A stormwater user fee model for operations and maintenance in small cities

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ABSTRACT

In this paper, a stormwater fee specifically for small municipalities was developed through a simplification of the Equivalent Residential Unit (ERU) system, which is the main method applied in the United States. The Simplified ERU is based on the amount of impervious area and the fee considers the operations and maintenance costs, besides having a single class of billing. It was applied in Santo Amaro da Imperatriz city, located in the southern region of Brazil, which can be classified as a small city. The value of the Simplified ERU (294.32 m^2) was similar to the average impervious area in the United States (269.42 m^2) and it was equivalent to $0.28 per square meter (within the range of other countries' fees). The method proved to be a feasible and rapid technique for funding stormwater services, and its simplicity allows its application in different locations. This funding model can generate revenue to address current stormwater problems, such as the lack of funding for existing drainage infrastructure, and contribute to downstream flooding reduction. This paper also intends to encourage discussion about the methods for designing a stormwater fee in the academic community, which is still incipient.

Key words | drainage fee, stormwater financing, stormwater regulation

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INTRODUCTION

The rapid urban development has been resulted in profound changes to the natural water cycle, creating a modified urban water cycle. These changes are driven from the local scale where water is demanded, sewerage is generated and impervious surfaces increase the rate and volume of stormwater runoff (Coombes 2018a). The impacts of local changes are varied (e.g. a greater cumulative risk of water shortages, flooding, and degradation of both ecological services and rivers/streams) and can be minimized by including sustainable stormwater solutions in municipal plans and maintaining the related infrastructure. However, the costs for water cycle services increase as cities grow, making stormwater management (SWM) more complex. For this reason, governments are facing limitations in generated revenues and they are constantly seeking innovative ways to fund their SWM programs.

Mechanisms of stormwater funding include bonding for capital improvements, capitalization recovery fees, developer extension/latecomer fees, federal and state funding opportunities (grants, loans, and cooperative programs), general fund/general tax revenues, impact fees, in-lieu of construction fees, plan reviews, development inspection, special user fees, property taxes, special assessments, and stormwater user (service) fees (Tasca *et al.* 2017). There are constitutional and other restraints on how these mechanisms, mainly taxes and fees, are structured and applied worldwide. Fees must be paid when someone chooses to use a government service and that payment should cover the cost of the service received. In other words, the user must pay for the service received, or else that service will not be provided. In turn, taxes are a compulsory contribution to state revenue in order to finance government activities; that is, they are not tied to what a citizen gets, and paying them is not a matter of choice. The implementation of charges always depends on national laws, but it must be well structured to avoid legal disputes.

A user fee based on stormwater utilities is being increasingly used as a plausible mechanism to address stormwater problems. A stormwater user fee provides a reliable and equitable source of revenue for local governments

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(Patterson *et al.* 2012), providing a steady stream of funding. This mechanism is dedicated exclusively to SWM needs and so it is adequate to meet budgeted financial needs (Benson 2002) to improve urban watershed and SWM. Beyond that, stormwater fees are important mechanisms to induce changes in the behavior of inhabitants, who are, at the same time, the clients paying indirectly for the project, users of the public infrastructure, and victims of urban floods and pollution (Chouli & Deutsch 2008).

Despite the benefits to society, there are few scientific papers about the funding of SWM with a focus on fees. Tasca *et al.* (2017) suggested that this is because the discussion about stormwater financing occurs in the technical field (e.g. service providers) in the developed countries, and much essential information is limited to the grey literature (Marsalek & Chocat 2002). The USA, for example, has developed satisfactory stormwater regulation and fees application, given that most of the related discussion is available on utilities webpages. In contrast, some detailed methods of stormwater fee structures were found in the scientific literature for countries that do not have stormwater regulation, such as Brazil and South Africa (Tasca *et al.* 2017). This may demonstrate that researchers from these countries with insufficient management of stormwater have resorted to the scientific community to broaden these discussions.

This discussion should be extended to the academic field since there is no consensus on stormwater fee implementation. This can avoid having the general public thinking that the taxation is just one more attempt by local governments to take money from citizens (Campbell 2013). In France, charging through a fee was finalized in 2014 by the authorities (Legifrance 2014) due to fears in the political environment, but the technical and research sectors were not consulted. Carron & Guénégou (2013) pointed out a number of difficulties in applying a fee, such as the calculation method, implementation, the costs of economic and municipal activities, social acceptance and non-recovery of the fees paid by real estate renters. Even in the USA, about 6% of stormwater utilities undergo court challenges (Kea *et al.* 2016), since there are concerns about unfair division of risks: about who benefits and who pays (Chalfant 2018). Already, the Senate of the Australian Parliament recommends that the Government should restore funding for stormwater research due to SWM problems, such as flooding, decline in waterways health, and recent droughts which have affected the entire country, stormwater harvesting needs, and the insufficiency of resources directed exclusively to SWM. In Brazil, a vast country in terms of water resources, just one out of 5,570 municipalities has implemented a stormwater fee, but this was suspended in 2012 (Tasca *et al.* 2017). The reason for the suspension was the method of calculation, which was not individualized for each taxpayer. Recently, another 21 Brazilian cities (0.8%) have stated that they charge a stormwater fee (Brazil 2018), but there is no clear information about this.

The fee implementation requires technical, political and legal effort, and the scientific field can make great contributions to this matter. Some of the existing doubts include: What is the stormwater fee and why do people have to pay it? Who should pay it and how? What is covered by the fee? Must property exempt from fees pay it? Some of these questions are easily answered, but others depend on the regularization or specific laws of each locality/country. For this reason, there is more discussion about stormwater fees in the technical area, since each jurisdiction must determine the best fee structure for itself. However, there is a common concern in many cities around the world: how can stormwater funding be organized where there is no regulation and insufficient resources for existing systems management? The experience of leading countries can shed light on the development of new methods or even the application of existing methods.

