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ENGINEERING SCIENCES

Solid waste generation model validation and economic loss estimation due lack of recycling

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Abstract: Urban Solid Waste Management (USWM) is one of the components that influences in the sustainable cities. It is a fundamental factor in achieving the Sustainable Development Goals (SDGs), 2030 agenda. This paper work aims to validate a mathematical model for solid waste generation and to estimate the economic loss due lack of recycling in the city of Campo Grande, State of Mato Grosso do Sul/Brazil. The model adopted was developed by Dias et. al. (2012), which allows projecting the mass of waste to be generated by the inhabitants from socioeconomic indicators, such as *per capita* income, social classes and size of population in a specific urban territory. Besides, waste composition was analyzed to determinate the value and share of the gravimetric characterization, in order to estimate the economic loss in areas, which there are no selective collection of Household Solid Waste (HSW). The model showed strong adherence, when compared to the real mass of HSW collected. The economic loss due to selective collection approaches nearly 9.6 million US$, or about 11 US$ *per* person *per* year. The study can provide support for economic evaluation of project sand public policies related to USWM executed in any other city with similar characteristics.

Key words: Household solid waste, urban solid waste management, waste generation model, validation of mathematical model.

INTRODUCTION

Urban Solid Waste Management (USWM) integrate the civil infrastructure of cities and is a critical and indispensable activity. So, strong attention should be given to the collection and discharge processes,in order to assure the correct environmental protection. Due to the significant increase in the individual consumption of goods and products, closely influenced by cultural and socioeconomic aspects, the Brazilian municipalities are challenged to identify adequate strategies to come to terms with the great growth of Household Solid Waste (HSW).

In developing countries, such as Brazil, where the public services is not so efficient, this task becomes harder and of difficult execution. It is worth mentioning that one of the targets proposed in the National Solid Waste Policy is the eradication of the dumpsites (BRASIL 2010). Such commitment should have been fulfilled four years after the publication of Law n° 12.305 of August 2010. Nevertheless, after more than five years since the Law came into effect, few more than 15% of the municipalities had achieved the determinations of the law (SENADO FEDERAL 2015). In view of the non-achievement of the targets, the temporary commission of the solid waste of the Federal Senate extended the deadline to extinguish the dump sites and replace with sanitary landfills (CÂMARA 2017). However, this issue still goes through several analyzes, facing opposition from some parliamentarians.

The problem of waste disposal is a current concern in Brazil and due to this, some studies show the harmful influence of the deposition of waste on the soil and water courses and the contamination of aquifers with harmful consequences to the environment. Cotta (2020) presented a study on the problem of deposition of waste in a waste pile in a uranium mining company. Assis et al. (2017) presents a work on the impact of waste produced by health services. The anthropogenic impact on the environment from the release of untreated sewage along the coast has been the subject of studies by Pitanga et al. (2012). The pollution problem due to the impact of metallurgical, electroplating, steel, petrochemical, and tannery companies was the subject of studies conducted by Schneider et al. (2014).

According to (Frésca 2007), the main causes of the problems related to USWM are social and economic characteristics of the local contexts, as well as the high urbanization rate that cities have been facing. Moreover, multiple processes related to USWM are responsible for Greenhouse Gas (GHG) emissions. (US EPA 2006). Those emissions occur throughout the life-cycle of the material produced, transportation, use and discharging, including greenhouse gases, which are relevant to climate change, such as methane (CH_4), carbon dioxide (CO_2) and nitrous oxide (N_2O) (Gentil et al. 2009).

In another strand, the strategies and infrastructure adopted by some countries have offered the recycling market, as opposed to the sanitary landfills, combustion and other alternative treatments, representing a positive landmark for the cities which adopt recycling as part of their systematization and USWM (ISWA 2018, ABRELPE 2018). Therefore, acknowledgement about waste generation is important not only to compliance with the legislation, but also to plan the activities of USWM. In this sense, according to Gaieski (1991), the *per capita* income and quantity of inhabitants influence on the waste generation in society, since there is a direct relationship between bigger consumption, larger populations, and the generation of HSW.

