Proposal for the Location of a Municipal Solid Waste Management Facility for a Metropolitan Region

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ABSTRACT

Only 16 of the 246 municipalities of Goiás State, Brazil, dispose their municipal solid waste (MSW) in licensed landfills. Therefore, this study proposes the host municipality (HM) of the future shared MSW management facility (MSWMF), serving the Metropolitana de Goiânia (MGyn) microregion. First, the potential areas to construct MSW final disposal facilities (landfills) were identified. Subsequently, using mass point geometry, the HM of the proposed MSWMF for MGyn was defined. The results show that only 19.4% of the area of the studied municipalities is available or subject to approval for landfill construction. The HM will be Aparecida de Goiânia, which will process most of the MSW and send the rejects of treated MSW to the landfill that will be established in the neighboring municipality of Hidrolândia. Additionally, this MSWMF will serve 19 municipalities and will have nine waste transfer stations that will receive waste from 17 municipalities, to minimize MSW transport costs.

Keywords: Host Municipality; Center of Mass; Statistical Analysis; Developing Country.

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The scenario of municipal solid waste (MSW) management in Goiás State, Brazil, is worrying. Of the 246 municipalities, only 15 have licensed landfills, according to the Environmental, Water Resources, Infrastructure, Cities and Metropolitan Affairs Office of Goiás - SECIMA/GO (2015). These landfills receive waste from 16 municipalities, since Cidade Ocidental shares its final waste disposal facility with the municipality of Valparaíso de Goiás (Colvero et al. 2015). This holds back proper MSW disposal.

To change this situation, Goiás needs MSW management strategies that observe technical, economic and legal aspects, and avoid damage to human health and the environment (Guerrero et al. 2013; Soltani et al. 2015). Thus, it is necessary to identify unrestricted areas for landfill construction, since MSW treatment facilities lack disposal processes for waste that cannot be reused or recovered (Cherubini et al. 2009).

The identification of permitted areas for construction of final disposal facilities for waste from other MSW processing technologies will be useful in the selection of MSW management facilities (MSWMF) for a specific region of Goiás (Colvero et al. 2017b). According to the National Policy on Solid Waste (Law no. 12305/2010), these MSWMF should preferably have shared management, i.e., to serve two or more municipalities (Brasil 2010). To ensure feasibility, their location needs to be optimized, to minimize the MSW transportation costs (Chen & Lo 2016).

The identification of available areas for landfills will also contribute for the definition of all the MSWMF of a given region in Goiás. Therefore, the MSWMF should be centralized between the municipalities that will receive the MSW, according to the Principle of self-sufficiency and proximity, of the Directive 2008/98/EC (EC 2008). In addition, having MSW processing facilities near to their sources, lowers the emissions associated with the transportation of such waste (Silva et al. 2012).

Since Goiás lacks proper final waste treatment and disposal technologies, the goal of this study was to propose the host municipality (HM) for a future MSWMF, shared by the Metropolitana de Goiânia (MGyn) microregion and neighboring municipalities. This microregion was considered, as it has the highest population density of Goiás (IBGE 2016) and, consequently, the one that generates the largest amount of MSW.

MATERIAL AND METHODS

In this study, the HM for the construction of the proposed MSWMF was defined for the municipalities of MGyn. The chosen HM will where the main waste processing technologies would be located, since all the municipalities integrating the referred MSWMF will send their waste to be

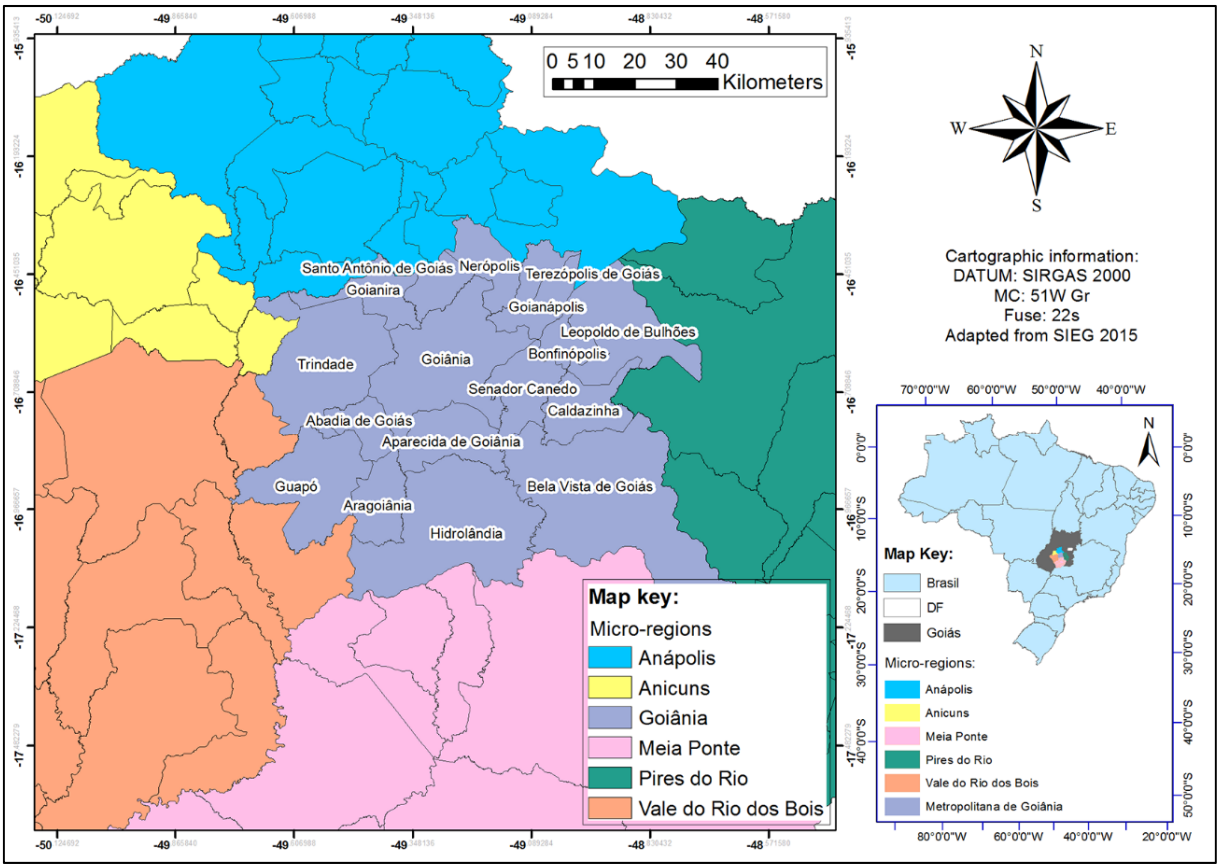
processed there. This MSWMF may comprise municipalities of microregions neighboring MGyn, while some municipalities of MGyn itself may not be served by the MSWMF. The distance between the municipalities will be decisive for the selection of the municipalities that will integrate the proposed MSWMF.