Thus, the focus of this paper is to present a stormwater fee developed specifically for smaller cities that do not have specific funding for SWM and specific programs. It was assumed that cities already grapple with a lack of funding for existing drainage infrastructure (maintenance and operations), where money may not be available in the tough competition with other urban services. This scenario may contribute to the occurrence of flooding. To design a fee model specific to these types of cities, the main method applied in the USA was modified and a fee model that can support the operation and maintenance costs of stormwater services was developed. This method was simulated in a small municipality located in the southern region of Brazil and the users' ability to pay was analysed. Finally, the authors carried out a critical analysis of this method.

STORMWATER FEES

Providing a stormwater service involves a large amount of funds to deploy and maintain infrastructure. These funds are typically divided into two categories: 1. operations and 2. maintenance and capital improvements. Besides that, fees can support the direct costs of SWM programs. These include a wide range of activities such as the improvement of stormwater quality and waterway health, flood control measures, development of drainage plans, river restoration, adding or improving streamside park space, installation of modern SWM systems including various best management practices, provision of both aesthetic values within the urban landscape and water for reuse, and so on. These programs can produce better water quality, healthier urban ecosystems, and improved quality of life (Walker 2001).

So, a stormwater fee encourages the recognition of stormwater as a resource, with fees tied to impacts. For that reason, fees have the potential to positively affect residents' behaviour, especially when they are based on impervious surfaces, or if a system of credits is included in the system (NEEFC 2005). At the very least, this charge raises awareness about the connection between human development activities and polluted runoff. Taxpayers should be aware of these benefits, so that they can gain public acceptance and the approval of a new tax. They need to know why they now have to pay for something that used to be free.

According to Kea *et al.* (2016), stormwater fees take two forms, one based on the use (availability) of the stormwater municipal conveyance system and management services, and the other on consumers' use of these systems and services. The first is a flat rate charge for all homeowners, regardless of how much they contribute to the additional runoff (Sharples 2007), which seems unfair. According to Coase (1947), there is an assumption that uniform prices are more desirable because this is commonly associated with the view that the undertaking as a whole should be self-supporting. However, this model has been criticized because it considers the demand of all consumers to be the same. Thus, if there is an additional cost to supply a certain group of consumers, other groups will have to pay for it under a cost-sharing approach. This may either raise or lower the average cost of supply to consumers. Besides that, these fees are economically inefficient for both consumers and producers, resulting in a view that a fixed stormwater fee is only a mechanism to collect revenue rather than a process that assists to solve a stormwater problem that benefits the whole of society.

The other fee is variable and is determined by the volume of stormwater runoff disposed from a property to the storm system. It can take many forms, as shown in Table 1.

Most of the methods mentioned above have in common the reference of impermeable areas, since these directly correlate to the amount of stormwater runoff. Reduction of soil infiltration results in an increased runoff volume into drainage systems and, hence, increased peak flows. Thus,

Table 1 | Funding mechanism descriptions (variable fees)

Method	Description
Distributed Alternative Transportation (DAT)	DAT considers the municipal roads runoff management and calculates the approximate cost based on the average trips generated by a specific user. This component is added to the residential stormwater fee.
Equivalent Residential Unit (ERU)	Funding mechanisms that determine usage based on the impervious area. One ERU is equivalent to the average amount of impervious area on residential properties. Typically, a charge is assessed per ERU used.
Meter	Funding mechanisms that charge based on the size of a parcel's water meter (often exhibited in tier systems).
Parcel acre	Funding mechanisms that charge a rate per parcel acre of imperviousness.
Residential Equivalence Factor (REF)	Funding mechanisms that determine usage using the Natural Resources Conservation Service (NRCS) runoff method or rational method.
Square foot (sq. ft)	Funding mechanisms that charge a rate per parcel sq. ft of imperviousness.
Tier	A system where consumers are categorized by quantifiable (such as the magnitude of impervious area or water use) or qualitative factors (such as land use type or water meter size) and charged accordingly. In many cases, a flat fee is charged for various ranges of impervious areas.
Two level/dual (residential/ commercial)	Funding mechanisms that assess different rates or use different methods (often fixed rate and ERU) for commercial and residential properties.
Usage	Funding mechanisms that charge according to parcel water usage (volume of runoff and rate at which runoff is produced). Runoff volume and rates can be determined using a number of factors (usually the impervious area is used).

Source: Adapted from Kea *et al.* (2016).

storm drains and streams can become inundated faster after heavy rains, resulting in floods. This results in increased maintenance and repair requirements of the storm system. Besides this, these systems route runoff directly to streams and rivers, thus exacerbating pollutant inputs and hydrologic disturbance, and result in the degradation of the ecosystem structure and function (Roy *et al.* 2008). In this way, the relationship between impermeable areas and their impact on stormwater is relatively easy for the public to understand. The number of billable units can be defined considering only the impermeable areas, which saves work time and is another advantage of its use. In general, this is considered fair. In contrast, the main disadvantage is that the potential impact of the stormwater runoff of permeable areas is not accounted for. In this system, the expenses are recuperated from a small area base (impermeable) and an update is required when new areas are built (EPA 2008).

Stormwater financing through stormwater fees was observed in Australia, Canada, Ecuador, France, Germany, Poland and the United States (Tasca *et al.* 2017). The average impervious reference area was similar in all these countries (160–300 m^2), but the fees charged varied significantly ($0.58–134.46 monthly), considering the United States Dollar ($). Germany has the highest fee per m^2 ($1.51), while the USA has the lowest ($0.02). In general, the billing methods are not detailed. The USA is a good example of a country that faced the problem of stormwater funding mechanisms, and the most widely used method is the Equivalent Residential Unit (ERU) system (Campbell *et al.* 2016). An ERU is usually the average impervious area on a single-family residential (SFR) parcel, although some communities define it as the average of all residential parcels (Campbell *et al.* 2016). An SFR, also known as single-family detached residence, is defined as a residential structure maintained and used as a single dwelling unit, a private home. SFRs are built on a single lot, with no shared walls. SFRs differ from condominiums, townhouses, cooperatives, and multi-family homes, which are all attached residences.

