CALCULATION AND ESTIMATION OF CHARGES FOR MUNICIPAL SOLID WASTE MANAGEMENT SERVICES BASED ON WATER CONSUMPTION: A CASE STUDY OF BRAZILIAN MUNICIPALITIES

DOI: http://dx.doi.org/10.55449/conresol.7.24.IV-021

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RESUMO
Os municípios brasileiros enfrentam diversos desafios na gestão de resíduos, como a disposição em locais inadequados, dificuldades na implementação e ampliação da coleta seletiva, e as baixas taxas de recuperação de resíduos. Mudar esta realidade exige recursos financeiros, que devem ser obtidos por meio da cobrança pelos serviços. Todavia, uma grande parcela das cidades ainda não adota essa prática ou não arrecada valores suficientes para suprir as demandas necessárias. Buscando oferecer uma solução para esta problemática, este trabalho desenvolveu uma ferramenta de cálculo de cobrança para serviços de gerenciamento de resíduos sólidos urbanos para municípios brasileiros baseada na relação entre consumo de água e geração de resíduos. Para isso, foram utilizados dados do Sistema Nacional de Informações sobre Saneamento (SNIS) e foi proposta uma adaptação do modelo de cobrança sugerido pela Agência Nacional de Águas e Saneamento Básico (ANA), de forma a deixar o cálculo mais simples e acessível para os municípios brasileiros, uma vez que muitos deles ainda não têm todos os dados disponíveis. A ferramenta criada considera os seguintes fatores no cálculo: tipo de construção (residencial, comercial, industrial e pública/filantrópica), frequência de coleta dos resíduos (uma vez por semana, 2 a 3 vezes por semana e diariamente) e o consumo de água. Além disso, ela possui duas funções: Modo de Informação (quando o município está presente na base de dados e o cálculo é automático) e Modo de Cálculo (o usuário precisa informar os dados manualmente). O usuário também pode escolher qual o índice de reajuste de preços deseja usar (IPCA ou IGP-M) e ao final pode visualizar os resultados nos formatos tabular e gráfico. Por fim, mostramos a aplicação da ferramenta para o município de Timbó, Santa Catarina.

PALAVRAS-CHAVE: resíduos sólidos urbanos, equilíbrio econômico, ferramenta de cálculo, SNIS, consumo de água.

ABSTRACT
Brazilian municipalities face several challenges in waste management, such as inappropriate disposal, difficulties in implementing and expanding selective collection, and low recycling rates. Changing this reality requires financial resources, which must be obtained through charging for services. However, a large portion of municipalities still do not adopt this practice or do not raise enough funds to cover the total expenses. In an attempt to provide a solution to this problem, this work developed a charging tool for municipal solid waste management services for Brazilian municipalities, based on the relation between water consumption and waste generation. For this, data from the National System of Water and Sanitation Data (SNIS) was used and an adaptation of the charging model suggested by the National Water and Sanitation Agency (ANA) was proposed, in order to make the calculation simpler and more accessible for Brazilian municipalities. Despite its reduced robustness compared to the ANA model as a result of the simplifications made, our model becomes more applicable in situations where information is scarce. The tool created considers the following factors in calculation: type of construction (residential, commercial, industrial, and public/philanthropic), frequency of waste collection (once a week, 2 to 3 times a week and daily), and water consumption. Furthermore, it has two functions: Information Mode (when the municipality is present in the database and the calculation is automatic) and Calculation Mode (the user needs to enter the data manually). The user can also choose which price adjustment index they want to use (IPCA or IGP-M) and, at the end, can view the results in tabular and graphic formats. Finally, we show the application of the tool for the municipality of Timbó, Santa Catarina.

KEY WORDS: municipal solid waste, financial sustainability, charging calculation tool, SNIS database, water consumption.

INTRODUCTION

Proper management of solid waste is crucial to ensure human well-being, promote public health, and preserve the environment. Nevertheless, Brazilian municipalities continue to face significant challenges in this regard. In 2022, Brazil produced more than 77 million tons of municipal solid waste (MSW), with a collection rate of 93%. However, despite the high collection rate, approximately 38.9% of the total collected waste is still disposed of in inappropriate sites such as dumps. This situation is even more critical in the northern and north-eastern regions, where over 60% of MSW ends up in inappropriate disposal sites (ABREMA, 2023).

Marques, Simões, and Pinto (2018) suggest that economic regulation is essential for MSW management due to potential problems such as inactivity and inefficiency caused by market failures and lack of incentives. The new Brazilian legal framework for sanitation (Law 14.026/2020) supports this idea by requiring the implementation of fees or tariffs to improve the efficiency of MSW management services. Additionally, this new framework also gave the Brazilian National Water and Sanitation Agency (ANA) new responsibilities, including setting standards to regulate public sanitation services.