Study Area

Goiás State, located in Brazil's Central-West region (Romero et al. 2014) had an estimated population of 6 610 681 inhabitants in 2015, distributed over an area of 340 000 km^2 (IBGE 2010; IBGE 2016), which is equivalent to a population density of 19.4 km^2.

Goiás is divided into 18 microregions by the Brazilian Institute of Geography and Statistics - IBGE, in a regionalization system aimed to establish homogeneous and functional areas. (Arrais 2002). Microregions are groups of neighboring municipalities aimed to organize, plan and perform public activities of common interest. This grouping of municipalities is meant to sanction studies on the identification of structures, such as MSWMF, that should be built in metropolitan regions or other forms of urban and rural agglomerations (Brasil 1988; IMB 2014a).

Figure 1. Metropolitana de Goiânia and neighboring microregions, Goiás State, Brazil.



Source: Adapted from SIEG (2015).

MGyn, one of the 18 microregions of Goiás, is composed of 17 municipalities and borders five other microregions (IMB 2014a): Anápolis (North), Anicuns (Northwest), Vale do Rio dos Bois (West and Southwest), Meia Ponte (South) and Pires do Rio (Southeast, East and Northeast), as shown in Figure 1.

The decision for proposing HM for future MSWMF in the MGyn microregion (and neighboring municipalities) is justified by the fact that it is the smallest of the 18 microregions in size (6 729 km^2) and concentrated 35.7% of the population of Goiás in 2015 (IBGE 2016), as shown in Table 1. Moreover, MGyn is the microregion of Goiás with the highest population density (350.8 $inhabitant \cdot km^{-2}$) and is the largest producer of MSW.

Table 1. Number of municipalities, area, population and population density in the Metropolitana de Goiânia microregion and in Goiás State.

Location	Number of municipalities	Area (km^2)	Population in 2015 Estimate from IBGE (inhabitants)	Population Density ($inhabitant \cdot km^{-2}$)
Metropolitana de Goiânia	17	6 729	2 360 847	350.8
Goiás State	246	340 111	6 610 681	19.4

Source: IMB (2014a) and IBGE (2010; 2016).

IDENTIFICATION OF AREAS FOR CONSTRUCTION OF MSW FINAL DISPOSAL FACILITIES

The first step to propose the MSWMF for the MGyn microregion and neighboring municipalities was to identify the restricted, subject to approval or available areas for construction of MSW final disposal facilities. The areas subject to approval are not restricted but depend on a permit of the Environmental Licensing Agency (OAL) for landfill construction.

According to Ferreira & Ferreira (2014), to map the available areas for landfill construction, the environmental aspects and criteria related to distances and accessibility must be assessed. Thus, five Brazilian legal documents that define environmental and geographic criteria to be met for the construction of landfills were examined in this study (Table 2). These guidelines, imposed by the Brazilian Association of Technical Standards (ABNT 1997), Brasil (2012), National Environment Council (CONAMA 2010), Ministry of the Environment (MMA 2015), and Goiás Environmental and Water Resources Affairs Office (SEMARH/GO 2014) establish the minimum distances between the landfill construction site and environmental preservation areas, watercourses, airfields, specific communities (such as quilombolas and indigenous) and areas where the soil is used or occupied for certain activities. In addition, the amounts of MSW produced by the municipalities may pose obstacles to the process of selection of a suitable area for the construction of a landfill (Gorsevski et al. 2012).

Table 2. Restrictive criteria and subject to approval for landfill constrution.