It is worth highlighting also that, the Waste Code of the Municipality of Campo Grande City establishes that, typically household solid waste in quantities below 200 liters or 50 kilograms per day shall be dealt with by the regular collection and carried out by the municipality services. On that line, it was verified about characteristics of the HSW, which are basically composed by recyclable material, such as: plastic packaging, paper, paperboard, sanitary and organic refuse (PMCG P. M. 2012).

The collection and transportation of the HSW are done over the all urban perimeter of the municipality, which is subdivided into regions to organize the collection schedule, using containers compactor trucks of two or three axles (PLANURB 2017). Finally, it is necessary to clarify that, the USWM of Campo Grande city is ruled by a Private-Public Partnership, on behalf of the Municipal Secretariat for Infrastructure and Public Services (SISEP).

The study applies the mathematical model for projection of HSW generation, as proposed by Dias et al. (2012), in order to validate it, by comparing the simulated results with the real values of waste collection in the city of Campo Grande-MS. The paper also aims to estimate the annual economic loss *per capita,* due the non-recycling of all the potential dry recyclable HSW. For that purpose, the mathematical model was applied for the years 2013 and 2017 and the economic loss was calculated for the year 2018.

MATERIALS AND METHODS

In 2012, Dias proposed in his doctoral thesis a model to estimate the generation of solid waste in an urban environment. The model was based on data from the city of Belo Horizonte and was developed at Federal University of Minas Gerais (UFMG). The mathematical model shows the relationship between size population, its income and HSW generation.

A linear regression was applied, using a dispersion of data pairs, including *per capita* income, in Brazilian currency (R$/inhab.month) and *per capita* collected mass of solid waste (kg/inhab.day). Note that, if the model will be used in other countries, currency should be converted to Brazilian Reals (R$), in order to maintain coefficients compatible.

Figure 1 shows the adjustment of an equation (Equation 1), achieved after five years of data observation (2006 to 2010). The Coefficient of Determination (R^2) reaches 0.8525, value that was considered quite sufficient, given the wide socioeconomic diversity and social inequality existing in the Brazilian reality.

Besides, before publishing, still during the thesis, in order to evaluate its quality, the model was also previously validated in Porto Alegre City, Rio Grande do Sul state, where it was applied, showing a relative error of only 0.4%, when comparing HSW estimated by the model and the real mass collected by local public service. Therefore, it may be inferred that a strong adherence of equation was suggested.

Thus, for bringing the case into Campo Grande city and verify if the model is still useful and accurate, the model was used for a period six-years, from 2013 to 2017, updating the number of residents and the monthly nominal household income, for this period.

$$C = \sum_{i}^{n} P * (- 0{,}00000005\, x^2 + 0{,}0006\, x + 0{,}2848)$$

(Equation 1).

Where:

C = total daily amount of household solid waste generated (kg/day).

x = *per capita* average monthly income of each defined socioeconomic stratum (R$/month).

P = existing population in each defined socioeconomic stratum in the analyzed region.

i= amount of defin ed socioeconomic ranges, from 1 to *n*.