In this context, Resolution ANA No. 79, of 14 June 2021 - Reference Standard No. 1 (NR1), defines the regime, structure, and parameters for charging for public services of municipal solid waste management. Public entities and regionalised service organizations are required to submit the established charging structure or its schedule to the Agency; failure to do so may result in not receiving federal funding (ANA, 2021). In addition, regarding the method of charging, the Agency suggests that it should be done through (i) a specific bill for waste management or (ii) co-billing with water supply or other public services.

In 2022, 44% of the municipalities included in the Brazilian National System of Water and Sanitation Data (SNIS) reported having a charging system for these services. The most common method is the inclusion of a specific amount in the invoice of the Urban Land and Territorial Tax (IPTU), used by 81.9% of municipalities. Other methods include a charge in the water bill (12.8%), a specific bill (4.9%) and a tariff-based system (0.4%) (BRAZIL, 2023). However, the average self-sufficiency index for MSW management services is 53.8%, indicating that the charging mechanisms are not implemented effectively to ensure economic and financial sustainability for the municipalities (BRASIL, 2023).

The implementation of an efficient charging system requires a comprehensive understanding of the physical and demographic characteristics of the municipality, including an in-depth analysis of the costs and revenues associated with managing MSW at the local level (BRAZIL, 2022). In Europe, waste management charges based on the amount of waste generated are already implemented and are proving to be an important instrument, contributing to reducing waste generation while also increasing both the quantity and quality of selective collection (ROMANO; MASSERINI, 2023). On the other hand, in Brazil, the calculation of waste charges is mainly based on the built-up area of properties, which may not accurately reflect waste generation, as demonstrated by Franco, Castilhos Júnior and Souza (2014). Furthermore, although ANA (2021) recommends calculation models for this purpose, there is no widely adopted established methodology. Some municipalities take into account factors such as the frequency of collection and the predominant activity in the neighbourhood (residential, commercial, industrial), among others.

When developing a method for calculating waste management charges, municipalities must maximize resources for public administration while also ensuring fairness and accessibility to users. Several research studies have shown a significant correlation between water consumption and the generation of solid waste (FARIA, 2012; FRANCO; CASTILHOS JÚNIOR e SOUZA, 2014; ONOFRE, 2011). Therefore, by linking the waste charge with water usage, municipalities can establish a more equitable system where households that use more water and consequently generate more waste pay a higher price for waste collection and management services. This approach aligns with principles of sustainability as it encourages responsible resource usage.

Considering the limited data available in most Brazilian municipalities and taking into account the information provided by the SNIS database, this work aims to develop a tool that can be used by Brazilian municipalities as a base framework for calculating charges for MSW management services. In addition, a new calculation model is proposed based on water consumption. The tool could serve as reference for municipal managers and decision makers seeking to improve the financial sustainability and efficiency of MSW management services. However, this study and the associated tool are limited to the calculation of the amounts necessary to recover the total expenses. The implementation method through fees or tariffs is beyond its scope.

OBJECTIVES

This study aims to develop a tool for calculating charges for municipal solid waste management services in Brazilian municipalities. Furthermore, a new calculation model is proposed based on the relationship between water consumption and solid waste generation.

METHODS

This study used the Brazilian National System of Water and Sanitation Data (SNIS) as its database. The general framework and the steps taken to achieve the final results are presented in Figure 1.

