 subbasins which generated runoff. Then the number of BMPs in each subbasin varied according to the dimensions of the BMPs, as well as the impermeable area. Therefore, the more urbanized the sub-basin more BMPs need to be applied. Runoff reduction was calculated in the basin outlet. The infiltration process in each subbasin was calculated using SCS-CN method, and Manning's equation was used to estimate the runoff in each subbasin outlet. Also, data measured in a rainfall-gauging station in the outlet of the basin was used for model calibration. To include the effects of climate change, the near future (2020-2045) time slice was considered using an ensemble of two Representative Concentration Pathways (RCP 4.5 and RCP 8.5).

The percentage of impervious area treated for each scenario was based on the percentages of impervious area treated in each one of the 16 sub catchments by each type of BMP, which were transformed into area values and summed. The same process was conducted for the impervious areas treated by each BMP in every sub catchment. It was applied to all sixteen sub catchments, and the results were summed so that the total impervious area treated by each scenario could be found. Such results were converted into percentage of impervious area treated by BMPs for all seven scenarios dividing them by the total impervious area in the basin.

3.3 RESULTS

3.3.1 Construction Costs.

The unit costs of each BMP were Permeable Pavement (300 m^2) = \$5,126.18, Rainwater Harvesting (5,000L) = \$458.22, and Infiltration Trench (10 m^2/10 m^3) = \$235.30 (\$1.00 = R\$5.59 21-06-2021 https://www.bcb.gov.br/). Table 7 shows the total costs of each scenario categorized by BMP. Scenario 6 was the most expensive, reaching 37 million dollars, whereas permeable pavement represents the biggest parcel of the cost in scenarios 4, 5, 6, and 7. For scenarios 1, 2 and 3, which used only one type of BMP each, SC1 showed the highest construction cost, although using only PP. In scenario 4, which considered the BMPs in the same proportion in the basin (25%), PP was the most expensive to implement, followed by RWH and IT. Infiltration trenches showed the lowest cost in each scenario tested.

Table 7 - Construction costs* for each of the seven scenarios distinguished by Best Management Practices. American dollar ($1.00 = R$5.04 21-06-2021 https://www.bcb.gov.br/). PP: Permeable Pavement; RWH: Rainwater Harvesting; IT: Infiltration Trenches. Scenarios are identified by SC#, and their numbers range from 1 to 7. Some values are 0 for SC1, SC2 and SC3 because they considered the application of only PP, RWH, and IT, respectively.

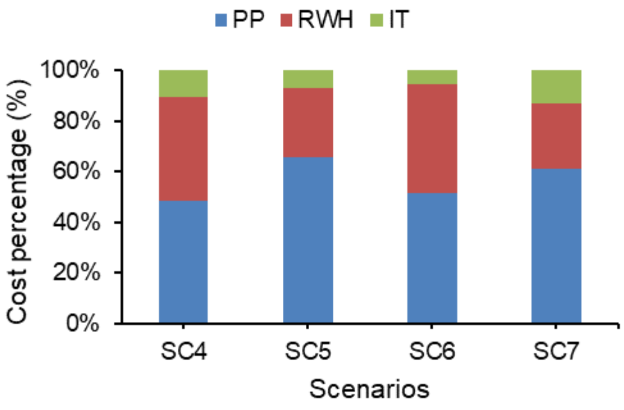
	SC1	**SC2**	**SC3**	**SC4**	**SC5**	**SC6**	**SC7**
PP	19,122,655	0	0	9,559,017	19,122,655	19,122,655	19,122,655
RWH	0	15,993,563	0	7,996,988	7,996,988	15,993,563	7,996,988
IT	0	0	4,125,780	2,062,784	2,062,784	2,062,784	4,125,780
Total	19,122,655	15,993,563	4,125,780	19,618,789	29,182,427	37,179,003	31,245,423

Source: Prepared by the author (2021)

The lowest construction cost was achieved in scenario 3 (SC3), which used only infiltration trenches, thus representing 21%, 14%, and 13% of the costs to build SC4, SC5, and SC7, respectively. The most substantial construction cost was required in SC6, which included the application of permeable pavement in 50% of the available public areas and rainwater harvesting absorbed 50% of the runoff volume from the impermeable areas.