Equations (1)–(3) show the ERU method (Kea *et al.* 2016), which is based on the average amount of impervious surface area on a residential parcel (Equation (1)). Each property is assessed to determine how many ERUs it possesses (Equation (2)), and finally a fee assessment rate per ERU is established and all properties are assessed accordingly (Equation (3)). Each SFR owner pays the cost of one ERU as a stormwater fee, while fees for other properties are expressed as multiples of ERUs. So, the fees provide for an equitable assignment of cost that is in proportion to the demand placed on the drainage system.

$$\text{ERU (area)} = \frac{\text{Total residential impervious area}}{\text{Total number of residential parcels}} \tag{1}$$

$$\text{Number of ERUs per parcel} = \frac{\text{Total parcel impervious area}}{\text{ERU (area)}} \tag{2}$$

$$\text{Total fee} = \text{Eq.2} \times \text{ERU (rate)} \tag{3}$$

In general, the stormwater funding observed in medium and large cities or countries has some kind of stormwater regulation. Small cities have been ignored by urban theorists, since urban research has been dominated by studies of selected big cities that exemplify best the key themes of urban studies (Bell & Jayne 2009), especially studies on rapid urbanization and its impacts. Recent research suggests that smaller providers face a variety of challenges, including diminishing customer bases, fewer financial resources, and a lack of engagement in long-range planning (Mack & Wrase 2017). This may intensify stormwater concerns in these cities. Besides that, the public or private orientation of providers also factors into rates in many countries, since private entities can make a profit on water services, while public providers are required to price on a cost-recovery basis. The intensive focus on the biggest cities limits the generalizability of some theories and inhibits the development and impact of urban studies in the broadest sense (Bell & Jayne 2009). Studying small cities enables us to see the full extent of this.

MATERIAL AND METHODS

The methodology was divided into three main stages. In the first, research was conducted to determine the main methods used in existing stormwater fees (as previously shown). In stage 2, smaller cities were defined and a stormwater fee for them was developed. In stage 3, the method was simulated in a small city and the affordability of stormwater services was investigated. After these steps, a critical analysis of the developed method was performed.

Definition of a small city

Any attempt to offer a rigorous definition of what constitutes a small city is problematic because urban hierarchies differ greatly in different parts of the world. It depends on many factors (such as the degree of urbanization, level of development and the economic structure of the country). In this research, the small-city status was determined by its population size (1,000 to 20,000 inhabitants) and some functional urban characteristics. Bell & Jayne (2009) observed that a small city in the USA is defined as having less than 50,000 inhabitants, while a small city in developing countries might have 5,000 to 20,000 inhabitants (and many such cities do not have specific policies), rating 10 times lower than that of the OECD (2014). This number varies from one country to another. This population size does not fit all and so this should not be an absolute. For that reason, 'smallness' also needs to be considered in other ways that complement such standard numerical measures. The following assumptions were assumed for small cities:

- The presence of predominantly residential development areas that are characterized mainly by dwellings sited on individual allotments, i.e. that are not dominated by an industrial or corporate presence and are not subdivided into monofunctional districts.
- Small urbanity, where green areas are predominant, and it is difficult to distinguish when rural landscapes give way to small towns, which are partially urban and partially rural.
- There are no private providers, just public providers.
- There is no combined sewage and stormwater network.
- There is no specific funding for SWM and, from this perspective, there are no specific programs.

In this scenario, it is assumed that small cities struggle with a lack of funding for stormwater infrastructure (maintenance and operations) and that public providers are not allowed to earn profits on services (just cost recovery alone). So, services are basically composed of the maintenance and operation of systems, which may not be available in the tough competition with other water services, including water supply and wastewater management (Marsalek & Chocat 2002).

Stormwater fee development

In order to develop a model to fund the costs of stormwater system operations and maintenance for small cities, we propose to construct a model which exhibits the essentials of the problem but which is sufficiently simple for the analysis not to be unduly complicated. The aim of the fee is not to achieve profits but to be self-supporting. The ERU system generated the knowledge base for the stormwater fee development specific to these types of municipalities. So, an ERU system simplification was developed and named the Simplified Equivalent Residential Unit (SERU). ERU was chosen because it is considered fair, distributing costs in proportion to the impervious area, besides its simple application. Besides this, urban development, which is directly reflected by the impervious areas, has been linked to changes in municipal stormwater runoff quality and quantity. This is relatively easy for the public to understand, as previously mentioned. By basing the fee on the impervious surface area, residents would pay for the water they contribute to the system.

SERU is defined as the average impervious area of all parcels (residential, industrial, commercial, etc.) located in the urban area (Equation (4)). This value can be monitored over time, becoming a reference for the city development as a key environmental indicator. It is limited to the urban area, since in rural areas there are no impervious areas or widely distributed infrastructure. The management of road surfaces was not considered in this fee for two reasons. One is because it is not possible to charge general road-users, but only the local residents. In this case, the individualization of all beneficiaries is complex. Other reason is that the maintenance of roads (and their public spaces) may be embedded into other rates. Again, local laws come into play. Because of this, the Simplified ERU was designed for parcels only, including public parcels.

A fee assessment per SERU is established (Equation (5)) and all urban properties are assessed proportionally to the impermeable area within the lot (Equation (6)). Thus, it is considered that runoff generated from a property is proportional to the impervious area of the property. This is used to calculate the stormwater fee for property owners, which constitutes an apportionment of the operations and maintenance costs by the total parcels.

$$\text{SERU (area)} = \frac{\text{Total impervious areas of urban lots in the city}}{\text{Total of urban lots in the city}} \tag{4}$$

$$\text{Annual fee per SERU} = \frac{\text{Operations and maintenance costs of stormwater}}{\text{Total of urban lots in the city}} \tag{5}$$

$$\text{Annual fee per parcel} = \frac{\text{Impervious area of parcel} \times \text{Eq.5}}{\text{Eq.4}} \tag{6}$$

The Simplified ERU could finance the operations and maintenance costs of stormwater services in small cities and generate revenue to address current problems, such as the lack of infrastructure maintenance. As there are no programs and no utilities, fee discounts (stormwater credits and incentives) are not offered. In other words, there is no consolidated management that allows the supervision or management of sustainable stormwater solutions.