Criterion	Restrictive values for landfill construction	Legal documents
Distance from the urban perimeter	3 km	Resolution of State Environmental Council - CEMAm No. 05/2014
Declivity of the area	Greater than 1% and less than 20%	Regulatory Standard (NBR) of ABNT no 13 896/1997 and Resolution CEMAm No. 05/2014
Distance from surface water bodies	0.3 km from any water bodies	Resolution CEMAm No. 05/2014
	0.5 km from water bodies used for water supply	
	2.5 km from the collection point for public supply	
Distance from Conservation units	3 km from the Conservation Unit's limit (distance subject to approval)	Resolution CONAMA No. 428/2010 Resolution CEMAm No. 05/2014
Distance from airfields	20 km (distance subject to approval)	Federal Law No. 12 725/2012
Presence of remaining native vegetation	It should preferably be located outside any legal reserve and also where, preferably, there is no need for deforestation	Resolution CEMAm No. 05/2014
Quilombola and indigenous lands	8 km (distance subject to approval)	Inter-ministerial Ordinance of the MMA No. 60/2015

Source: Adapted from ABNT (1997), Brasil (2012), CONAMA (2010), MMA (2015) and SEMARH/GO (2014).

Since the proposed MSWMF may encompass neighboring municipalities of MGyn, the following available, subject to approval and areas off limits for landfill construction of six microregions were identified: Metropolitana de Goiânia, Anápolis, Anicuns, Meia Ponte, Pires do Rio and Vale do Rio dos Bois.

In addition to the legal aspects, the population projections of the municipalities of Goiás that compose the six microregions investigated in this study were also considered. Such data is important to estimate the urban spots that represent the population occupation in the assessed territory. This is the only way to define the *buffers* of the minimum distances between the urban perimeters and a future final waste disposal facility, that must be obeyed.

The estimates of future populations were based on the population projection methodologies of Qasim (1999) and Marques & Sousa (2008). The population projections were made for the year 2040, as a 20-year period was set for the National Policy on Solid Waste, according to Law No. 12 305 (Brasil 2010). It is predicted that, until 2020, the municipalities of Goiás must close their dumps, and install and start to operate their new and adequate MSWMF. So, the estimated population for the end-of-life of these facilities must be for the year 2040.

Thus, based on the established assumptions in the legislation, the Geographic Information System (GIS) tool ArcGIS, version 10.3.1, was used to map the available areas for the construction of MSW disposal facilities, according to the studies of Gorsevski et al. (2012), Gbanie et al. (2013), and Ferreira & Ferreira (2014). The GIS is a spatial analysis tool used to collect, manage, integrate,

manipulate and analyze geospatial or geo-referenced data (Hannan et al. 2015). The *shapefiles* containing the criteria to be analyzed in the elaboration of the maps of restricted, subject to approval and available areas for landfill construction in Goiás were obtained from the database of the State Geo-information System of Goiás (SIEG 2015). The System of Geocentric Reference for Americas (SIRGAS 2000 projection) was used to generate the maps.

Furthermore, the geographic coordinates from licensed and unlicensed landfills by SECIMA/GO, and the existing dumps were surveyed in the municipalities of six microregions referred to above. This information is important, because with the location of existing landfills and dumps of these microregions, it was determined if these systems of MSW disposal are in areas restricted, subject to approval or permitted for landfill construction.

To obtain the location data for the final MSW disposal facilities of Goiás municipalities, the primary data from a questionnaire (with open and closed questions), that was sent in 2013 to municipalities Goiás by SECIMA/GO, was analyzed. This questionnaire aimed to provide a diagnosis of the current MSW situation in Goiás. It was answered by a total of 220 municipalities (89%), ensuring the representativeness of the sample (Colvero et al. 2017a). Primary data were cross-checked with the SIEG (2015) *shapefiles,* and with the geographic coordinates of the landfills and dumps shown in a study by Freitas (2015).

MSW Production and Statistical Analysis

For the identification of the geographically centralized municipalities (as will be presented in item *Geographically centralized municipalities*), the MSW production of the municipalities of each of the six microregions assessed was necessary. To calculate it, the population of each municipality, obtained at the IBGE (2016) database, was multiplied by the *per capita* MSW generation of each of these municipalities (Colvero et al. 2017a), as shown in Equation (1):

$$P_i = \frac{p \cdot g}{1000} \quad (1)$$

Where: P_i = MSW production of each municipality, in t·day^{-1}; p = population of each municipality in 2015 (IBGE 2016), in number of inhabitants; g = *per capita* MSW generation, in kg·inhabitant^{-1}·day^{-1}.

Although in this article the *per capita* MSW generation is treated as a fixed value, different parameters may result in variations of this value. Thus, in order to promote the identification of the variables associated to the *per capita* MSW generation in the municipalities that will compose the proposed MSWMF, the Kendall rank correlation coefficient (Thanh et al. 2010; Pauletto 2010) was

estimated. The Kendall coefficient (τ) is a suitable correlation measure for use in non-parametric studies. The variables are measured on an ordinal scale, assigning ranks to each of them (Siegel & Castellan 1988).

According to studies regarding this subject (Johnstone & Labonne 2004; Afon & Okewole 2007; Mazzanti & Zoboli 2009; Pauletto 2010; Thanh et al. 2010), the following independent socioeconomic and demographic variables were related: "Electric power consumption"; "Average yields"; and "Population geometric growth". This statistical analysis, which was performed with Data Analysis and Statistical Software (Stata 11), was important for a better understanding of the factors that may influence the *per capita* generation and hence MSW production. Therefore, MSW generation is directly linked to the definition of the future MSWMF's building location. As mentioned by Gorsevski et al. (2012), the increase in MSW production directly affects the choice for areas for the MSWMF. For example, regarding landfills, larger areas are needed to receive the produced MSW. Moreover, the MSWMF's economical feasibility has to be accessed, because each treatment technology has to treat a minimum amount of MSW, in order to be economically feasible (Tsilemou & Panagiotakopoulos, 2006).