Figure 12 shows the percentage of costs for the construction of BMPs for the scenarios that considered the three practices. The percentage of the infiltration trench in the cost for such four scenarios was lower than 15% (10.5%, 7%, 5.5%, and 13.2% respectively). PP is responsible for 50 to 65% of the construction costs of the scenarios. Comparing the total costs, scenario 4 showed the lowest, with the highest coverage of streets and permeable area; however, it was the fourth in reduction of runoff in the basin. When considered in the same proportion as the permeable pavement, rainwater harvesting accounts for a considerable part of the construction costs.

Figure 11 - Cost percentage for each BMP distinguished by scenario. Scenarios 1, 2, and 3 are excluded because they use only one type of technique. Permeable pavement represents the highest cost for all the scenarios, but rainwater harvesting. PP: Permeable Pavement; RWH: Rainwater Harvesting; IT: Infiltration Trenches. Scenarios are identified by SC#, and their numbers range from 1 to 7. SC1 considers only PP, SC2 only RWH, and SC3 only IT.



Source: Prepared by the author (2021).

3.3.2 Reduction of impervious areas

Table 4 shows the reduction in impervious areas for all scenarios. SC1 reduced the smallest portion of impervious area (13.87%), followed by SC2 and SC3, which both reduced 37.11%. SC6 and SC7 showed the highest percentage of impervious area treated (69.52%) among those that used more than one technique, and were followed by SC5 (50.97%) and SC4 (44.03%). SC6, on the other hand, showed the highest runoff reduction (42%) and also the most significant impervious area treatment. Interestingly, SC3 and SC4, which used only IT and RWH, showed 19% and 32% runoff reductions, respectively. SC4 and SC5 achieved similar runoff reductions, i.e., 30% and 31%, respectively; however, the SC5 construction cost was almost $ 10.000.000 higher than that of SC4. The runoff reductions achieved by SC6 and SC7 were, respectively, 42% and 37%.

3.4 DISCUSSIONS

Regarding scenarios that use BMPs individually, the rainwater harvesting showed the highest peak runoff reduction (32%), and, in terms of cost, social participation, and diversity of strategies, scenario 4 (SC4) was the most adequate. Its total cost was close to the cost of only changing 50% of the available areas into permeable pavement (SC1). Both scenarios are interesting options to be implemented in the basin after further studies on the placement of such practices. Moreover, rainwater harvesting and permeable pavement are two of the most used stormwater BMPs in lot scale in Brazil, according to a survey conducted by Sousa et al. (2021). SC3 showed a 18% runoff reduction at a much lower cost using infiltration trenches, and its construction cost was 4.75-fold lower than that of SC4. Its only setback is the lack of variety of BMPs, which could make it less acceptable. In comparison to SC3 and SC4, SC5 showed a runoff reduction above that of SC4, but does not justify a 10-million-dollar difference. SC6 has the highest runoff reduction rate, 42%, but it is also the costliest scenario. Finally, SC7's increase in runoff reduction to 35% is too small to justify a 12 million-dollar increase in construction costs in relation to SC4, corroborating the results of Liu et al. (2016a), who claimed costs greatly increase in function of more significant runoff volume depletion.

Liu et al. (2015) reported construction and maintenance costs of $ 20,913,355.00/km² for reducing 26% of runoff volume using stormwater BMPs in a basin of 51.29 km² in the state of Indiana, USA. By adding 5% annual maintenance costs for 20 years in SC4, which reduced 28% of runoff, the total cost would be $ 1,226,174.37 / km². This value is considerably lower than the one reported by Liu et al. (2015), but it can be explained by the greater variety of BMPs used in their study, which may have led to different construction and maintenance costs. Similar to our study, the authors reported prices for building permeable pavements were the highest if considered individually. On the other hand, they found lower construction costs for RWH, probably due to land use and land cover, since most of the area of the basin studied was covered by a low-density residential region, whereas 40% of Prosa basin is comprised of commercial and residential areas. If the reduction of pollutants from the runoff is also considered in the calculation, the costs may increase considerably.

Liu et al. (2016) reported a study conducted in the Trail Creek basin also in Indianapolis, USA, which revealed $ 652,741.00 / km² / year would be necessary for reducing 23% of runoff, 57% of suspended solids, 36% of the total phosphorus, 41% of Total Kjeldahl Nitrogen, and 36% of Nitrate + Nitrite.