The difference between the ERU and SERU systems is related to the coverage area, reference impervious area, and billing classes. The ERU method covers entire communities or districts, and the reference impervious area is represented by Single Family Residences (SFR) with variable billing classes (SFR, commercial, institutional, vacant, industry, etc.). The SERU method covers the urban area of a small city, considering all lots to calculate the impervious area, and there is a simple billing class system. Usually, most parcels in a community are residential parcels and these may either all have a single fee or be divided into a few tiers (Campbell *et al.* 2016). This simplifies the administration for local planners and it is especially important for those who do not have a specific sector for SWM.

There is no single way of calculating fees through SERU. If the municipality has a multipurpose territorial cadastre, it will be able to calculate the fee regardless of how these files are stored. However, it is indicated that fee calculation can use a Geographic Information System (GIS) database. In the USA, for example, cities are required to generate maps showing properties that generate stormwater runoff and the fee applicable to them. A comprehensive GIS database should be developed as part of the permit program and the results should be made available to the public. So, the use of GIS tools has a crucial role and allows problems to be addressed in an efficient manner, such as through the creation and updating of GIS-based data for SWM.

The data required to apply SERU are: the impervious surface area (Step 1), parcel boundary data (Step 2), and annual indirect costs of stormwater services (Step 3).

Step 1 – estimating the impervious surface area

The first step is to estimate the total impervious areas of urban lots through remote sensing. The impervious area refers to land that is covered and cannot absorb water. These areas include residential access, rooftops, sidewalks, pools, and buildings within the parcels. A variety of remote sensor data sources can be used, such as aerial photography, digital aerial imagery, satellite imagery, and Lidar (Jensen *et al.* 2005). Extraction information can be performed from manual image interpretation or using automated computer processing methods. High and moderate spatial and temporal resolution data are required, because inaccuracies in calculation mean that someone will pay a disproportionate amount.

Step 2 – parcel boundary data

Parcel boundary data allow individualization of the impervious areas estimated in the previous step. The imperviousness (estimated in Step 1) and parcel boundary data can be overlaid to calculate the actual impervious area that generates stormwater runoff within each parcel. Steps 1 and 2 result in the SERU area (Equation (4)). In this method, tax assessor data are not necessary.

Step 3 – official data on stormwater costs

Stormwater services costs are needed, and there are commonly two ways to obtain these. The first way is to derive price information from provider websites or call providers to get pricing information. The second approach is to use information/survey of existing stormwater fees. In many locations, there is no individualized charge for these services, and these services are included as part of another program. Depending on the SWM priority, getting this data can be a challenge, and it can be complex to estimate the real costs of these services. In addition, there should be a check on the costs that can be charged through a fee. Specific local conditions and laws come into play. To maintain an updated database, these costs should be reviewed annually and they must be well drafted in order that the charging is not judicially challenged.

SERU simulation

The Simplified ERU was simulated for Santo Amaro da Imperatriz, a small city located in Santa Catarina State, in the south of Brazil. There is no national stormwater regulation in Brazil, and although it is a country that is abundant in water resources, the traditional urban drainage (grey infrastructure) is predominant. SWM can be worse in small Brazilian municipalities, that is, those having fewer than 20,000 inhabitants. These municipalities are not legally required to have an urban development master plan and have limitations in generating revenues. In addition, municipalities have problems regarding professional qualifications, municipal technical capacity, lack of integration of sanitation management, political will, and individualized billing, among others. In this scenario, there is a lack of urban stormwater planning and these services are not a priority in the municipal framework. Commonly, maintenance is performed reactively, i.e. it receives greater attention from local authorities after the occurrence of flooding. It should be noted that this is the normal case in Brazil.

Santo Amaro da Imperatriz has an area of 344.05 km^2, of which 63% is integral preservation area. Although the urban area occupies only 27.07 km^2, it has 75.51% of the population (almost 15,000 inhabitants) according to the last national census (IBGE 2011). The economic base is seated in industries (52%), services (44%) and agriculture (4%). This last one composes the landscape of the urban area, formed predominantly by pastures and green areas, characteristics common to the small cities in this State. The main river is the Cubatão do Sul, which is widely used for water supply to the Florianópolis metropolitan area (the capital of Santa Catarina State). It supplies about 700,000 people out of its jurisdiction, demonstrating the importance of preserving its water quality. Its population has been growing, but there is no legal instrument (such as an updated master plan) for urbanization planning.

In this city, stormwater services are provided directly by the city hall as part of various programs. They are included in the paving and drainage of streets and sidewalks, construction of culverts, and road maintenance. The responsibility for SWM is dispersed between various government agencies and departments and, given the billing is not individualized, operations and maintenance are insufficient. In other words, there is a complex panorama to SWM, where these services are practically forgotten by the local government. In this scenario, the stormwater issue is considered low priority and flooding disaster management is mostly reactive. Essentially, managers only carry out operations and maintenance of traditional drainage systems, although this is insufficient.

The simulation of each step of the method is described in the following sequence.

Step 1 – Extraction of impervious surfaces was carried out from the digital orthophotos from Santa Catarina State mapping (Figure 1), available in SDS (2017): Red/Green/Blue (RGB) composite imagery and scale from 1:5,000 (image resolution of 39 cm). ArcMap 10.4.1 was used to process the digital orthophotos and to classify them to identify the impervious area.

