Stormwater Fee for Watersheds Based on Directly Connected Impervious Area

Redevance de drainage pour bassins versants fondée sur la surface imperméable directement connectée

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RÉSUMÉ

L'étude présente une proposition de redevance destinée à financer la gestion des eaux pluviales urbaines dans des bassins versants, en réponse à l'insuffisance de financement adéquat pour la drainage urbaine, souvent négligée par les administrations municipales. La méthode adapte le modèle américain de l'Unité Résidentielle Équivalente, en remplaçant la Surface Totale Imperméable (STI) par la Surface Imperméable Directement Connectée (SIDC). La SIDC représente plus précisément le volume de ruissellement effectivement acheminé vers le réseau public. L'estimation de la SIDC, identifiée comme une lacune scientifique, a été obtenue au moyen de techniques de géotraitement combinées à des inspections de terrain. Les résultats ont montré que la SIDC diminue sur les grandes parcelles, tandis que la voirie publique constitue la plus grande contribution totale. Le ratio moyen SIDC/STI était proche de 50 %, avec une légère surestimation du modèle fondé sur SIG (4 %). L'analyse a indiqué que l'inspection sur site est indispensable pour les zones comptant peu de parcelles, tandis que pour les autres strates, l'approche combinée a démontré une bonne précision. L'Unité Résidentielle Connectée (URC) correspondait à 172,46 m², équivalant à 0,81 R$ par m² par an, une valeur inférieure à celles appliquées internationalement sur la base de la STI. La méthodologie a démontré sa faisabilité, avec des coûts opérationnels jugés abordables et un potentiel de réplication dans d'autres bassins, offrant un outil plus équitable et plus efficace pour le financement de la gestion des eaux pluviales urbaines.

ABSTRACT

The study presents a proposal for a fee to finance urban stormwater management in watershed areas, addressing the lack of adequate funding for urban drainage, which is often overlooked by municipal administrators. The method adapts the U.S. model of the Equivalent Residential Unit, replacing the traditional Total Impervious Area (TIA) with Directly Connected Impervious Area (DCIA). DCIA provides a more accurate representation of the runoff volume that is actually conveyed to the public system. The estimation of DCIA, identified as a scientific gap, was obtained through geoprocessing techniques combined with field inspections. The results showed that DCIA decreases on larger parcels, while public roads account for the largest total contribution. The average DCIA/TIA ratio was close to 50%, with slight overestimation by the GIS-based method (4%). The analysis indicated that on-site inspection is indispensable for areas with few parcels, whereas for other strata, the combined approach demonstrated good accuracy. The Connected Residential Unit (CRU) corresponded to 172.46 m², equivalent to US$ 0.16 per m² per year, a value lower than those applied internationally based on TIA. The methodology demonstrated feasibility, with operational costs considered affordable and potential for replication in other catchments, offering a fairer and more efficient instrument for financing urban stormwater.

KEYWORDS

Stormwater fee, Stormwater financing, Stormwater regulation, Financial sustainability, Regulation in sanitation.

1 INTRODUCTION

Urban expansion has intensified surface impermeabilization, profoundly altering the hydrological cycle and increasing both the frequency and severity of impacts associated with stormwater runoff, such as flooding, degradation of water bodies, overloading of drainage infrastructure, and the loss of ecosystem services. Despite the clear importance of urban stormwater management systems, drainage remains, in much of the world, an underfunded sanitation public service. This financial gap stems from multiple factors: competition for public resources, the low political visibility of the issue, and the mistaken perception that drainage does not require its own dedicated funding source. Countries such as the United States, Germany, Australia, and Canada have already advanced by establishing specific stormwater fees integrated into programs that ensure continuous operation, maintenance, and investment in urban drainage. In contrast, in most countries this discussion is still incipient and limited, hindering the proper management of infrastructure and the implementation of sustainable solutions.

Structured financing for stormwater management has been identified as a key element for urban resilience, promoting the recognition of stormwater as a resource. Impact-based fees have the potential to positively influence user behavior (NEEFC, 2005), mitigating negative externalities. Among the fee parameters used internationally, Total Impervious Area (TIA) is traditionally employed to estimate the runoff potential of each urban parcel. However, it is recognized that it overestimates the actual contribution to the public system, since not all impervious surfaces are hydraulically connected.