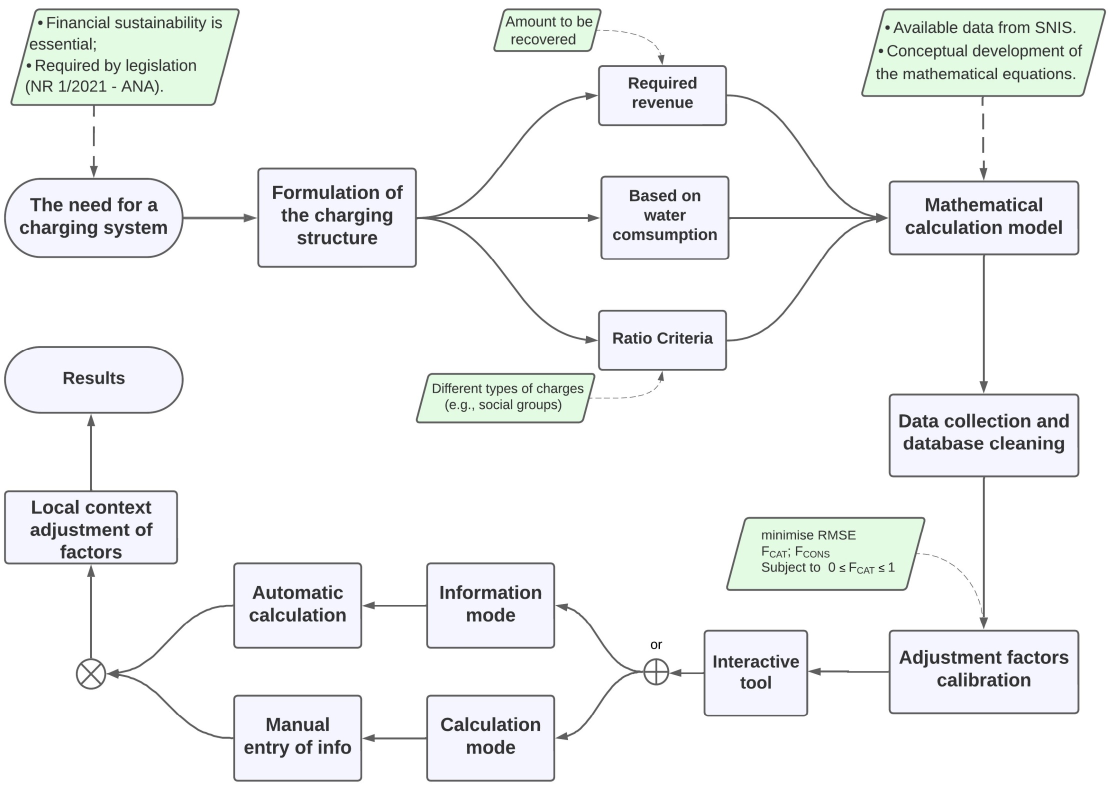

Figure 1: Flowchart of the study framework. Source: Authors.

Mathematical calculation model

The calculation model was developed on the basis of an exploratory selection of data and indicators from the SNIS. In Brazil, water and sewage service providers have a more advanced charging structure and information disclosure than solid waste service providers. For example, new constructions must be registered with the water supply agency for individual measurement-based billing, whereas individual measurements are inexistent for solid waste services. Therefore, the model framework was designed to incorporate universal cost data from solid waste management and detailed information (individual measurements) from water supply services. Furthermore, it benefits from the strong correlation between water consumption and solid waste generation (FARIA, 2012; FRANCO; CASTILHOS JÚNIOR e SOUZA,2014). Table 1 presents the selected indicators from SNIS for modelling the calculation framework.

The mathematical modelling approach is derived from the model proposed by the Brazilian National Water and Sanitation Agency (ANA, 2021). However, since the equations used to construct this model are based on the data available in the SNIS (Table 1), the modelling process must prioritise simplicity of input variables. Therefore, despite being less robust than the ANA model due to the simplifications adopted, our model gains applicability in scenarios with limited information, such as several Brazilian municipalities. Although based on an existing model, our original configuration takes into account the scarcity of data from Brazilian municipalities.

Table 1. Selected indicators from SNIS for modelling the calculation framework. Source: Authors.

SNIS Module	CODE	Description	Unit
Solid Waste	POP_TOT	Total population of the municipality (Source: IBGE*)	inhab
	POP_URB	Urban population of the municipality (Source: IBGE*)	inhab
	FN211	Total expenditure on waste collection from health services	R$
	FN214	Total expenditure on cleaning of streets and public facilities services	R$
	FN220	Total expenditure on municipal solid waste management services	R$
	IN005	Financial self-sufficiency of the municipality with MSW management	%
Water and Sewage	AG003	Number of active water consumption units	un
	AG008	Total volume of water measured on hydrometers	1000 m³/year
	IN029	Tax evasion index	%

*IBGE - Brazilian Institute of Geography and Statistics

The final charge varies depending on the building category, waste collection frequency, and water consumption. It consists of a fixed component related to the availability of the service and a variable component related to the actual use of the service, as shown in equation (1). The modelling framework considers that building category and waste collection frequency are related to the fixed component, while water consumption is related to the variable component of the equation. This approach allows for more accurate and fair calculation of charges for municipal solid waste management services, as it takes into account the specific circumstances of each household or business.

$$\boldsymbol{TMRS = TDF * F_{CAT} * F_{FREQ} + VU_c . F_{CONS}} \qquad \text{equation (1)}$$

Where $TMRS$ is the municipal solid waste charge value ($). TDF is the monthly cost for each unit of active water consumption ($) given by equation (2). F_{CAT} is the building category factor (dimensionless), F_{FREQ} is the waste collection frequency factor (dimensionless) and F_{CONS} is the water consumption band factor (m³). VU_c is defined as a unit value based on water consumption ($/m³) given by equation (3).

$$\boldsymbol{TDF = \frac{1}{12} . \frac{RR}{AG003} . (1 + \frac{IN029}{100}) . \left(1 + \frac{T_{inv}}{100}\right)} \qquad \text{equation (2)}$$

$$\boldsymbol{VU_c = \frac{RR}{1000 . AG008}} \qquad \text{equation (3)}$$

Where RR is the annual required revenue ($/year), $AG003$ is the number of active water consumption units, $IN029$ is the tax evasion index (%), T_{inv} is the investment rate (%) and $AG008$ is the total volume of water measured on hydrometers (1000 m³/year). Considering equations (2) and (3) and the cumulative price index adjustment (IGP-M or IPCA) since January 2021 (IRT), equation (1) can be rewritten as Equation (4).