Supervised classification of images was used to automatically extract estimates of the imperviousness, through the pixel classification algorithm (Maximum Likelihood). A classifier was designed from 364 training samples to guide this process. Six classes of land use were reported: permeable (vegetation/pasture, exposed soil, and watercourses) and impermeable (surfaces, public roads, and pools). The permeable areas, in addition to impermeable areas, were analysed to avoid mixing and misclassification. The use of automated computer processing methods should be followed by rigorous procedures because subtle changes in the spectral response can interfere with the result. In fact, a preliminary analysis showed a high variability (heterogeneity) of the rooftops

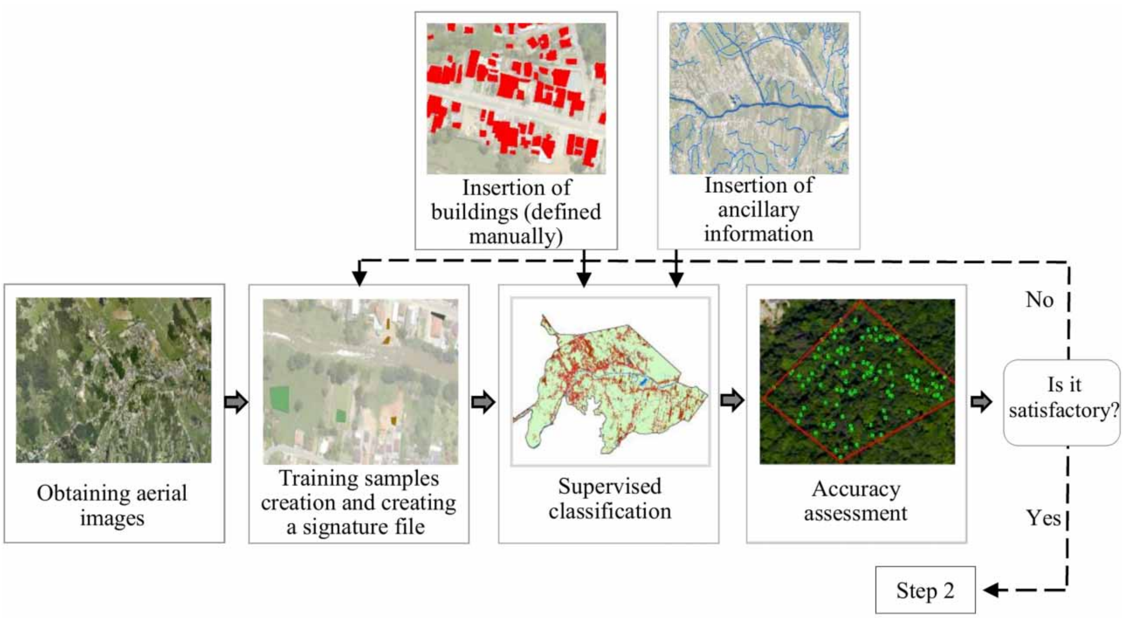

Figure 1 | Imperviousness estimate process (Step 1).

spectral response, which prevents a precise delimitation of the building. So, buildings were delimited manually in order to obtain a correct quantification. Depending on the accuracy desired, the manual delimitation is not required.

Auxiliary information (watercourses/streams features) was inserted into the supervised classification file generated. The original shapefile is available from the SDS (2017) and was trimmed to the urban area. Thus, a classified image of land-use types was obtained. The classified polygons (added to the delimited buildings and to the pre-existing auxiliary information) were compared with the training samples to evaluate the accuracy of the method. There was an overall accuracy of 97%. The authors compared the size of residential and industrial parcels and its influence on the SERU quantification. This was done to verify if class simplification of all lots as residential is valid for small municipalities. So, industries were identified as buildings larger than 300 m^2, by visual analysis of orthophotos.

Step 2 – The parcel boundary data were provided by the municipal government of Santo Amaro da Imperatriz, representing 99.4% coverage (6,864 lots) in the urban area.

Step 3 – In this specific case, the municipal government did not report about the annual costs of stormwater services. As services are diluted in various departments, it is believed that they do not really know how much they spend. Thus, operations and maintenance costs were estimated as 5% of the total investments in this sector. This proportion was suggested by Cruz (2004) after a 12-year study of the Porto Alegre city, also located in southern Brazil. Total investments were surveyed over the Transparency Portal (Brasil 2018), a tool that aims to increase the fiscal transparency of the Brazilian Federal Government through open government budget data. Data have been available since 2010 and in this research the costs from 2010 to 2017 were used. The local currency (Real) was converted to US Dollars ($) in order to allow international comparison. For this, the average quotation of each year was used, based on the Central Bank of Brazil (BCB 2017). These costs are shown in the supplementary material (available with the online version of this paper).

The average annual cost corresponds to $568,371.3 and this value was used as the basis of the costs to be recovered through the collection. These costs were unknown and this study has provided a first estimate of these values. Few resources were directed to the stormwater systems until 2014. By contrast, there was an increase in 2015 and 2016. Despite this, there was a greater exchange variation in the currency conversion of this period. A consideration of the full financial and economic costs of stormwater is more comprehensive, but data are not available in this case. Besides that, annual budgets should include adequate staffing and financial resources to conduct the maintenance activities needed to assure that stormwater systems operate properly. However, since stormwater is not regulated and there are no specific resources, there is also no specific staffing.

Benchmarking affordability

Given the concern about users' ability to pay, an analysis was carried out in order to quantify affordability at full cost recovery rates. Income-based benchmarks are more popular for such quantification (Mack & Wrase 2017). In Brazil, there is no national representative database on stormwater prices. This makes level assessments of affordability challenging. For this reason, the price of other sanitation services was used as a basis. The US Environmental Protection Agency (EPA) proposes that households spend no more than 4.5% of their median household income on water and wastewater services. This value is similar to that income benchmark recommended (5%) by World Bank (Mack & Wrase 2017). Expenses higher than this amount are considered unaffordable. Brazilian households from the southern region (study area) spend 0.9% of their monthly income on these services, the same value as the Brazilian average (IBGE 2010).