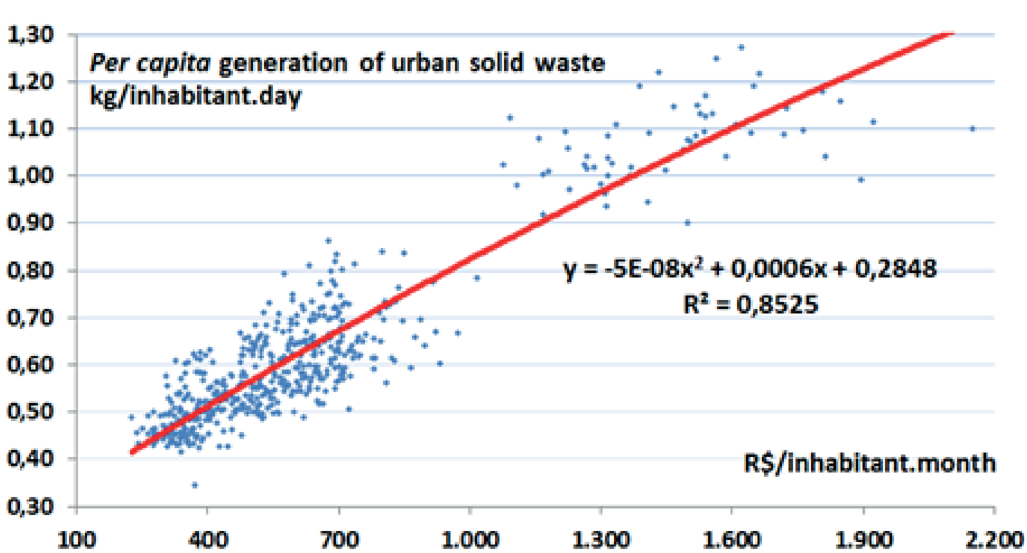

Figure 1. HSW generation model. Source: Dias et al. (2012).

Then data sources came from Brazilian official statistics institute (IBGE) and from the Campo Grande Municipal Secretariat for Infrastructure and Public Services (SISEP). The values and annual increases of the minimum wages as set by the Central Bank of Brazil (BCB 2018a) were calculated for the evolution of nominal household income and then assigned to the median of each income range distribution.

The HSW mass, for the correct comparison with the values simulated by the proposed model, were obtained from the annual report on household waste collected in Campo Grande, produced by SISEP and published in (PLANURB 2017). Subsequently, in order to determine the *per capita* income variable, the rate of residents per households in the city of Campo Grande was considered: around 3.12 residents per household, according to the IBGE (2018). Simultaneously, to calculate the economic loss due lack of recycling, a characterization of physical composition of HSW generated was obtained, based on the scope of the Selective Collection Plan. Also, the values of recyclable materials in the local market were obtained from price quotation and from systematized information in the Situational Diagnosis of the current Selective Collection Plan of the municipality of Campo Grande (PMCG P.M. TOMO III/IV 2017).

RESULTS AND DISCUSSION

Model validation in Campo Grande

The distribution of the population, according in come *per capita* ranges was computed, excluding those households without income. The total quantity of households registered was 244,499, divided into eight income ranges, as presented in Figure 2.

This analysis deals with the identification of the frequency of households which compose each socioeconomic range. The low economic condition of the population is clear, since almost 90% of them have an income below 10 minimum wages per month.To make possible comparisons, it was necessary to clarify that, in 2018, the official minimum wage was equal R$ 954.00 in Brazil, which means an amount around