$$\boldsymbol{TMRS = \left[\left(\frac{1}{12} . \frac{RR}{AG003} . (1 + \frac{IN029}{100}) . \left(1 + \frac{T_{inv}}{100}\right)\right) * F_{CAT} * F_{FREQ} + \left(\frac{RR}{1000 . AG008}\right) . F_{CONS}\right] * IRT} \qquad \text{equation (4)}$$

Data collection and preprocessing

In 2020, the SNIS database contained information on the solid waste management systems of 4589 municipalities (BRASIL, 2021). However, since the database consists of self-reported information from municipalities, it requires preprocessing to enhance the reliability of the result and prevent errors in mathematical operations, especially inconsistencies due to divisions by zero or null values.

Municipalities with invalid numbers of active water economies (null or zero) were excluded. In addition, those with negative required revenues and those reporting zero measured water volume values were also excluded. Table 2 illustrates the data cleaning and the quantity of data remaining after each step.

Furthermore, the Tukey method, also known as the interquartile range method, was used to detect outliers in the data from AG003, AG008, and IN029. This statistical approach is based on quartiles and the interquartile range (IQR), which calculates the difference between the third quartile (Q3) and the first quartile (Q1). The lower and upper limits are then determined using equations (5) and (6), respectively. Data points beyond these boundaries are classified as outliers (ROUSSEEUW; HUBERT, 2017).

$$\boldsymbol{L_{lim} = Q1 - 1,5 * IQR} \quad \text{equation (5)}$$
$$\boldsymbol{U_{lim} = Q1 + 1,5 * IQR} \quad \text{equation (6)}$$

Table 2. Database cleaning procedures and remaining amounts of data.
Source: Authors.

Data cleaning procedure	Excluded data	Remaining data
Raw data from the database	-	4589
Municipalities with zero or no active water consumption units (AG003)	126	4463
Municipalities with negative required revenue (RR)	3	4460
Municipalities with measured volume (AG008) equal to zero	325	4135
Removal of outliers by Tukey's method applied to AG003, AG008 and IN029	764	3371

The process of removing outliers was conducted for different population groups, as the data distribution shows a positive skewness due to the majority of data points being from cities with populations of less than thirty thousand. Therefore, using the Tukey method over the entire range could bias results by incorrectly identifying values as outliers. The entire dataset was divided into 9 population groups with an approximately Gaussian distribution. The method was then applied to each group individually.

The total expenditure on waste management services (FN220) includes all municipal administration expenses related to urban cleaning and municipal solid waste (MSW), including administrative costs. However, this study excludes the expenditure on waste collection from health services (FN211) and cleaning of streets and public facilities (FN2014). This decision was made because the charges associated with the collection of healthcare waste require a different calculation methodology. Additionally, in the case of charges for cleaning streets and public facilities, Brazilian legislation considers it impractical, as it is impossible to determine the individual consumption of this service per user (BRASIL, 2009). Therefore, the required revenue (RR) used in our model is derived by subtracting FN211 and FN214 from FN220. We also assume that municipalities not reporting FN211 and FN214 values did not include them in their total expenditure.

Adjustment factors calibration

The results for equation (4) were structured as follows: building categories were divided into residential (standard and social), commercial, industrial, and public or philanthropic, each assigned a factor. Collection frequency was categorized as once per week, 2-3 times per week, and daily, with 3 adjustment factors. Water consumption was segmented into eleven bands, each with its own factor. This approach yields 5 values for F_{CAT}, 3 for F_{FREQ}, and 11 for F_{Cons}, resulting in a total of 165 values provided for each location based on the combinations of category, frequency, and consumption.

The waste collection frequency factor was set as the ratio between the number of collections per week and the number of days per week. For collections once per week, the factor was set as 1/7; for collections 2 or 3 times per week, the factor was set as 3/7. Lastly, daily collection frequency has a factor of 1. To calibrate our model for accuracy, we used charging rates from Araraquara, São Paulo. This location was selected based on a study conducted by Santos, Leite, and Schalch (2020), which showed that its charging revenues were sufficient to cover all waste management costs, achieving a self-sufficiency index of over 100%.

The real data were adapted to the model's presentation structure, resulting in two sets of values: the calculated values and the real values. The objective of calibration was to minimise the Root Mean Square Error (RMSE) between these sets, using Excel Solver. This is an optimisation problem that can be written as follows:

$$\underset{F_{CAT};F_{CONS}}{\textbf{minimise}}\ \boldsymbol{RMSE}$$
$$Subject\ to\ 0 \leq F_{CAT} \leq 1 \qquad \text{equation (7)}$$

The solver was executed individually for each building category and configured to minimise RMSE as its objective function, while varying a single cell value representing the category factor and 11 consumption factors associated with each category (decision variables). A constraint was imposed to ensure that the category factor remained between zero and one. Table 3 shows the resulting RMSE for each building category after calibration.