Thus, the use of Directly Connected Impervious Area (DCIA) gains relevance—an indicator that more accurately reflects the volume that effectively reaches the public network. It represents the connectivity of impervious surfaces to the drainage system. DCIA is a more precise predictor of the impact of urban development, representing a direct relationship between urbanization, changes in hydrological processes, and the impairment of aquatic ecosystems caused by channelized stormwater runoff (ROY; SHUSTER, 2009). DCIA aligns tariff collection with the principle of fair contribution, linking the fee amount to the actual impact of each parcel on the public system. However, estimating this parameter poses a significant technical challenge, given the lack of consolidated methods and the effort required to determine hydraulic connectivity at the watershed scale. No stormwater fees based on DCIA were identified in the literature.

This paper presents, in a concise manner, a methodology for calculating stormwater fees based on AIDC, applied to river basins, highlighting its importance for the sustainable financing of stormwater programs. The approach incorporated geoprocessing using open-source software, connectivity analyses, and economic evaluation.

2 METHODOLOGY

The methodology is based on the development of a stormwater fee model for operation and maintenance (O&M) costs. The Equivalent Residential Unit (ERU), the principal parameter used in the United States, was replaced by the Connected Residential Unit (CRU) as the billing basis, which corresponds to the average directly connected impervious areas (DCIA) of residential properties to the public drainage network (Eq. 1). The average connectivity is considered the reference value for calculating the fee for each residential parcel and is therefore termed the reference CRU.

The total number of CRUs in the watershed measures the overall proportion of connected areas relative to the reference unit (Eq. 2). These values can be monitored over time, becoming a reference environmental indicator for watershed development. Dividing the estimated annual O&M budget by the total number of CRUs indicates how much must be charged per average square meter (CRU) to cover annual stormwater costs (Eq. 3). The fee per CRU represents a distribution of O&M costs among all property owners connected to the public drainage system, not only residential ones. For billing purposes, it is necessary to determine the cost per square meter and multiply this value by each parcel's DCIA (Eq. 4), thus individualizing the charge. These costs were projected to support service continuity and ensure financial sustainability.

$$1\text{ CRU } (m^2) = \frac{\sum DCIA\ residential\ in\ the\ watershed\ (m^2)}{\sum connected\ parcels\ in\ the\ watershed} \quad \text{(Eq. 1)}$$

$$\text{Fee for } 1\ URC = \frac{\text{O\&M costs}}{Eq.2} \quad \text{(Eq. 3)}$$

$$\sum\text{URCs in the watershed} = \frac{\sum DCIA\ in\ the\ watershed\ (m^2)}{Eq.1} \quad \text{(Eq. 2)}$$

$$\text{Fee by parcel} = \frac{\text{Eq.3}}{Eq.1} \quad \text{(Eq. 4)}$$

The identification of connected parcels and of the DCIA constitutes the technical core of the proposal and represents a considerable challenge. To estimate these components, a set of complementary techniques was employed:

- Satellite image classification and the use of GIS tools;
- Stratification of parcels according to urban typologies, anticipating similar hydrological behaviors;
- Assessment of hydraulic connectivity using Google Street View and Google Earth for the preliminary identification of directly connected surfaces;
- On-site inspections aimed at validating and refining the estimates produced through remote analysis.

The final DCIA for each parcel was determined through a weighted average between the GIS-derived results and field-based adjustments, increasing the accuracy of the value adopted for tariff purposes. The estimated DCIA was compared with the empirical equations of Laenen (1983), Alley and Veenhuis (1983), Wenger et al. (2008), Mroczek (2018), and Sultana et al. (2020), all of which use TIA as a parameter for estimating DCIA. Finally, the economic impact on users was assessed through income-based analyses (0.75% is the maximum allowable commitment of monthly household income).

The model was applied to the Córrego Grande watershed in Florianópolis, Santa Catarina, southern Brazil. With an area of 4.12 km² and an approximate population of 11,000 inhabitants, the watershed has a large floating population and substantial urbanization, exerting strong pressure on existing water resources, which ultimately discharge into the Itacorubi mangrove. This mangrove is an environmentally protected area and contains the second largest urban mangrove in Brazil.

3 RESULTS

A total of 424 parcels were identified as connected and subsequently stratified into categories (residential, multi-family buildings, commercial and industrial properties, mixed-use parcels, vacant lots, institutional areas, and roads/sidewalks). The residential category was further subdivided by lot size. For all categories, the average DCIA/TIA ratio was determined—initially through GIS analysis and later refined based on field inspections conducted on 50% of the samples. The parcel-specific fees calculated from the DCIA are presented in Fig. 1:

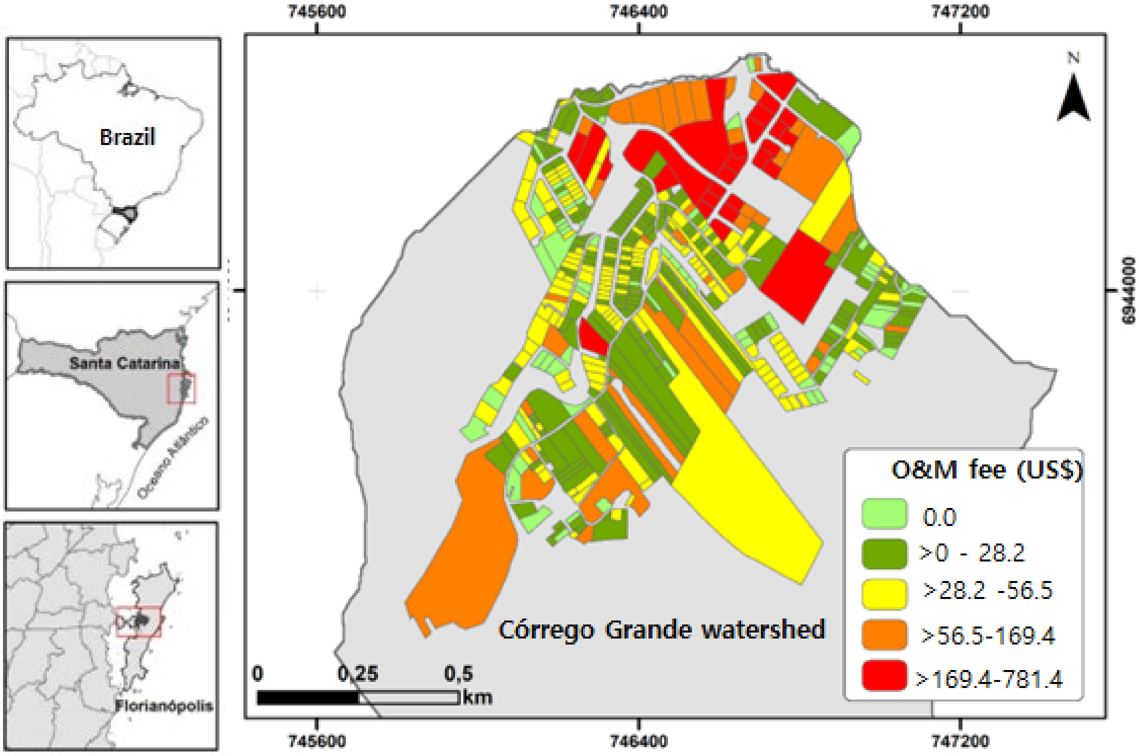

Figure 1: Annual Operation & Maintenance (O&M) fee for each urban parcel

The application of the method made it possible to identify relevant hydrological and financial patterns, demonstrating the effectiveness of using DCIA as a tariff-setting parameter :

- **DCIA and connectivity:** The mean DCIA represented approximately half of the basin's total impervious area (51% using GIS and 47% after field adjustments). Thus, the combination of GIS analysis and field inspections demonstrated high accuracy, with a mean overestimation of only 4% by the remote method. For categories with a small number of parcels, full field inspection was essential; for the others, the mixed approach proved efficient and economically advantageous. When compared with empirical equations, the method that most closely approximated the DCIA estimated in this study was that of Laenen (1983), differing by only 10%. Despite this similarity, drainage practices in the study area are highly diverse and lack standardization in stormwater hydraulic installations, preventing the establishment of any direct relationship at this stage. These comparisons showed that DCIA cannot be accurately predicted using existing empirical relationships.
- Paved roads accounted for the largest share of the total DCIA (32.8%), confirming their predominant role in directing runoff to the public drainage system.
- Determination of the CRU: The CRU was estimated at 172.46 m² of DCIA, resulting in an annual fee of US$ 28.23 per parcel with this typical level of connectivity — equivalent to US$ 0.16/m², which is lower than international values that use total impervious area.
- Equity of the charge: The adoption of DCIA demonstrated greater tariff fairness by accounting for the volume that effectively reaches the public drainage system, thus avoiding the overestimations that occur when total impervious area is used.
- Financial feasibility: The O&M fee fully recovered the associated costs, with values considered affordable. Only in one sector of the basin was the impact deemed high, corresponding to 0.80% of monthly household income (662 people affected).
- Method replicability: The approach developed, along with the detailed methodological framework, demonstrates strong potential for application in other urban catchments, particularly in contexts where stormwater management lacks a dedicated funding source.

4 CONCLUSIONS

The results show that using Directly Connected Impervious Area as the central element of a stormwater fee represents a significant step toward a tariff model that is fairer, more effective, and better aligned with actual urban hydrology. Adequate financing of stormwater management — a topic still insufficiently discussed in the global context — finds in this method a robust and replicable alternative capable of promoting the financial sustainability of stormwater services.

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