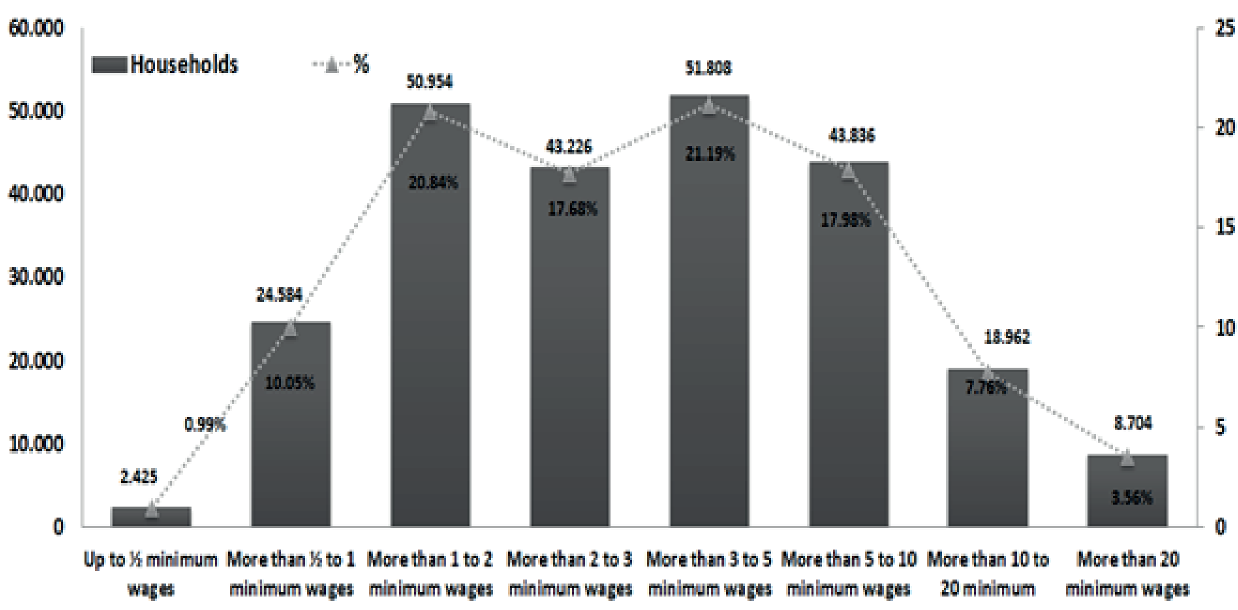

Figure 2. Distribution of the monthly income ranges of the Campo Grande households. Source IBGE 2018.

US$ 244.00, considering average exchange rate of August (ADVFN 2018).

In figure 3, it is possible to see, through a dimensionless analysis of the waste generation, the variation between the maximum and minimum mass collected, where the value “1” represents the average of the year, calculated from the nominal HSW generated in the analyzed period and divided by the average.

The relationship between HSW generation and the seasonal influences in the period analyzed years shows rising peaks, that may be produced by population habits, as well as weather factors and cultural aspects related to the holiday season, combined also with the Christmas-bonus effect on the economy. The downtrend, after the economic heating, it could be due to the personal indebtedness, which consequently interferes with the purchasing power. It is possible to realize also that, at the end of each year the HSW generation reaches an increase of around 20%. Seasonality also shows that, in winter months the reduction in solid waste generation reaches around 10%.

Based on the results calculated by the model, HSW generation in Campo Grande city was 22,724 metric tons per month, at an average computed in the five years analyzed. Table I shows values calculated by the model and values appointed by SISEP. The relative error for each year analyzed was the deltas shown at the last line of the table. The deltas pointed out the comparison between the real values of the monthly average collected and the values simulated by the model. The simulated values are lower when compared to the real values up to the year 2015, resulting in a small negative delta. After this, in 2016, there was an improvement in the selective collection system in the urban regions of Campo Grande, which probably cause the positive delta, reaching an error around 8% for 2017.

A detailed analysis of the projection of the model of generation of HSW in kg/person-day is shown in Figure 4. The levels of population with lower income, less than 1 minimum wage, have remained its HSW generation linearly, while the bands from more than 1 up to 20 minimum wages per person had significant growth. However, people with more than 20 minimum wages per month had a 6% decline in the generation of HSW in the period evaluated. The fact of this reduction could be a reflection of the use of inhabitants or a better level of education and more awareness of the side effect of unmanaged solid waste.