Table 3. Root Mean Square Error (RMSE) after model calibration.
Source: Authors.

	Residential		Commercial	Industrial	Public and philanthropic
	Stardard	Social			
RMSE (R$)	0,00308726	0,29574975	0,00309207	0,00464741	0,00309207

Therefore, the default building category and water consumption band factors have been calibrated based on real values for Araraquara. However, we strongly recommend that each user conduct their own analysis based on the local context.

RESULTS

General algorithm

The tool operates in two main modes: Information Mode and Calculation Mode, which differ according to whether the location is available in the database or not. In information mode, if the municipality is present in the database, all results are automatically calculated and displayed. However, if the municipality is not in the database, the tool switches to the calculation mode, where the user must manually enter all required information. The purpose of the information mode is to cater for municipalities that are looking for values that come entirely from the SNIS database. The overall process of using the tool is illustrated in Figure 2.

The user initiates the process by entering the location, which can be selected from an existing list of 4135 municipalities or entered manually. The selected location is then checked against the SNIS database. If the location is found in the database, the user must select the preferred price adjustment index from options that include IPCA (IBGE) or IGP-M (FGV). If the location is not found in the database, the user must manually enter all the calculation variables.

Following successful location verification, the required revenue, volume measured, active water units, and evasion index variables are retrieved from the database. However, users still have the option to manually adjust each of these variables. The default investment rate is set to zero, i.e. no new investment is considered, and the charging goal is to cover all expenses represented by the required revenue. This variable is not queried within the database, but users are free to enter their desired rate if they wish.

To achieve the best results, it is recommended that the user carefully reviews and customises the adjustment factors to their specific local context, even though the default values are provided from the previous calibration process. Waste collection frequency factors are divided into three categories: once a week, 2-3 times a week, and daily. There are five building category factors: residential standard, residential social, commercial, industrial, and public or philanthropic. The water band consumption factors are divided into 11 intervals of $10m^3$ from 0 to $100m^3$, each with its own factor.

Finally, the user is able to view the results presented in both tabular and graphical formats. They can also generate a report and save their results in PDF format for further analysis or sharing.