Although the construction costs for the scenarios were considerably high, the losses suffered by people in flood-prone areas can justify the investments. Abreu (2019) studied two flood events (one in 2015 and the other in 2018) in a commercial area in the city of São Carlos, São Paulo, Brazil, and calculated the losses including direct and indirect ones suffered by shopkeepers, cleaning, services, and infrastructure recuperation by the city council. In 2015, the losses were R$ 6,627,681 ($ 1,185,971), and in 2018, the estimated amount was R$ 2,785,036 ($ 498,360) in a floodplain area of 109.113 m². Wang et al. (2021) evaluated a flood event in Beijing, China, in July 2012, which caused an economic loss of more than 1.9 billion dollars for the city. Both examples demonstrate the values invested in stormwater BMPs can avoid flood losses.

Every scenario has a percentage of runoff reduction but some combinations can lead to the same reduction at a lower price. Therefore, each case must be evaluated individually, which requires frameworks that can be replicated. The evaluation of ecosystem services provided by stormwater BMPs may help plan the application of such techniques and reward owners of BMPs in lot scale for elaborating such techniques. Moreover, if property owners receive incentive and accept some techniques in their homes, the overall construction costs of implementing BMPs decrease. According to a survey conducted by Sousa et al., (2021), over 80% of the participants would use rainwater harvesting in their houses, and almost 55% would use permeable pavement. The authors reported people considered infrastructure techniques, such as permeable pavement more efficient. Therefore, they should be included in stormwater management plans towards increasing acceptance by the population. An example is the IPTU verde, which reduces municipal property based on environmental conservation practices in the properties (e.g., water reuse, rainwater harvesting, solar water heat, green roof, and maintenance of permeable areas) (Jahnke, Willani, and De Araújo 2013; Guarulhos 2010). Incentives can increase the number of BMPs constructed due to reductions in general construction costs. Moreover, if runoff reduction is considered, the costs can be divided among the stakeholders according to their benefits, such as lower flood risks and reduced losses (Ossa-Moreno, Smith, and Mijic 2017; Abreu 2019). Moreover, other ecosystem services of support, regulation, and cultural can be considered.

3.5 CONCLUSIONS

This study proposed the calculation of construction costs and ecosystem services provided by stormwater Best Management Practices (BMPs) in the city of Campo Grande, Mato Grosso do Sul, Brazil. The scenarios assumed different proportions for the application of three stormwater BMPs, namely permeable pavement, rainwater harvesting, and infiltration trenches. In a hypothetical scenario, infiltration trench was the most adequate, since the scenario to which it was applied individually was the cheapest, with a satisfactory runoff reduction. Regarding the adoption of the three techniques together, scenario 4 (25% of each BMP) showed the best cost-benefit. The high construction costs in all the scenarios can be justified by the losses suffered in flood-prone areas, which will increase due to the effects of climate change even if land use and land cover change are frozen. There is a need for further studies considering BMPs' project and maintenance costs, evaluating BMPs efficiency in reducing runoff, promoting infiltration, and recovering ecosystem services.

This study can be used as a framework to apply SINAPI to calculate the cost of stormwater BMP implementation scenarios in Brazil. It also provides the services that are needed to build permeable pavement, infiltration trenches, and rain water harvesting units. Therefore, it can contribute to the creation of new frameworks and policies for the planning of stormwater BMP in Brazilian urban areas. Future proposals and studies should also take into consideration the new National Policy of Payment for Ecosystem Services (Law #14,119, from January 13th, 2021) (Brazil 2021), which establishes the types of ecosystem services to be considered in the country, the new Legal Framework for Sanitation (Law #14,026, from July 15th, 2020) (Brazil, 2020), and some qualitative impacts of the application of stormwater BMPs.

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4 GENERAL CONCLUSIONS

Due to the impact that the application of stormwater BMPs have on the people that live in the city, basin, or region being considered, citizen consultations may help the acceptance of implementation plans and the sense of responsibility. Therefore, in this study citizen viewpoints about the application of stormwater BMPs in Brazil were investigated. However, construction cost is a decisive characteristic of implementation plans. Then this study presented an evaluation of stormwater BMP application scenarios with various configurations in an urban basin to understand how their construction costs would change. Moreover, there is the possibility that stormwater BMPs may provide some ecosystem services. In this work, the scenarios were evaluated in terms of regulation services of softening of extreme events.

Most of the participants in the first part of this study had previous knowledge of at least one of the BMPs presented. In terms of the selection of stormwater BMPs, the results showed that people consider infrastructure techniques such as permeable pavement and retention basins more efficient. However, most of the respondents showed availability to use other techniques at their properties, such as rain barrels, bioretention, green roof, and permeable pavement. Level of education was the socioeconomic characteristic that most showed a statistical relationship with the other variables. These results could help decision-making on urban stormwater management or the creation of incentive programs for the use of stormwater BMPs at lot scale.