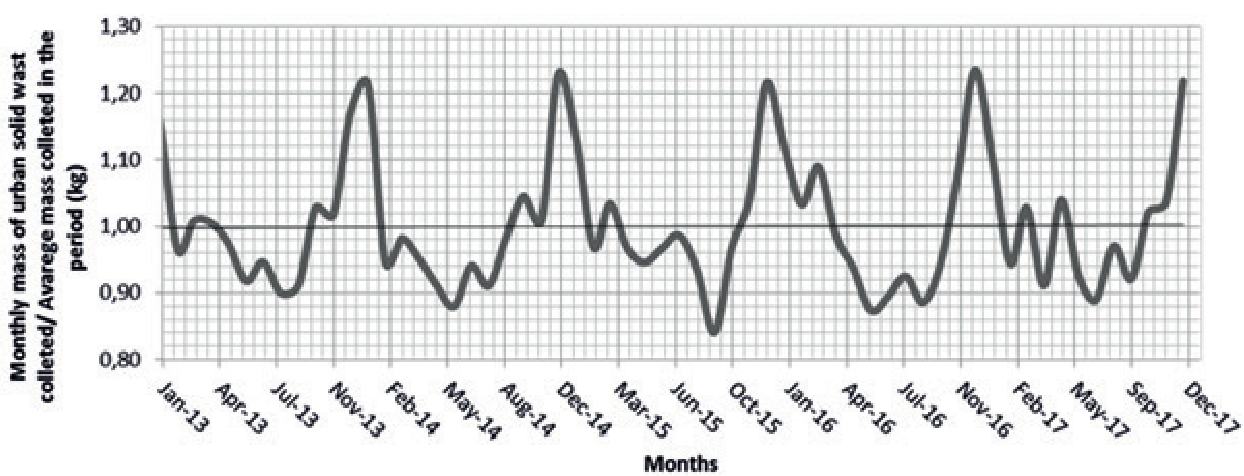

Figure 3. Evolution of HSW generation in Campo Grande in dimensionless values. Source: SISEP 2018.

Table I. **Evaluation of the model by the annual average of HSW generation in Metric tons/month.**

Years under evaluation	2013	2014	2015	2016	2017
Total calculated by the model	20,478	21,421	22,592	24,076	25,056
Real total reported by SISEP	20,862	22,920	22,770	22,727	23,213
Delta	-1.84%	-6.54%	-0.78%	5.94%	7.94%

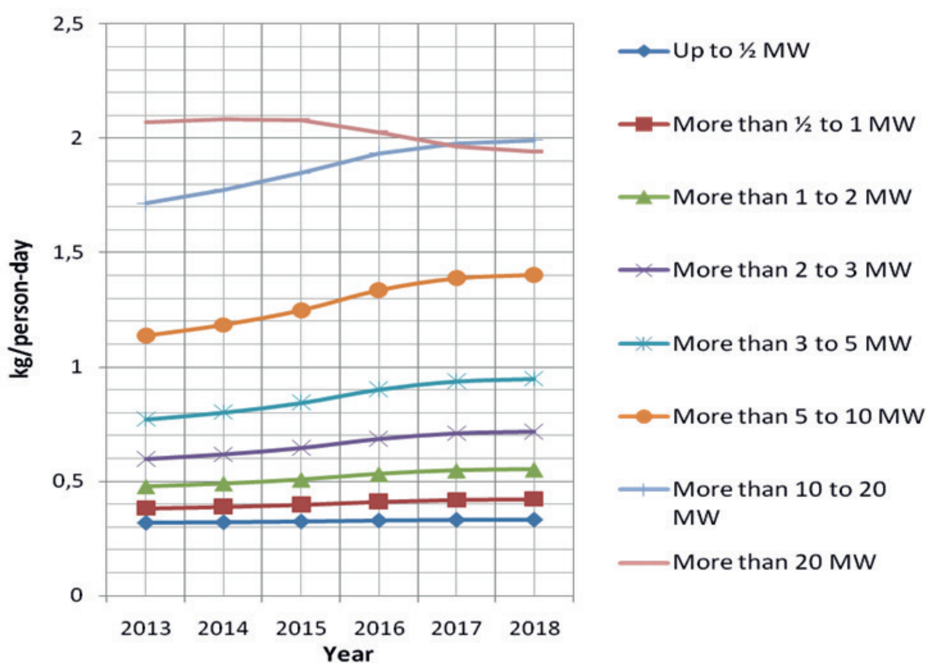

Figure 4. **Projection of the evaluation of the model in kg/person-day for the range in Minimum Wages.**

Economic losses

An average apparent specific gravity of 166.99 kg/m^3, as well as a detailed composition of the waste collected by regular collection were set, based on gravimetric composition. The analysis of the qualitative physical characterization shown the composition as 46.34% of organic waste, 16.60% of refuse, 0.07% of hazardous waste and 36.99% of dry recyclables.