In this study, affordability was assessed similarly to the EPA's affordability benchmarks, adapting the values to the Brazilian reality. The question of whether such Brazilian value can be considered desirable or undesirable is beyond the scope of this article. The same importance for stormwater bills was adopted in this study. Thus, bills that constitute more than 0.9% of the median household income are considered unaffordable. For this analysis, the fee, which had previously been calculated per parcel, was grouped by census block, generating an average fee for each sector. A census block is a territorial unit established for cadastral control, formed by a continuous urban or rural area, which contains a certain quantity of households. This is the smallest unit of analysis that can be discretized through official census data in Brazil. The most recent data available refer to the year 2010, the last national census year (IBGE 2011). The costs of stormwater services refer to the period 2010–2017, so the income data were adjusted to 2017 according to the increase of the minimum wage in this period (83.73%).

RESULTS AND DISCUSSION

Impervious land occupies approximately 10.60% of the study area; this can be considered of low-intensity

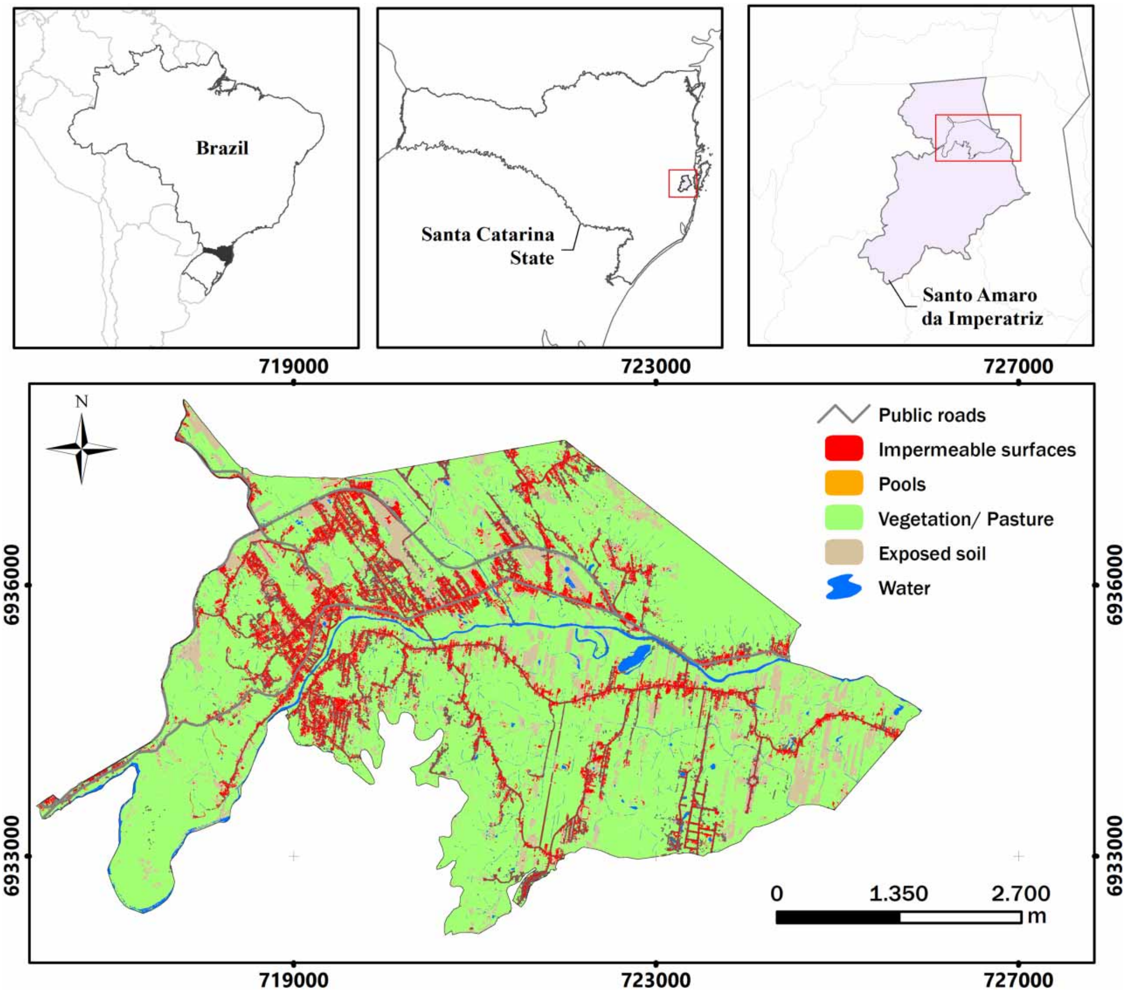

Figure 2 | Location and land-use map of urban area of Santo Amaro da Imperatriz, Brazil.

development (Figure 2). The impermeable areas in the parcels, input parameters for the fee application, represent 7.5% (2.03 km^2). It was possible to identify 4,951 lots (72%) with some type of impervious areas, while 1,913 lots were vacant (28%). So, there is no calculation basis for collection in empty lots. The SERU estimate also considers this kind of parcel in the calculation (total of urban lots in the city in Equation (4)), since they can be quickly occupied given the current dynamics related to the growth of cities. However, the lots effectively occupied are charged for the operation and maintenance of stormwater services (Equations (5) and (6)).

Fee collection in vacant lots is common in the international scenario because the 'non-polluting' users also benefit from the stormwater services. Despite this, the Simplified ERU methodology disregards this collection because it is difficult to convince these users to contribute to environmental improvement when its degradation is not directly imputed to them. Otherwise, there are examples of the taxation of vacant lots in order to encourage their occupation. Vacant lots in urban areas encumber the State, which is forced to spend resources on new urbanization to accommodate city growth, while vacant lots fuel real estate speculation. Consideration or not of the taxation of vacant lots must be a decision made by each municipality in agreement with its urban policies.