Regarding the construction cost, the choice of BMPs had a great influence on the scenarios. Some scenarios presented the same runoff reduction rates at much lower cost and by recovering more ecosystem services. The results from chapter 3 showed that infiltration trenches present runoff reduction rates similar to the other techniques at a lower cost. However, in the interviews conducted in chapter 2, people were considerably less willinhg to apply infiltration trenches. Therefore, infiltration trenches should be more promoted among stakeholders of BMP implementation plans.The scenario using pervious pavement, which is an infrastructure technique, supported by the respondents from chapter 2, was more expensive than a scenario using three different BMPs. On the other hand, scenarios using only infiltration trenches showed lower costs with similar runoff reduction. This shows the need for testing different combinations of techniques.

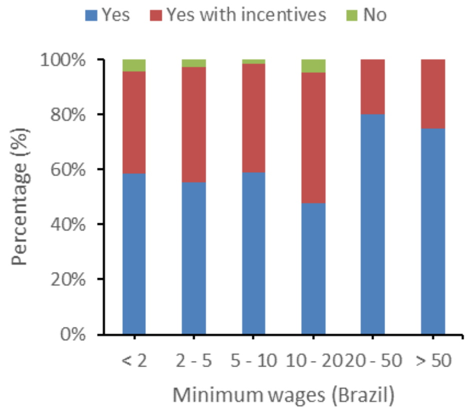
The combination of citizen viewpoints with cost and ecosystem services evaluation may be an option for the optimization of stormwater BMP application. This work may help policymakers to create stormwater BMPs' implementation plans based on citizens' preferences, increasing the population's sense of ownership and responsibility. Moreover, it may serve as a framework for future studies evaluating investment and return from these strategies. The testing of different combinations of techniques can support decision making to choose which set of techniques to apply depending on the budget availability.

More detail may be added to the type of survey used in this study, as well as adapting it to more specific cases and different scales. Furthermore, stormwater BMP optimization studies should include citizen viewpoints because they are the most positively impacted by these practices. The evaluation in terms of ecosystem services may also be a way to show the public the advantages of adopting such practices, in both lot and basin scale. However, more detail should be added to the analysis, such as more types of services apart from regulation, as well as including it in optimization strategies.

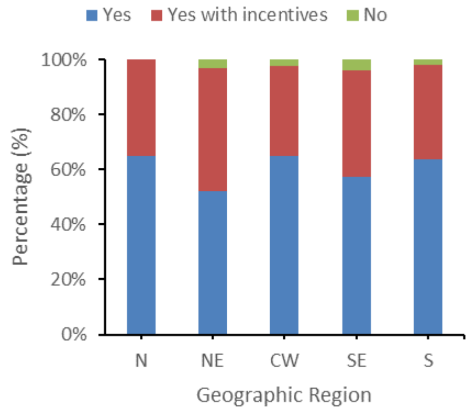
APPENDIX A

Relationship between knowledge of BMPs, WTP, support for public investments on BMPs (WTA) and socioeconomic characteristics and experiences with floods.

Figure 12 - Relation between people's WtP and their: a) monthly income and b) geographic region.IPS: Incomplete Primary School; CPS: Complete Primary School; ISS: Incomplete Secondary School; CSS: Complete Secondary School; IUD: Incomplete Undergraduate Degree; C CUD: Complete Undergraduate Degree; M: Master.



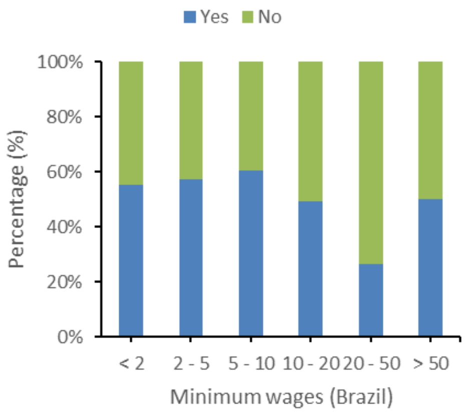
a)



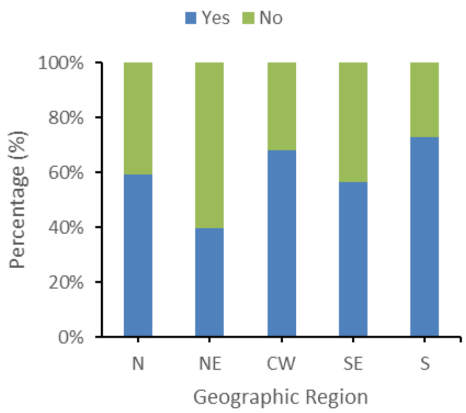
b)

Source: Prepared by the author (2021).