GEOGRAPHICALLY CENTRALIZED MUNICIPALITIES

After the definition of the available areas for construction of final MSW disposal facilities, the second criterion for the definition of the HM of the MSWMF for MGyn, the geographic location, was examined. So, mass point geometry was adopted, using the x and y coordinates (in decimal values), and the MSW production (in $t \cdot day^{-1}$) of the municipalities of the region for which the center of mass (CM) must be obtained. The identification of the CM of the municipalities represents the reduction of MSW transportation costs, because the MSWMF will be located closer to the centers that generate such waste (Bridi 2008; Pereira et al. 2013).

The used geographic coordinates were those of the geographical centers of the urban area of each municipality, obtained from the *shapefiles* of SIEG (2015), while the amounts of MSW of each location are those calculated in item *MSW production and statistical analysis*. Calculations were made to obtain the CM using the expressions shown in Equations (2) and (3) (Pereira et al. 2013; Russo 2003).

$$y = \frac{\sum(y_i \cdot P_i)}{\sum P_i} \quad (2)$$

$$x = \frac{\sum(x_i \cdot P_i)}{\sum P_i} \quad (3)$$

Where: x = longitude; y = latitude; x_i and y_i = geographical coordinates of the waste generating centers (geographical center of the urban area of the municipalities), in decimal values; P_i = production of municipal waste in each municipality, in t·day^{-1}. The values of x and y are the geographical coordinates where the CM of the region of interest is located.

In order to ensure that the proposed MSWMF only includes municipalities that are close in terms of road distances, the CM of the MGyn microregion and the five neighboring microregions were calculated. This is important because some MGyn municipalities may be closer to another microregion's CM and therefore be part of a management facility other than that of MGyn. Also, municipalities of neighboring microregions may integrate the MSWMF of MGyn.

The HM of the MSWMF of MGyn shall be geographically centralized, according to the coordinates obtained in the CM. However, the HM might be some neighboring municipality to the CM, in case of legal impediment (see analysis of item *Identification of areas for construction of MSW final disposal facilities*) or any other relevant aspect that may be important in the decision to change the HM. In any case, the proposed MSWMF should be located as close as possible to the calculated CM. This facility should also be interconnected to other municipalities by paved roads (NURSOL/UFG 2015; Russo 2003). This assumption is important, because better highways reduce time for collection and transport of MSW and, consequently, the costs associated with MSW management (Guerrero et al. 2013).

DISTANCES FROM THE HOST MUNICIPALITIES AND THE OTHER MUNICIPALITIES

The next step after the selection of the HM of the MGyn microregion and the five neighboring microregions was to define to which HM the Non-Host Municipalities (non-HM) would send their waste for disposal, since these municipalities will have more than one alternative HM to send their waste. To reduce transportation costs, the non-HM would send their MSW to the nearest HM (considering only displacements on asphalted roads).

The maximum road distances between the MSWMF of the HM and the urban centers (center of the MSW production sources) of the non-HM should be 25 km (Chen & Lo 2016; FEAM & Engebio 2010). This distance was defined to reduce to one hour the round-trip time spent with MSW transportation between the center of the waste-generating source and the HM of the MSWMF. The definition of these parameters also considered an average speed of the waste transportation vehicles of 50 km·h^{-1} (Suzuki & Gomes 2009).

If the road distance from a non-HM to the nearest HM exceeds 25 km, these non-HM should initially transfer its waste to a transfer station (TS). The maximum distance from the urban centers of the non-HM to the TS should be 25 km. On the other hand, since waste transportation from the TS to the HM will be made by a vehicle with larger waste carrying capacity, the maximum distance considered will be 100 km (FEAM & Engebio 2010). This criterion was based on the fact that for distances greater than 25 km, it is more economically advantageous to unload the MSW in a TS than transport it directly to the HM (US EPA 2002).

Thus, the logistics for transporting the MSW from a non-HM to the HM of the proposed MSWMF and to the HM of the TS will be done as follows:

- Maximum distance of 25 km from the urban center of the HM to the site of the waste management facility: MSW transportation to the proposed MSWMF will be made by a waste collection vehicle. This guideline is important, because of the large size of some municipalities, or due to the restrictions described in item *Identification of areas for construction of MSW final disposal facilities*, the proposed MSWMF had to be located more than 25 km from the urban center;
- Maximum distance of 25 km from the urban center of a neighboring municipality of the HM of a MSWMF: MSW transportation to the proposed MSWMF will be made by a waste collection vehicle;
- Maximum distance of 25 km from the urban center of a neighboring municipality of the HM of a TS: MSW will be transported to the TS by a waste collection vehicle.
- Maximum distance of 100 km between a TS and the proposed MSWMF: MSW will be transported to the MSWMF by a larger vehicle.

A mathematical model of the above conditions would contemplate the following variables: x = distance from the non-HM to the HM; y = distance from the non-HM to a TS; z = distance from TS to the HM.