It was possible to identify 76 industrial buildings distributed in 52 lots, totalling 0.13 km^2 of impervious area. The SERU (Equation (4)) was estimated at 294.32 m^2, considering industrial users, or 277.57 m^2 when analysing only the residential areas. This is a small difference (16.75 m^2) and it confirms that simplification of the charge classes for residential lots can be carried out in small municipalities with low-intensity development. The SERU value (294.32 m^2) is

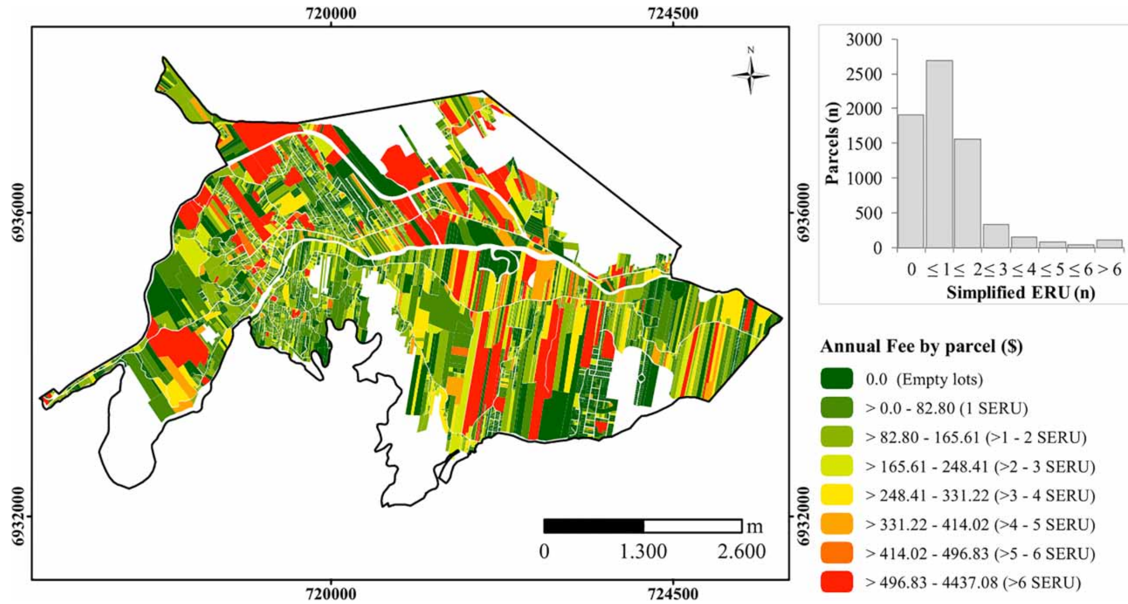

Figure 3 | Annual fee ranges by parcel.

very close to the average impervious area from the United States, which is 269.42 m^2 (Campbell *et al.* 2016), although the stormwater services provided are very different.

The annual fee is $82.80 by SERU (Figure 3), which is equivalent to $6.90 monthly. Thus, each resident must pay $0.28 for each m^2 of impervious area. This value is within the range of international fees ($0.02–$1.51/m^2) shown by Tasca *et al.* (2017). However, different types of cities with different mixes of land uses, topography and population densities will have vastly different outcomes. Research in the Greater Melbourne region in Australia, for example, showed an average value of $0.86/$m^2$ and $583/property, constituting the impervious area tariffs (Coombes 2018b). This author utilized a combination of local and regional costs of SWM that includes infrastructure, amenity, waterway health, and recreation actions, that is, this fee has been set to account for the revenue required to pay all costs of SWM throughout the region. On the other hand, SERU has been set to account for the revenue required for pay operations and maintenance costs of stormwater and its total revenue was $568,371.30. Most lots (67%) must pay up to 1 SERU, while 23% must pay between 1 and 2 SERUs.

The distribution of impermeable areas by parcel versus annual fees can be analysed as in Figure 4. Due to the

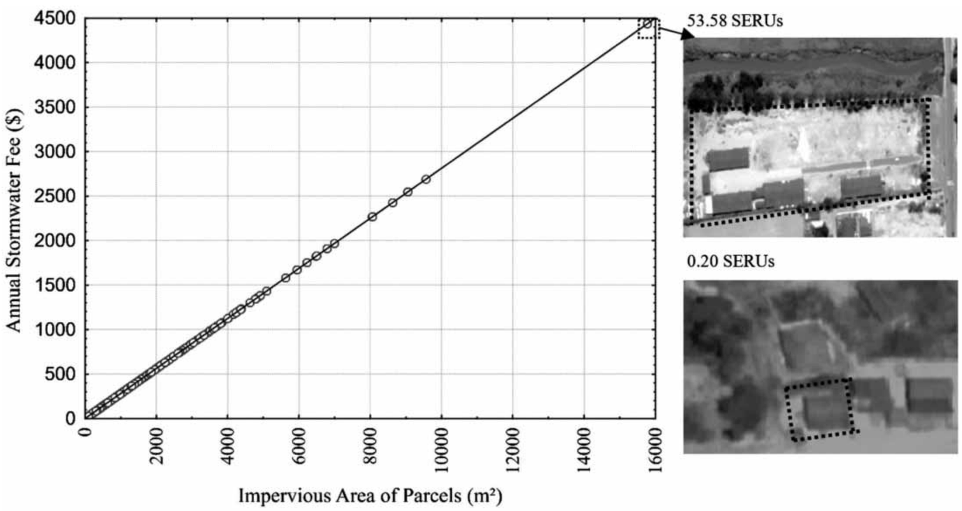

Figure 4 | Impermeable areas by parcel x annual fees, with emphasis on more and less impervious lots.

SERU design, there is a direct relationship between these variables: as one variable increases, the other also increases. In these instances of prediction, higher impermeable area values led to higher annual stormwater fees.

There are a few lots with high payments. The highest annual fee ($4,437.08) refers to a lot with 53.58 SERUs, a Municipal Exhibition Park. It was considered that public areas should also be charged according to their impervious areas, but it is not the purpose of this study to discuss who should pay this fee. The lowest charge refers to a small residential lot (0.20 SERU), which is also charged because there is no minimum reference unit. Any kind of decision about who must pay can be easily incorporated into the calculation methodology once the database is already prepared. In this sense, the methodology is adaptive to the planning process.