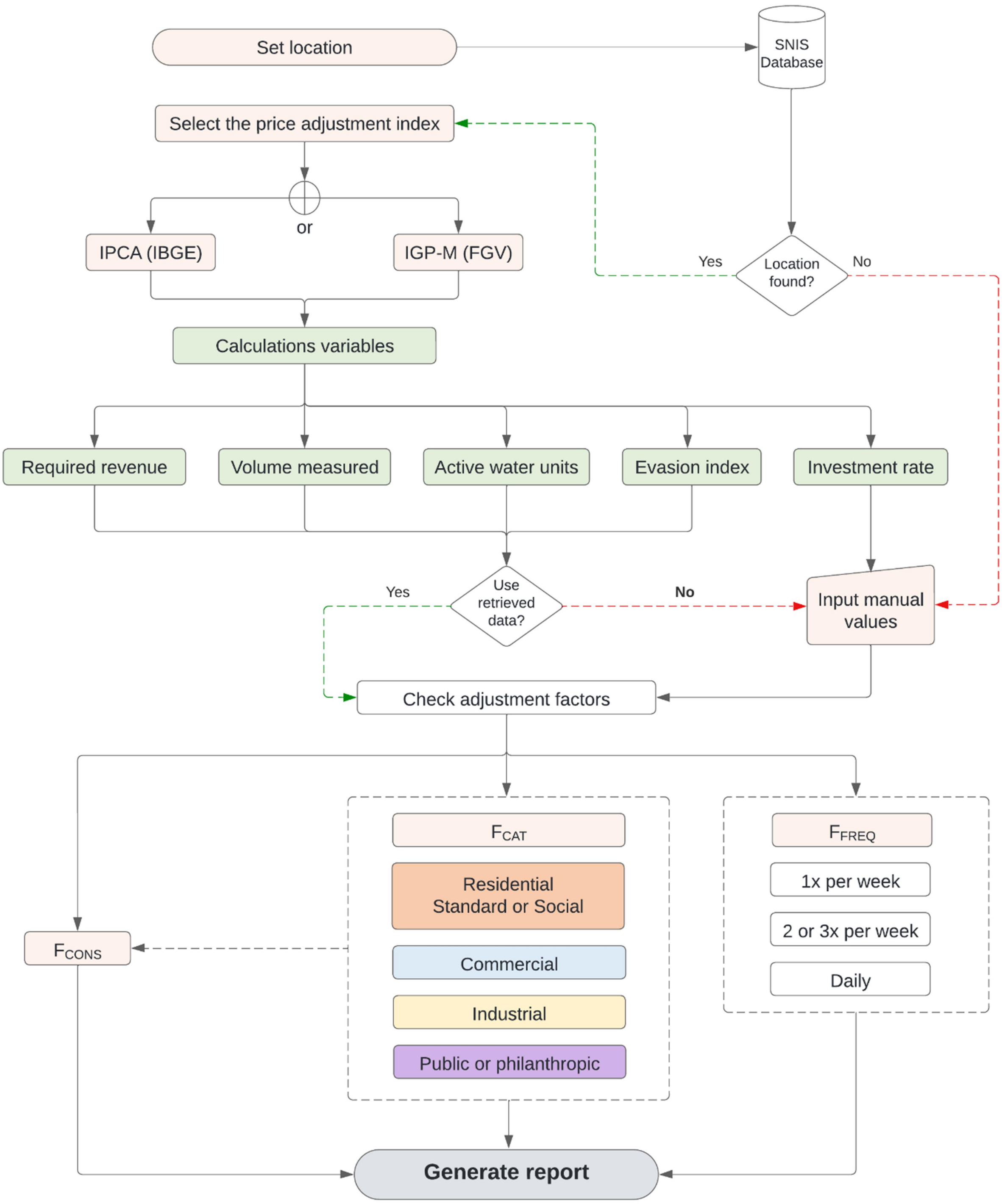

Figure 2: General usage algorithm. Source: Authors.

Results presentation and model performance assessment

The results are displayed in tabular format, consisting of 165 values representing all combinations of building category, water consumption band, and waste collection frequency. Graphs are also included to illustrate the relationship between water consumption and the charge value for each building category. Figure 3 illustrates the tabular format of the results obtained for the municipality of Timbó, Santa Catarina.