Based on the above assumptions, if the distance (d) from a non-HM to the HM is less than or equal to 25 km, the mathematical function of Equation (4) is used:

$$d = x, 0 < x \leq 25 \quad (4)$$

Else, if the distance from a non-HM to the HM exceeds 25 km, the function of Equation (5) is considered:

$$d = y + z, 0 < y \leq 25 \wedge 0 < z \leq 100 \quad (5)$$

It should also be noted that the non-HM will have separate collection of part of the recyclable materials and organic waste, in order to divert part of the MSW. These diversions aim to meet the goals of the National Plan for Solid Waste - PLANARES (MMA 2012), as well as to prioritize the waste hierarchy (EC 2008; Brasil 2010). Also, locally processing of part of the MSW will reduce the transportation costs.

RESULTS AND DISCUSSION

RESTRICTED, SUBJECT TO APPROVAL OR AVAILABLE AREAS FOR CONSTRUCTION OF A FINAL WASTE DISPOSAL FACILITY IN THE MICROREGIONS

Using the previously described the methodology for the identification of the HM (items *MSW production and statistical analysis* and *Geographically centralized municipalities*), the proposed MSWMF will include 19 municipalities. Of these, 13 are municipalities of MGyn and other six belong to neighboring microregions (Anicuns, Anápolis and Meia Ponte).

The 19 municipalities are heterogeneous in terms of population and, consequently, MSW production. According to IBGE (2016) population estimates, in 2015, 15 municipalities of this MSWMF had less than 50 thousand inhabitants (Araújo & Nunes 2013). Considering the population ranges defined by the National Department of Environmental Sanitation (SNSA 2016), in 2015, 14 municipalities were included in the population range of up to 30 thousand inhabitants. Also, the population of one municipality was in the range of 30 000-100 000 inhabitants and the other four municipalities had a population of more than 100 thousand inhabitants. Among the most populous municipalities, Goiânia has a population of more than 1.4 million inhabitants, as of 2015 (IBGE 2016) and it is expected to reach 2 million people, in 2040. Regarding the population growth of each municipality of the proposed MSWMF, Goianira, whose population in 2040 is expected to be four times higher than in 2015, deserves discussion. According to IMB (2017), this demographic increase in Goianira that can be observed in a geometric growth rate of 4.4% between 2006 and 2015 (10 years). According to Anjos (2009), the motive for the growth of Goianira's urban network of is a consequence of the demand for new housing areas for the neighboring municipality (and capital), Goiânia. This expansion has been occurring since the beginning of the 2000s, when the construction of GO-070 highway (located to the northwest of Goiânia) resulted in a conurbation between three municipalities: Goiânia, Goianira and Trindade.

Of the 19 municipalities of the proposed MSWMF, nine do not have available areas for landfill construction: Abadia de Goiás, Aparecida de Goiânia, Goianapolis, Goiânia, Goianira, Santa Bárbara de Goiás, Santo Antônio de Goiás, Senador Canedo and Trindade (Table 3). In these municipalities, there are only areas subject to approval or off limits for landfill construction. This is mostly due to the type of urban territorial occupation and the presence of airfields.

Table 3. Restricted, subject to approval and available areas for the proposed MSWMF for the Metropolitana de Goiânia microregion and neighboring municipalities.

Municipalities	Municipality total area (SIEG 2015)	Restricted area for landfills		Area subject to approval for landfills		Available area for landfills	
	km²	km²	%	km²	%	km²	%
Abadia de Goiás	147.3	144.3	97.9	3	2.1	0	0.0
Aparecida de Goiânia	291.1	286.8	98.5	4.3	1.5	0	0.0
Aragoiânia	217.4	190.3	87.5	1.6	0.7	25.5	11.7
Bonfinópolis	121.3	106.4	87.7	6.4	5.3	8.5	7.0
Brazabrantes	124.6	102.4	82.2	18.4	14.7	3.8	3.0
Caldazinha	252.2	178.1	70.6	7.6	3	66.5	26.4
Caturaí	206.6	132.1	63.9	26.3	12.7	48.2	23.3
Cromínia	363.9	294.5	80.9	0.0	0.0	69.4	19.1
Goianápolis	161.1	144.5	89.7	16.6	10.3	0.0	0.0
Goiânia	737.5	736.4	99.8	1.1	0.2	0.0	0.0
Goianira	202.1	182.7	90.4	19.4	9.6	0.0	0.0
Guapó	515.7	331.7	64.3	20.5	4.0	163.5	31.7
Hidrolândia	942.7	737.9	78.3	79.1	8.4	125.7	13.3
Mairipotaba	497.4	338.2	68.0	0.0	0.0	159.2	32.0
Professor Jamil	349.4	290.3	83.1	0.0	0.0	59.1	16.9
Santa Bárbara de Goiás	140.7	99.8	70.9	40.9	29.1	0.0	0.0
Santo Antônio de Goiás	134.7	123.5	91.7	11.2	8.3	0.0	0.0
Senador Canedo	245.4	243.4	99.2	2.0	0.8	0.0	0.0
Trindade	711.9	470.6	66.1	241.3	33.9	0.0	0.0
Total	**6 363.0**	**5 133.9**	**80.7**	**499.70**	**7.9**	**729.40**	**11.5**

Source: Authors.