Santo Amaro da Imperatriz has 22 census blocks in the urban area, totalling 4,671 households and 14,970 residents. The median monthly income of the urban area is $1,434.19 and the standard deviation is $420.36. The variation is 960.99 (Sector 18) to 2,423.43 (Sector 2) as shown in Figure 5. The annual fees shown in Figure 3 were transformed into monthly fees and were grouped by census block, generating a monthly average fee for each sector. This database was crossed with the median monthly incomes (Figure 5(a)), which makes it possible to quantify the affordability at full cost recovery rates (Figure 5(b)). Just two sectors (21 and 22) will face affordability challenges to payment. This means that 323 households will have to allocate monies from other expenses to pay for stormwater services. Although this may not be a problem for higher-income households, this is an issue for low-income households and those in poverty who barely make enough money to pay for basic living expenses. In order for these households to spend no more than 0.9% of their monthly income, the monthly fee would have to be reduced by 22% and 36% in sectors 21 and 22, respectively.

Critical analysis of the SERU methodology – limitations

The Simplified ERU method uses the concept of the total impervious area (TIA), which is widely used as an indicator of environmental quality (Arnold & Gibbons 1996). However, this concept has some limitations. TIA represents the fraction covered by construction, that is, non-infiltrating surfaces (concrete, asphalt, and buildings). Hydrologically, this definition is incomplete for two reasons (Booth & Jackson 1997):

1. TIA ignores pervious surfaces that are sufficiently compacted or otherwise so low in permeability that the rate of runoff from them is similar to or indistinguishable from pavement.
2. TIA includes some paved surfaces that may contribute nothing to the storm-runoff response, such as gazebos, tents, wooden structures suspended from the ground. Indeed, the effective impervious areas (EIA) – impervious surfaces with a direct hydraulic connection to the stream networks via stormwater infrastructure – are really contributing to runoff and their use may result in overestimation of runoff volumes and stormwater fees.

EIA is an integrative measure characterizing urbanization, too, but it is not easily quantifiable because it requires information on the connectivity of impervious surfaces (Bell et al. 2016). So, it is complicated to identify TIA and EIA and estimate their contribution to the runoff, although there are some studies designed for this. These approaches were not addressed in the SERU method. The

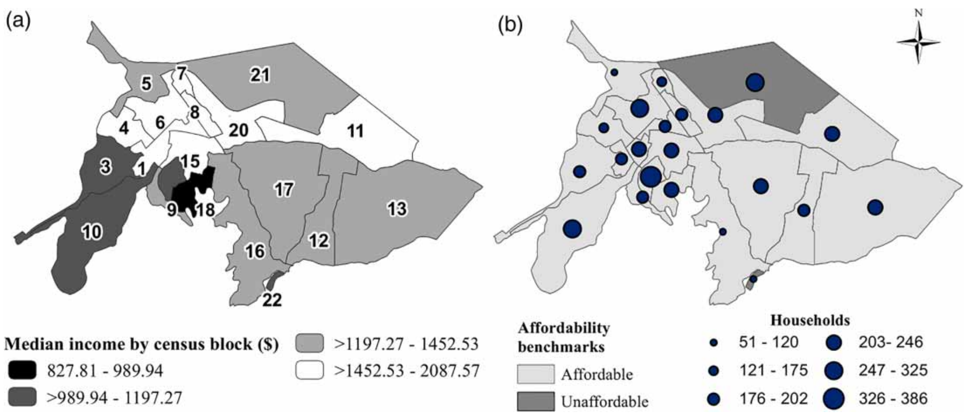

Figure 5 | (a) Average monthly income by census block in the urban area. (b) Impact distribution by census block.

collection under the TIA concept does not encourage the adoption of stormwater control measures (SCMs) since it charges the same for all lots. Selection of the appropriate SCM is dependent on local environmental conditions, and economic incentives and fee discounts should therefore be analysed for each region. In addition, SCMs implementation is related to SWM regulation. SERU considers locations without regulation. However, these incentives can be applied at any time and each property owner can choose to pay the stormwater fee or to reduce the volumes of stormwater runoff discharging from their parcel.

Besides that, many urban applications, including impervious surface and building infrastructure mapping, require a high to moderate temporal resolution of from 1 to 5 years. These types of applications also utilize high spatial resolution, often at or below 1×1 m, in order to capture the detail and complexity of the urban landscape (Jensen & Cowen 1999). Many municipalities, especially the smaller ones, may not have data with this level of detail. Lastly, the SERU method does not consider the municipal roads runoff management because this service may be embedded into other rates (generally as part of road budgets), as it happens in Brazil. Besides this, the individualization of all beneficiaries (residents and non-residents) is complex and other options, such as a fixed fee, should be evaluated.

CONCLUSION

This study presented a stormwater fee model developed for small municipalities to finance the operations and maintenance costs of stormwater services. The objective was to generate funding to solve the current stormwater problems mainly where services are not well delineated, and to be self-supporting. In this way, the main method (Equivalent Residential Unit – ERU) from the United States was simplified and based on the amount of impervious area of all parcels located within the urban area. The Simplified ERU has a single billing class, simplifying the administration of local planners and it is especially important for cities that do not have a specific sector for SWM.

The Simplified ERU was simulated in Santo Amaro da Imperatriz, a small city in the southern region of Brazil, where there is no attention to drainage systems because adequate resources and financing are not available. Just two sectors faced compounding economic factors that have an impact on their ability to pay for water services. This method was shown to be a feasible and rapid method for the design of service fee structures. Thus, given its simplicity, it could be reapplied in small municipalities that do not have a complex SWM. Besides being simple and relatively easy to apply, it requires few resources for its development. It can be easily adapted according to the peculiarities of each city. Changes in the type of cost considered, billing classes, fee discounts, for example, can be applied at any time. Stormwater fees are necessary to maintain the public stormwater system, and represent an equitable way for the community to share the cost of a public service in order to reduce the impacts of urbanization. A broad scientific discussion can contribute to the widespread dissemination of the importance of a stormwater fee system and its benefits.

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