TDF:		R$ 173,50			Timbó-SC				VU$_c$: R$ 1,23 /m³		
Building category (F_{CAT})		Water consumption (F_{CONS})			Waste collection frequency (F_{FREQ})						
					1 x	0,1429	2 or 3 x	0,4286	Daily	1	
					Standard	Social	Standard	Social	Standard	Social	
Residential	Standard	0	10	1,058	R$ 2,51	R$ 2,49	R$ 4,33	R$ 4,29	R$ 7,98	R$ 7,88	
Residential		10	20	4,196	R$ 7,24	R$ 7,22	R$ 9,06	R$ 9,02	R$ 12,71	R$ 12,62	
Residential		20	30	9,472	R$ 15,19	R$ 15,18	R$ 17,02	R$ 16,98	R$ 20,67	R$ 20,57	
Residential	0,36094	30	40	16,577	R$ 25,91	R$ 25,89	R$ 27,73	R$ 27,69	R$ 31,38	R$ 31,28	
Residential		40	50	25,257	R$ 38,99	R$ 38,98	R$ 40,82	R$ 40,78	R$ 44,46	R$ 44,37	
Residential		50	60	34,732	R$ 53,28	R$ 53,26	R$ 55,10	R$ 55,06	R$ 58,75	R$ 58,65	
Residential	Social	60	70	45,025	R$ 68,80	R$ 68,78	R$ 70,62	R$ 70,58	R$ 74,27	R$ 74,17	
Residential		70	80	55,885	R$ 85,17	R$ 85,16	R$ 86,99	R$ 86,95	R$ 90,64	R$ 90,55	
Residential		80	90	67,283	R$ 102,35	R$ 102,34	R$ 104,18	R$ 104,14	R$ 107,83	R$ 107,73	
Residential	0,35557	90	100	79,337	R$ 120,53	R$ 120,52	R$ 122,35	R$ 122,31	R$ 126,00	R$ 125,91	
Residential		100	-	88,063	R$ 133,68	R$ 133,67	R$ 135,51	R$ 135,47	R$ 139,16	R$ 139,06	
Commercial	0,77778	0	10	2,302	R$ 5,44	-	R$ 9,37	-	R$ 17,23	-	
Commercial		10	20	9,077	R$ 15,65	-	R$ 19,58	-	R$ 27,44	-	
Commercial		20	30	20,468	R$ 32,82	-	R$ 36,75	-	R$ 44,62	-	
Commercial		30	40	35,814	R$ 55,96	-	R$ 59,89	-	R$ 67,75	-	
Commercial		40	50	54,556	R$ 84,22	-	R$ 88,15	-	R$ 96,01	-	
Commercial		50	60	75,014	R$ 115,06	-	R$ 118,99	-	R$ 126,86	-	
Commercial		60	70	97,220	R$ 148,54	-	R$ 152,47	-	R$ 160,33	-	
Commercial		70	80	120,708	R$ 183,96	-	R$ 187,89	-	R$ 195,75	-	
Commercial		80	90	145,312	R$ 221,05	-	R$ 224,98	-	R$ 232,84	-	
Commercial		90	100	171,343	R$ 260,30	-	R$ 264,23	-	R$ 272,09	-	
Commercial		100	-	190,185	R$ 288,71	-	R$ 292,64	-	R$ 300,50	-	
Industrial	0,92238	0	10	2,732	R$ 6,45	-	R$ 11,11	-	R$ 20,43	-	
Industrial		10	20	10,769	R$ 18,57	-	R$ 23,23	-	R$ 32,55	-	
Industrial		20	30	24,279	R$ 38,94	-	R$ 43,60	-	R$ 52,92	-	
Industrial		30	40	42,479	R$ 66,38	-	R$ 71,04	-	R$ 80,36	-	
Industrial		40	50	64,704	R$ 99,88	-	R$ 104,55	-	R$ 113,87	-	
Industrial		50	60	88,963	R$ 136,46	-	R$ 141,12	-	R$ 150,44	-	
Industrial		60	70	115,297	R$ 176,17	-	R$ 180,83	-	R$ 190,15	-	
Industrial		70	80	143,164	R$ 218,18	-	R$ 222,84	-	R$ 232,16	-	
Industrial		80	90	172,341	R$ 262,17	-	R$ 266,83	-	R$ 276,15	-	
Industrial		90	100	203,196	R$ 308,69	-	R$ 313,35	-	R$ 322,67	-	
Industrial		100	-	225,541	R$ 342,38	-	R$ 347,04	-	R$ 356,36	-	
Public and philanthropic	0,77778	0	10	2,302	R$ 5,44	-	R$ 9,37	-	R$ 17,23	-	
Public and philanthropic		10	20	9,077	R$ 15,65	-	R$ 19,58	-	R$ 27,44	-	
Public and philanthropic		20	30	20,468	R$ 32,82	-	R$ 36,75	-	R$ 44,62	-	
Public and philanthropic		30	40	35,814	R$ 55,96	-	R$ 59,89	-	R$ 67,75	-	
Public and philanthropic		40	50	54,556	R$ 84,22	-	R$ 88,15	-	R$ 96,01	-	
Public and philanthropic		50	60	75,014	R$ 115,06	-	R$ 118,99	-	R$ 126,86	-	
Public and philanthropic		60	70	97,220	R$ 148,54	-	R$ 152,47	-	R$ 160,33	-	
Public and philanthropic		70	80	120,708	R$ 183,96	-	R$ 187,89	-	R$ 195,75	-	
Public and philanthropic		80	90	145,312	R$ 221,05	-	R$ 224,98	-	R$ 232,84	-	
Public and philanthropic		90	100	171,343	R$ 260,30	-	R$ 264,23	-	R$ 272,09	-	
Public and philanthropic		100	-	190,185	R$ 288,71	-	R$ 292,64	-	R$ 300,50	-	
Required revenue (RR):		R$ 2.889.890,54			Active water units (AG003):		16.656,00		Investment rate (Tinv):		
Volume measured (AG008):		2.344,56			Evasion index (IN029):		0,00		0,00		

Figure 3: Tabular presentation of results. Source: Authors.

Comparing calculated values with actual values is challenging due to the limited use of water consumption-based charges by municipalities. For instance, none of the 27 Brazilian capitals apply this system, instead relying mostly on metrics such as built-up area, despite its limited correlation with waste generation.

Moreover, in municipalities that use water consumption for charging purposes, data availability is often poor. Even when data are available, there is often a lack of detail on the calculation method and the breakdown of values into different categories and frequencies.

Nevertheless, we attempted to compare the predicted results for the municipality shown in Figure 3 with the actual values to assess the accuracy of our model. This particular municipality was selected because the calculation model is based on water consumption and prices are available publicly. The comparison between the modelled values and the actual data is shown in Figure 4.