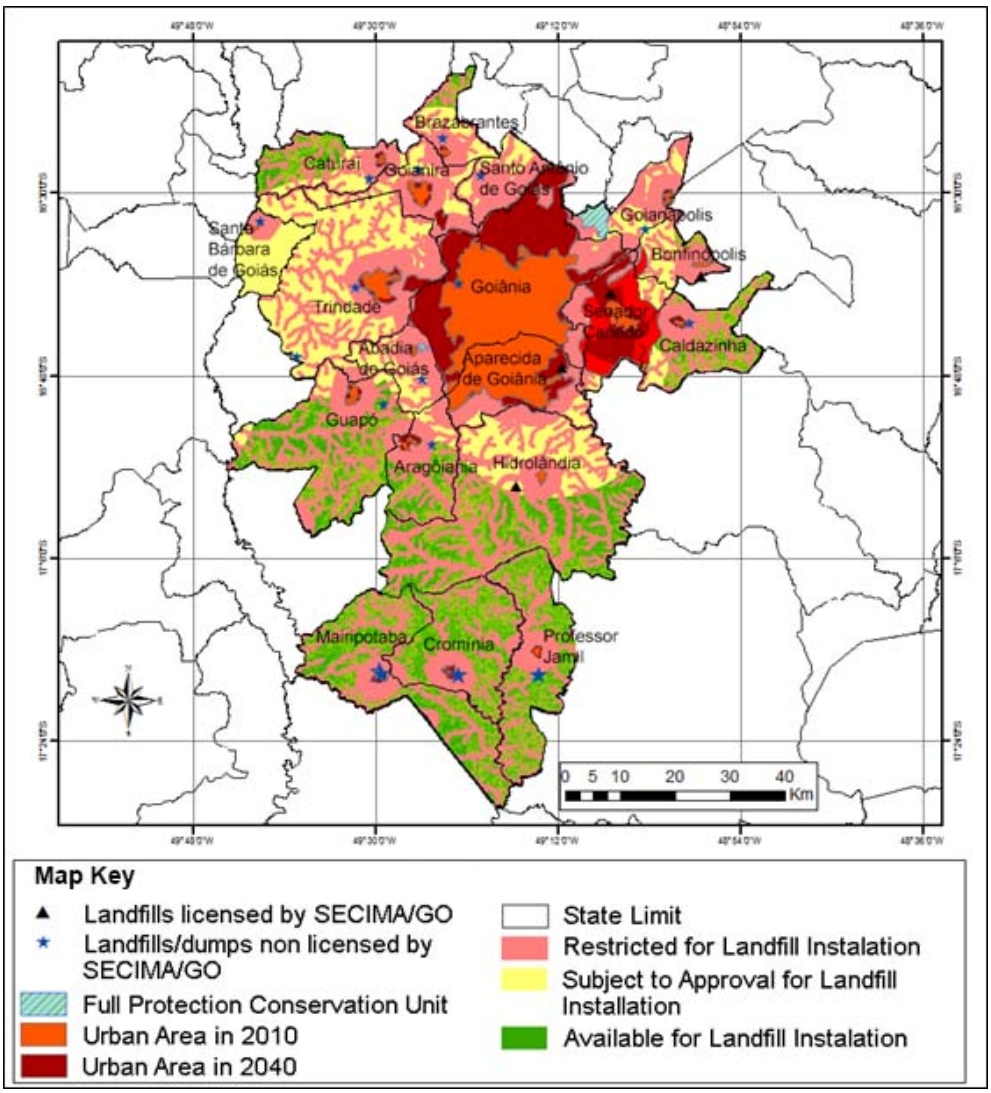
Only 19.4% of the area of the municipalities of the proposed MSWMF is permitted or subject to approval for construction of final MSW disposal facilities. Moreover, almost 100% of the area of three of the four municipalities with the largest populations is restricted for the construction of landfills, namely Aparecida de Goiânia, Goiânia and Senador Canedo. Conversely, Trindade (the third largest municipality in population, of this region) has most of its territory restricted landfill construction, but 34% of the area is subject to approval, i.e. a final MSW disposal facility can be constructed, if authorized by the OAL.

Therefore, to identify the municipalities that generate the largest MSW amounts and to verify if they have permitted areas for landfill construction is essential to the establishment of any MSWMF. The reason is that the closer the MSW processing facilities are to the waste generation sources, the

greater savings in transportation costs and atmospheric emissions are, while also agreeing with the Principle of self-sufficiency and proximity (EC 2008; Silva et al. 2012).

The map of the available, subject to approval and restricted areas for construction of the final MSW disposal facilities for the proposed MSWMF is shown in Figure 2. Besides that, 21 final MSW disposal facilities were identified in the 19 assessed municipalities (since Trindade and Mairipotaba had two facilities to receive MSW - in this last municipality there were two dumps in neighboring geographic areas).

Figure 2. Map of available, subject to approval or restricted areas for the construction of final MSW disposal facilities in the 19 municipalities that integrate the proposed MSWMF.



Source: Authors.

- 14 dumps, nine in restricted areas, three in areas subject to approval and two in available areas for landfill construction;

- three unlicensed landfills, all located in areas off limits for landfill construction;
- four licensed landfills, all in restricted areas for landfill construction.

The scenario of the MSW disposal facilities in the assessed municipalities agrees with Pinheiro et al. (2015), which reports that most of Goiás' facilities operate irregularly, without any monitoring. Moreover, irregularities were also found in all licensed landfills identified in this study: they are located in areas off limits for landfill construction, which are inadequate areas.