Figure 13 - Relation between people's knowledge of LIDs and their: a) monthly income and b) geographic region. IPS: Incomplete Primary School; CPS: Complete Primary School; ISS: Incomplete Secondary School; CSS: Complete Secondary School; IUD: Incomplete Undergraduate Degree; CUD: Complete Undergraduate Degree; M: Master.



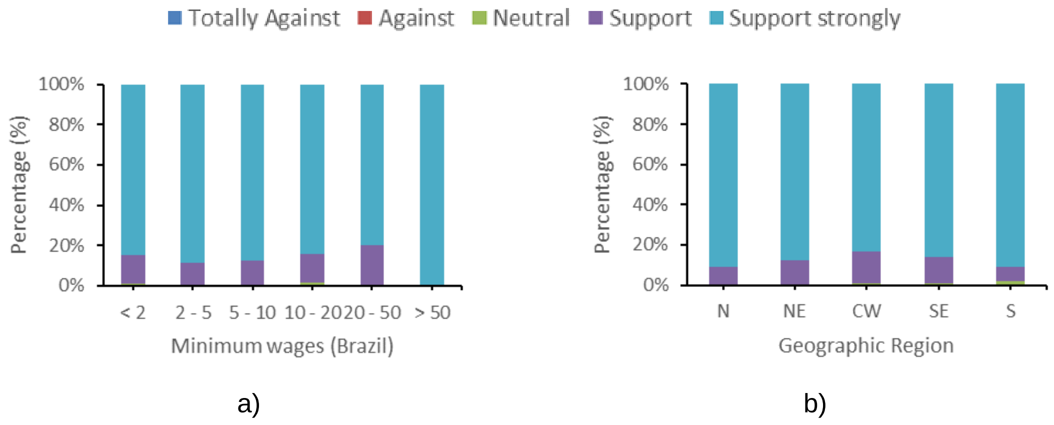
a)



b)

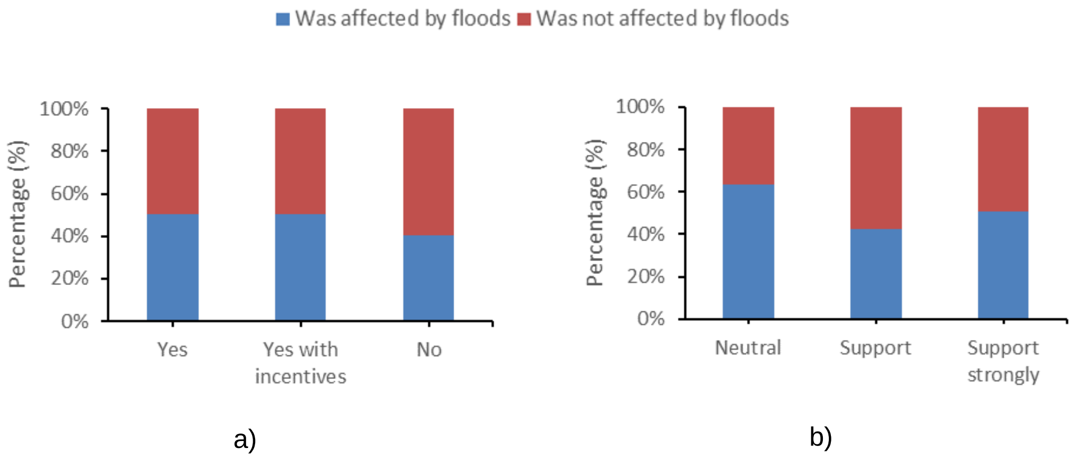
Source: Prepared by the author (2021).

Figure 14 - Relation between people's support for public investments on LIDs as infrastructure and their: a) monthly income and b) geographic region. IPS: Incomplete Primary School; CPS: Complete Primary School; ISS: Incomplete Secondary School; CSS: Complete Secondary School; IUD: Incomplete Undergraduate Degree; CUD: Complete Undergraduate Degree; M: Master.



Source: Prepared by the author (2021).

Figure 15 - Relation between people's Willingness to Pay (a) (pay to build and maintain a technique) and public investments on LIDs as infrastructure (b), and their experience with floods. No one in this research declared to be totally against or against public investments on LIDs.