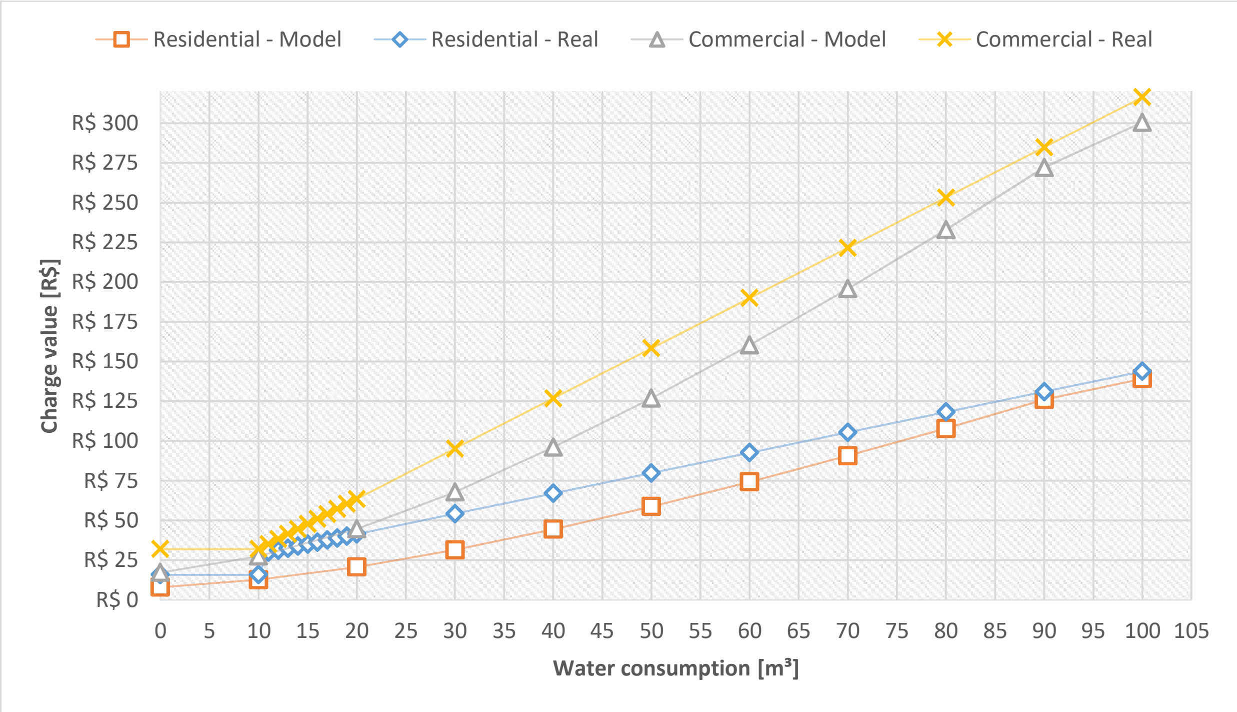

Figure 4: Comparison of model predictions with actual values. Source: Authors.

The model performed relatively well in predicting charges for lower consumption intervals, particularly within the residential category. It is important to highlight that the majority of households fall within the 0 to 10 cubic meters interval in the residential category, which also corresponds to where the model demonstrated its best performance. Furthermore, in terms of general trend, the model's predictions are consistent with actual charges, demonstrating its ability to capture general patterns of behaviour in the evolution of prices with consumption. It is important to note that the values calculated by the model are derived entirely from SNIS data (obtained using the information mode of the tool). Therefore, adjustments to the input variables and refinement of the category factors based on local specificities can significantly improve the accuracy of the results.

FINAL CONSIDERATIONS

This research resulted in an easy-to-use tool aimed at municipal managers who wish to implement or improve charging for municipal waste management services. The application in a municipality that already charges proportionally to water consumption showed that the tool performed well and has the potential to be used by other municipalities.

As most Brazilian municipalities still do not have a charging system, this tool can serve as a foundational framework for estimating potential charges. However, it's imperative to emphasize that determining the required revenue for effective waste management is a multifaceted process. The calculation heavily relies on detailed and localized assessments of waste management costs. We recommend that municipalities should conduct detailed studies to identify these costs accurately. Only after this analysis, should this tool be used with locally validated values instead of SNIS values. By following this approach, municipalities can ensure that the calculated charges align better with the actual financial demands of their waste management systems, increasing the tool's benefit and relevance at the local level.

Besides that, the use of the SNIS as a database in our tool presents certain limitations, especially due to the nature of the data it contains, which are self-reported by municipalities. However, it's crucial to note that significant efforts were made to cleanse and validate this database, ensuring its reliability to a certain extent. Nevertheless, the tool's flexibility is a key asset, as it allows users to input their own data, bypassing the reliance on SNIS information entirely or just for some variables. This feature not only enhances the tool's adaptability but also addresses concerns regarding the accuracy of SNIS data by empowering users to utilize their own datasets for calculations.

Future versions of the tool might include additional calculation methods to enable comparison of methodologies. Conducting a sensitivity analysis on key factors, such as category, frequency, and consumption factors, can provide valuable insights into the model's robustness. Monte Carlo simulations may be utilised to explore the variability of these factors and their impact on the final charges.

Given the limited availability of data in most Brazilian municipalities, it could be useful to employ the tool to generate simulated values for all entries in the database. This can then be followed by statistical analysis, such as outlier removal and regression modelling, which may aid in the derivation of equations connecting final charges to water consumption. These equations would expand the utility of the tool by making it applicable to scenarios with even scarcer data.

ACKNOWLEDGEMENT

This study was financed in part by the Coordination for the Improvement of Higher Education Personnel – Brazil (CAPES) – Finance Code 001.

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