MSW PRODUCTION AND ANALYSIS OF VARIABLES ASSOCIATED TO *PER CAPITA* MSW GENERATION

With the population (in number of inhabitants) and the *per capita* MSW generation (in kg·inhabitant^{-1}·day^{-1}), the MSW production was calculated for each municipality of the proposed MSWMF. It is estimated that, in 2015, the 19 municipalities produced a total of 2 163 t·day^{-1} of MSW. Only the capital, Goiânia, and its neighboring municipality, Aparecida de Goiânia, (with the two largest populations in Goiás) generated 89% of the MSW generated in the 19 municipalities (Table 4).

Table 4. Population, *per capita* generation and MSW production of the municipalities suggested for the MSWMF of Metropolitana de Goiânia microregion and neighboring municipalities.

Municipalities	Population in 2015 (IBGE 2016)	Estimated *per capita* MSW generation in 2015 (Colvero et al. 2017a)	Estimate of MSW production in 2015
	inhabitants	kg·inhabitant^{-1}·day^{-1}	t·day^{-1}
Abadia de Goiás	7 895	0.50	4.0
Aparecida de Goiânia	521 910	0.89	465.1
Aragoiânia	9 444	0.52	4.9
Bonfinópolis	8 694	0.51	4.4
Brazabrantes	3 526	0.46	1.6
Caldazinha	3 624	0.46	1.7
Caturaí	4 977	0.47	2.4
Cromínia	3 616	0.46	1.7
Goianápolis	11 024	0.53	5.8
Goiânia	1 430 697	1.02	1 461.9
Goianira	39 484	0.63	24.8
Guapó	14 441	0.55	7.9
Hidrolândia	19 761	0.57	11.3
Mairipotaba	2 432	0.46	1.1
Professor Jamil	3 380	0.46	1.6
Santa Bárbara de Goiás	6 259	0.49	3.1
Santo Antônio de Goiás	5 527	0.48	2.7
Senador Canedo	100 367	0.71	71.5
Trindade	117 454	0.73	85.5
Total	**2 314 512**		**2 163.0**

Source: Adapted from IBGE (2016) and Colvero et al. (2017a)

According to the MSW collection rate in the municipalities of Goiás (IMB 2014b), and based on the estimated amounts of waste produced in the municipalities of the proposed MSWMF, it is

estimated that approximately 99.1% of the generated MSW in this region are collected. Almost all (more than 99%) of the generated MSW in the most populated municipalities, such as Goiânia and Aparecida de Goiânia, is collected. However, in municipalities like Caldazinha and Professor Jamil, with less than 5,000 inhabitants (IBGE 2016), the percentage of collected MSW is just 73% (IMB 2014b).

However, a study by BNDES (2012) revealed that the source-separated collection of dry recyclable materials in the municipalities of Goiás reaches approximately of 3% of the total MSW produced. Thus, given that only eight of the 19 municipalities that integrate the proposed management facility have source-separated collection of recyclables, it is estimated that about 2.8% of the generated MSW in these municipalities was separately collected, in 2015. As for source-separated collection of biowaste, it is not performed in any of these municipalities.

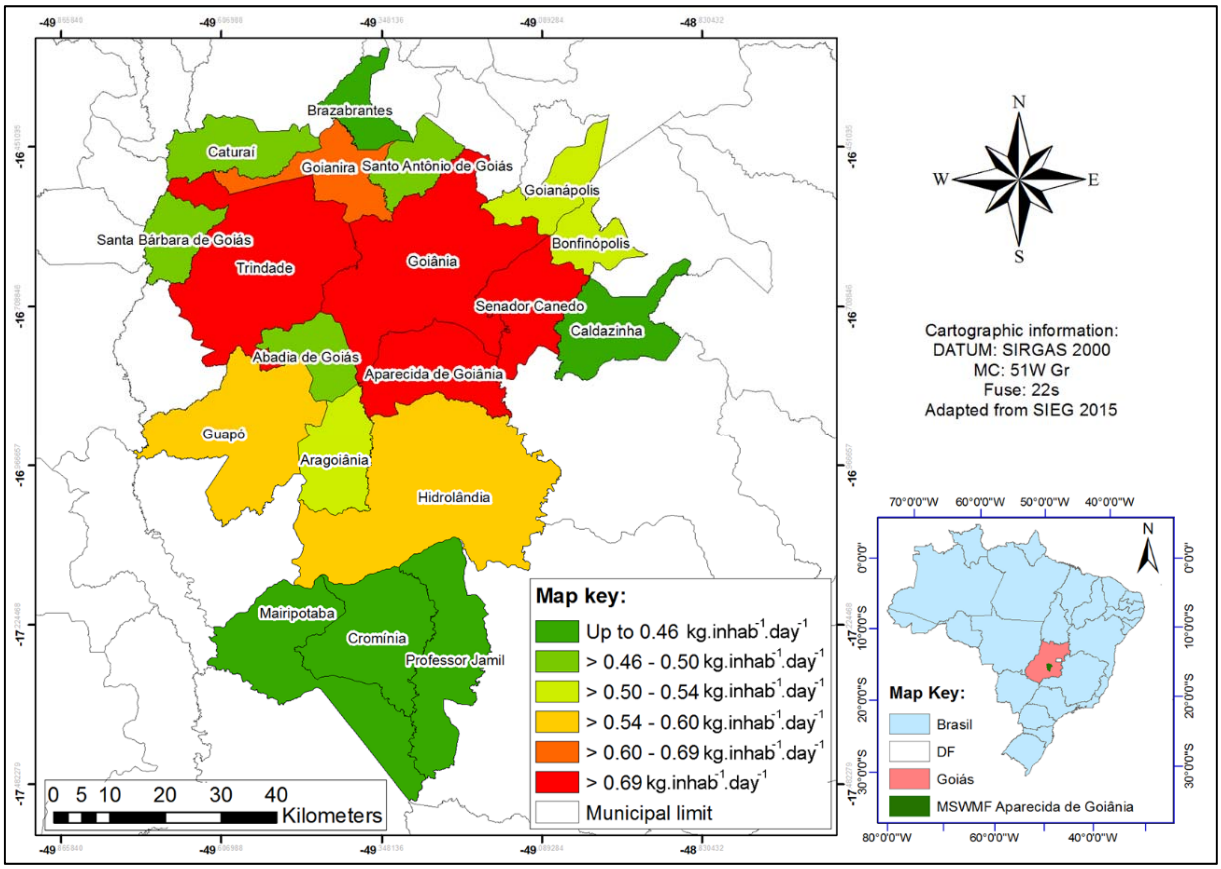
According to NURSOL/UFG (2014), it is estimated that 30% of the total recyclable materials sent to sorting centers through source-separated collection ends up in landfills (licensed and unlicensed) and dumps. Also, according to data from SECIMA/GO (2015) and SIEG (2015), 16 of the 19 municipalities of send their MSW to inappropriate final waste disposal facilities (dumps or unlicensed landfills). Thus, it is estimated that 72.4% of the MSW of this region are disposed in unlicensed landfills or dumps, and another 0.9% of the MSW is not collected in this region. Another 24.7% is disposed in licensed landfills, and only 2% is diverted and recycled.