Source: Prepared by the author (2021).

APPENDIX B

Services from SINAPI and suppliers used for cost estimation (in Portuguese)

Table 8 - Infiltration trench

Código	Descrição	UN	Custo unit. (R$)	Quant.	Custo total (R$)
101230	ESCAVAÇÃO VERTICAL A CÉU ABERTO, EM OBRAS DE INFRAESTRUTURA, INCLUINDO CARGA, DESCARGA E TRANSPORTE, EM SOLO DE 1ª CATEGORIA COM ESCAVADEIRA HIDRÁULICA (CAÇAMBA: 0,8 M³ / 111 HP), FROTA DE 3 CAMINHÕES BASCULANTES DE 14 M³, DMT ATÉ 1 KM E VELOCIDADE MÉDIA 14 KM/H.	m³	7.1	10	71
73883/002	EXECUCAO DE DRENO FRANCES COM BRITA NUM 2	m³	98.14	10	981.4
73881/001	EXECUÇÃO DE DRENO COM MANTA GEOTÊXTIL 200G/M²	m²	5.53	24	132.72
				Total	1,185.12

Source: Prepared by the author (2021).

Table 9 - Permeabe Pavement

Código	Descrição	UN	Custo unit. (R$)	Quant.	Custo total (R$)
101140	ESCAVAÇÃO HORIZONTAL, INCLUINDO ESCARIFICAÇÃO, CARGA, DESCARGA E TRANSPORTE EM SOLO DE 2A CATEGORIA COM TRATOR DE ESTEIRAS (150HP/LÂMINA: 3,18M3) E CAMINHÃO BASCULANTE DE 10M3, DMT ATÉ 200M	m³	11.73	75	879.75
92401	EXECUÇÃO DE VIA EM PISO INTERTRAVADO, COM BLOCO RETANGULAR DE 20 x 10 CM, ESPESSURA 10 CM	m²	62.88	300	18864
73883/002	EXECUCAO DE DRENO FRANCES COM BRITA NUM 2	m³	98.14	45	4416.3
73881/001	EXECUÇÃO DE DRENO COM MANTA GEOTÊXTIL 200G/M²	m²	5.53	300	1659
				Total	25,819.05

Source: Prepared by the author (2021).

Table 10 - Rainwater Harvesting

Código	Descrição	UN	Custo unit. (R$)	Quant.	Custo total (R$)
89578	TUBO PVC, SÉRIE R, ÁGUA PLUVIAL, DN 100 MM, FORNECIDO E INSTALADO EM CONDUTORES VERTICAIS DE ÁGUAS PLUVIAIS.	m	33.73	4	134.92
89584	JOELHO 90 GRAUS, PVC, SERIE R, ÁGUA PLUVIAL, DN 100 MM, JUNTA ELÁSTICA, FORNECIDO E INSTALADO EM CONDUTORES VERTICAIS DE ÁGUAS PLUVIAIS.	un	32.24	2	64.48
89675	TÊ DE INSPEÇÃO, PVC, SERIE R, ÁGUA PLUVIAL, DN 100 MM, JUNTA ELÁSTICA, FORNECIDO E INSTALADO EM CONDUTORES VERTICAIS DE ÁGUAS PLUVIAIS	un	47.86	1	47.86
89693	TÊ, PVC, SERIE R, ÁGUA PLUVIAL, DN 100 X 100 MM, JUNTA ELÁSTICA, FORNECIDO E INSTALADO EM CONDUTORES VERTICAIS DE ÁGUAS PLUVIAIS.	un	54.44	1	54.44
94489	REGISTRO DE ESFERA, PVC, SOLDÁVEL, DN 25 MM, INSTALADO EM RESERVAÇÃO DE ÁGUA DE EDIFICAÇÃO QUE POSSUA RESERVATÓRIO DE FIBRA/FIBROCIMENTO – FORNECIMENTO E INSTALAÇÃO	un	21.43	1	21.43
94703	ADAPTADOR COM FLANGE E ANEL DE VEDAÇÃO, PVC, SOLDÁVEL, DN 25 MM X 3/4", INSTALADO EM RESERVAÇÃO DE ÁGUA DE EDIFICAÇÃO QUE POSSUA RESERVATÓRIO DE FIBRA/FIBROCIMENTO – FORNECIMENTO E INSTALAÇÃO	un	17.44	2	34.88
	TANQUE DE POLIETILENO 5.000L	un	1949.9	1	1949.9
				Total	2307.91

Source: Prepared by the author (2021).