The detailed distribution of components of recyclable HSW is shown in Table III. Note that share defined as “Non-attributed” means components that do not reach economic advantages, such as: fabric, mixed polymers and styrofoam. The values for materials classified as recyclables are shown in Table II.

The planning established for 2018 was to collect selectively 11.8% of the mass of dry recyclable HSW through the modalities proposed, including door to door or voluntary disposal point. It means that about 88.2% of urban household solid waste will neither be dealt with by the municipal waste sorting unit and, consequently, not it will have the chance of being recovered.

Considering the amount of HSW estimated for the year 2018, the share of dry recyclables (36.99%) and the goals for selective collection (11.8%), it means that 1,098 metric tons/month of the dry recyclable waste were designated to recycle. In return, a portion of 8,206 metric tons/

Table II. **Values of clean material, prices per metric tons.**

Materials valued based on Dry Recyclables	Average Value (US$)
Paperboard	65.69
White Paper	92.46
Multilayer packaging (long-life)	24.33
Steel cans (ferrous metal)	60.83
Aluminum cans	802.92
Glass	34.06
Rigid plastic	72.99
Plastic film	291.97
PET	304.14

Currency converted from R$ to US$ on 8/29/2018 (BCB 2018b).

month was deposited in landfills without any adequate method of collection or treatment.

Moreover, for an effective calculation of the HSW dry recyclables, only a portion of the material selectively collected is actually recovered, since part of the collected material will either be composted or become refuse. Considering factors of operational capacity of service providers and the index of correct segregation of the waste destined to selective collection, a rate of 44.52% will be refused.

It should be noted that this high rate of refuse it is a consequence from the precarious education of the users of the selective collection service of the municipality, that weak the recovery chain of recyclable products and leads to the economic losses.

Therefore, the dry recyclable HSW production which can indeed be recovered is set at a total of 4,552 metric tons per month. Thus, the economic loss due to the lack of selective collection and recycling of recyclable materials produced in Campo Grande becomes evident as can be seen in Table III.

Thus, the estimated economic the loss in USWM in Campo Grande was US$ 9,671,343 (Nine million, six hundred and seventy-one thousand, three hundred and forty-three American Dollars) per year, which equals a loss of 11,11 USD per person in the analyzed year (currency conversion from BRL to USD on 08/29/2018) (BCB 2018b). Besides that, such generation of dry recyclable waste, if fully recovered by the recycling system, would allow the reduction of nearly 18% of the total waste daily disposed in the dump site.

In addition, considering also that the total value of US$14,904,703 was paid in 2017 by the city hall to the company that collects, transports and discharges the HSW (Bitencourt 2018), it is possible to affirm that, around 65% of the that cost could be amortized by recycling procedures, considering the same expenditure for the year 2018.

CONCLUSIONS

The present investigation reinforces the significant role of USWM, which can cause an impact on the environment as well in the cost, when not properly carried out with convenient strategies. It was demonstrated that better efficiency, productivity and innovation can be achieved.

The mathematical model evaluated in this article allows public and private managers to have a systemic view of the local waste problem so that the planning of infrastructure actions, such as the collection, treatment and final destination of waste can be adjusted to the local reality. Therefore, the use of a mathematical model which links the HSW collected amount, the existing population and the defined socioeconomic stratum was considered an adequate choice.

With the systematic and detailed monitoring of the generation of dry recyclable HSW, it is possible to come up with strategies and identify the investment needs of the recycling sector.

Table III. Economic loss for the non-recycling of dry recyclable household waste for the year 2018.

Recyclable materials	Gravimetric composition	Dry Recyclable HSW generation (metric ton/month)	Economic loss (US$/month)
Paperboard	25.14%	1,145	74,826
White paper + colored paper	6.22%	283	26,045
Multilayer packaging (long-life)	2.70%	123	2,980
Steel cans (ferrous metal)	1.68%	76	4,619
Aluminum cans	0.84%	38	30,485
Tinted +clear glass	6.97%	318	10,764
Rigid plastic	4.54%	207	15,019
Plastic film	45.01%	2,049	595,392
PET	3.33%	151	45,817
Non-attributed	3.57%	162	0
TOTAL	100%	4,552	805,945

The present study has also pointed out the significant economic potential wasted in dump sites or landfills that could be used to help achieve the Sustainable Development Goals or others investments.

For the correct steps in the management of dry recyclable HSW and an effective insertion into the recycling market, first it is necessary a collective action of both society and government representatives to rationalize and value this fraction of waste that can be reused.

Environmental awareness to make cities more sustainable will only take place when society awakens to the value paid for its own waste. Therefore, we should be wise enough to see dry recyclable waste as a valuable source, subsidizing taxes such as the waste fee and, in an integrated manner, paving the way for the appropriated treatment and economic compensation for the society.

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REFERENCES

ABRELPE - ASSOCIAÇÃO BRASILEIRA DE EMPRESAS DE LIMPEZA PÚBLICA E RESÍDUOS ESPECIAIS. 2018. Resíduos sólidos: Manual de boas práticas no planejamento. São Paulo. Available at: < http://abrelpe.org.br/>. Last accessed: 05-02-2018.

ADVFN. 2018. Portal de investimentos em ações da Bolsa de Valores do Brasil. Available at: < https://br.advfn.com/moeda/dolar/2018/08>. Last accessed: 08-31-2018.

ASSIS MC, GOMES, VANIELLE AP, BALISTA WC & FREITAS RR DE. 2017. Use of performance indicators to assess the solid waste management of health services. An. Acad. Bras. Cienc 89: 2445.

BCB - BANCO CENTRAL DO BRASIL. 2018b. Cotações e boletins. Available at: <https://www4.bcb.gov.br/pec/taxas/port/ptaxnpesq.asp>.Lastaccessed: 08-29-2018.

BCB - BANCO CENTRAL DO BRASIL. 2018a. SGS-Sistema Gerenciador de Séries Temporais-*v2.1*. Available at:<https://www3.bcb.gov.br/sgspub/localizarseries/

localizarSeries.do?method=prepararTelaLocalizarSeries>.Lastaccessed: 04-23-2018.

BITENCOURT E. 2018. O jacaré. Coleta de lixo na Capital é uma das mais caras do Brasil; taxa começa a ser paga neste mês. Available at: <http://www.ojacare.com.br/2018/04/13/coleta-do-lixo-na-capital-e-uma-das-maiscaras-do-brasil-taxa-comeca-a-ser-paga-neste-mes/>. Last accessed: 07-19-2018.

BRASIL. 2010. Lei Federal n°12.305, de 2 de agosto de 2010. Institui a Política Nacional de Resíduos Sólidos; altera a Lei n° 9.605, de fevereiro de 1998; e da outras providências. Available at: <http://www.planalto.gov.br/ccivil_03/_Ato2007-2010/2010/Lei/L12305.htm>.Last accessed: 08-29-2018.

CÂMARA - AGÊNCIA CÂMARA DE NOTÍCIAS. 2017. Impasse adia para quarta análise de prorrogação de prazo dos lixões. Available at: <http://www2.camara.leg.br/camaranoticias/noticias/POLITICA/523907-IMPASSE-ADIA-PARA-QUARTA-ANALISE-DE-PRORROGACAO-DE-PRAZO-DOS-LIXOES.html>. Last accessed: 03-04-2018.

CEMPRE - COMPROMISSO EMPRESARIAL PARA RECICLAGEM. 2017. Compromisso empresarial para reciclagem. Available at: <http://cempre.org.br/cempre-informa/id/105/preco-dos-materiais-reciclaveis>. Last accessed: 04-26-2018.

COTTA RM, COTTA CPN, VAN GENUCHTEN MTH, SU J & QUARESMA JOÃO NN. 2020. Integral transform analysis of radionuclide transport in variably saturated media using a physical non-equilibrium model: application to solid waste leaching at a uranium mining installation. An Acad Bras Cienc 92: e20190427.

DIAS DM, MARTINEZ CB, VASCONCELOS RTBN & LIBÂNIO M. 2012. Modelo para estimativa da geração de resíduos sólidos domiciliares em centros urbanos a partir de variáveis socioeconômicas conjunturais. Eng Sanit Ambient [online] 17: 325-332.

FRÉSCA FRC. 2007. Estudo da geração de resíduos sólidos domiciliares no município de São Carlos, SP, a partir da caracterização física. Dissertação de Mestrado, Escola de Engenharia de São Carlos, Universidade de São Paulo, São Carlos. doi:10.11606/D.18.2007.tde-09042008-111912. Available at: <www.teses.usp.br>. Last accessed: 02-12-2019.

GAIESKI AA. 1991. Curitiba: o gerenciamento dos resíduos sólidos, passado, presente e perspectivas. Available at: < https://repositorio.ufsc.br/handle/123456789/111993>. Last accessed: 30_04-2018.

GENTIL E, CHISTENSEN T & AOUSTIN E. 2009. Greenhouse gas accounting and waste management. Available at: <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.906.1700&rep=rep1&type=pdf>. Last accessed: 02-28-2018.

IBGE - INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. 2018. Cidades@. Available at: < https://cidades.ibge.gov.br/brasil/ms/campo-grande/panorama>. Last accessed: 05-05-2018.

ISWA - INTERNATIONAL SOLID WASTE ASSOCIATION. 2018. Available at: <https://www.iswa.org/>. Last Accessed: 07-05-2018.

PITANGA ME, MONTES MJF, MAGALHAES KM & REIS TNV. 2012. Quantification and classification of the main environmental impacts on a Halodule wrightii seagrass meadow on a tropical island in northeastern Brazil. Anais da Academia Brasileira de Ciências (Impresso)JCR 84: 35-42.

PLANURB - AGÊNCIA MUNICIPAL DE MEIO AMBIENTE E PLANEJAMENTO URBANO. 2017. Perfil socioeconômico de Campo Grande Mato Grosso do Sul. 24ª edição. Available at: <http://www.campogrande.ms.gov.br/planurb/downloads>. Last accessed: 05-02-2018.

PMCG - PREFEITURA MUNICIPAL DE CAMPO GRANDE. 2012. (27 de Dezembro de 2012). Institui o Código Municipal de Resíduos Sólidos e disciplina a limpeza urbana no município de Campo Grande. Fonte: Lei complementar n° 209 de 12-27-2012.

PMCG - PREFEITURA MUNICIPAL DE CAMPO GRANDE. 2017. Plano de Coleta Seletiva. *Metas, projetos, ações e programas*. Tomo III/IV.

SCHNEIDER IL, TEIXEIRA EL, RODRIGUES MLK & ROLIM SBA. 2014. Metal content and distribution in surface sediments in an industrial region. An Acad Bras Cienc 86: 90-107.

SENADO FEDERAL. 2015. Comissão de Meio Ambiente e Desenvolvimento Sustentável. Projeto de Lei (PL) nº 2,289, de 2015. Prorroga o prazo para a disposição final ambientalmente adequada dos rejeitos de que trata o art. 54 da Lei nº 12,305, de 2 de agosto de 2010.

SISEP - SECRETARIA DE INFRAESTRUTURA E SERVIÇOS PÚBLICOS DE CAMPO GRANDE. 2018. Available at: < http://www.campogrande.ms.gov.br/sisep/>. Last accessed: 05-15-2018.

US EPA - UNITED STATES ENVIRONMENTAL PROTECTION AGENCY. 2006. Solid waste management and greenhouse gases: a life-cycle assessment of emissions and sinks. 3. ed. Washington: US EPA,2006. Available at: <http://www.epa.gov/climatechange/wycd/waste/SWMGHGreport.html>. Last accessed: 03-16-2018.

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Caio T. Áspet was responsible for data collection, calculations, analyzes and graphic interpretations. Antonio C. Paranhos was responsible for guiding the research. David M. Dias contributed to the validation of the proposed mathematical model, translation, revision and preparation of the article for publication. Carlos B. Martinez was responsible for manuscript planning and review.