These figures demonstrate and justify the need to implement a MSW management facility in the 19 municipalities of this study. One alternative would be the construction of management facilities that divert and recycle MSW, according to the stipulated on PLANARES (MMA 2012). One example of a changed scenario of solid waste management occurred in Portugal: the country had 341 waste dumps until 1997. Currently, not only all these dumps were eliminated, but the country now counts on MSWMF that obtain energy from waste from incineration in large urban centers (Lisbon and Porto), and from anaerobic digestion (of the biodegradable fraction of the MSW) that generates biogas in medium-sized cities - such as the districts of Coimbra and Aveiro (Dias et al. 2013; APA 2015).

These Portuguese facilities that receive more than 1 000 $t \cdot day^{-1}$ of MSW (APA 2015), can serve as a model for the proposed MSWMF for the MGyn microregion and neighboring municipalities, which will process more than 2 100 $t \cdot day^{-1}$ of produced MSW by 2.3 million inhabitants. The population is distributed over an area of 6 363 km^2, which is equivalent to a population density of 363.7 $inhabitant \cdot km^{-2}$.

According to a study by Colvero et al. (2017a), the larger the population size of a municipality, the higher the *per capita* MSW generation is. Goiânia is the only municipality where the population produces more than 1 kg·inhabitant^{-1}·day^{-1} of MSW. As shown in Figure 3, some municipalities bordering the State capital, generate greater amounts of MSW *per capita,* because they have larger populations.

Figure 3. *Per capita* MSW generation in the 19 municipalities that integrate the proposed MSWMF.



Source: Adapted from SIEG (2015)

In addition to the number of inhabitants, which is directly associated with the *per capita* waste generation, other factors may explain the MSW production in this region. From the application of the Kendall coefficient (τ), it is possible to analyze the correlation between socioeconomic and demographic variables, and *per capita* MSW generation in the selected sample (Table 5).

Regarding "Electric power consumption", it is assumed, with 1% of significance, that there is a strong positive correlation with MSW generation in MGyn, considering the presented coefficient ($\tau = 0.89$). Thus, the *per capita* generation of the municipalities of the proposed MSWMF is strongly associated with the amount of energy consumption in the municipalities. Franco et al. (2014) also found a strong association between the electricity consumption and the generation of solid waste in

Florianópolis city, in southern Brazil. Pauletto (2010) has shown a positive relationship between the electricity consumption and the MSW generation, in the same region. It should be noted that electricity consumption has been used as a parameter to indicate an association with solid waste generation, as it is an indicator of society welfare and consumption (Tolmasquim 2008).

Table 5. Analysis of the association of variables with the *per capita* MSW generation in the municipalities of the proposed management facility.

Variables	Kendal coefficient (τ)**	Significance
Electric power consumption	0.8859	0.0000***
Average wage	0.5364	0.0019***
Geometric population growth	0.3315	0.0563****

Source: Authors.
Notes: *dependent variable; **Kendall's tau-b; ***/****statistical significance at 1% and 10%, respectively.

The results of the association between the variables "Average yields" and *per capita* MSW generation in MGyn, according to the obtained coefficient ($\tau = 0.54$) has shown a moderate positive correlation between the two variables. It can be stated, with 1% of significance, that the higher levels of yield are associated with a higher *per capita* waste generation. Corroborating this finding, in Nigeria, Afon & Okewole (2007) found statistically significant results to explain the positive relationship between the family income and *per capita* solid waste generation. Mazzanti & Zoboli (2009) also reported a significant positive association between the *per capita* income and the waste generation in countries of the European Union.

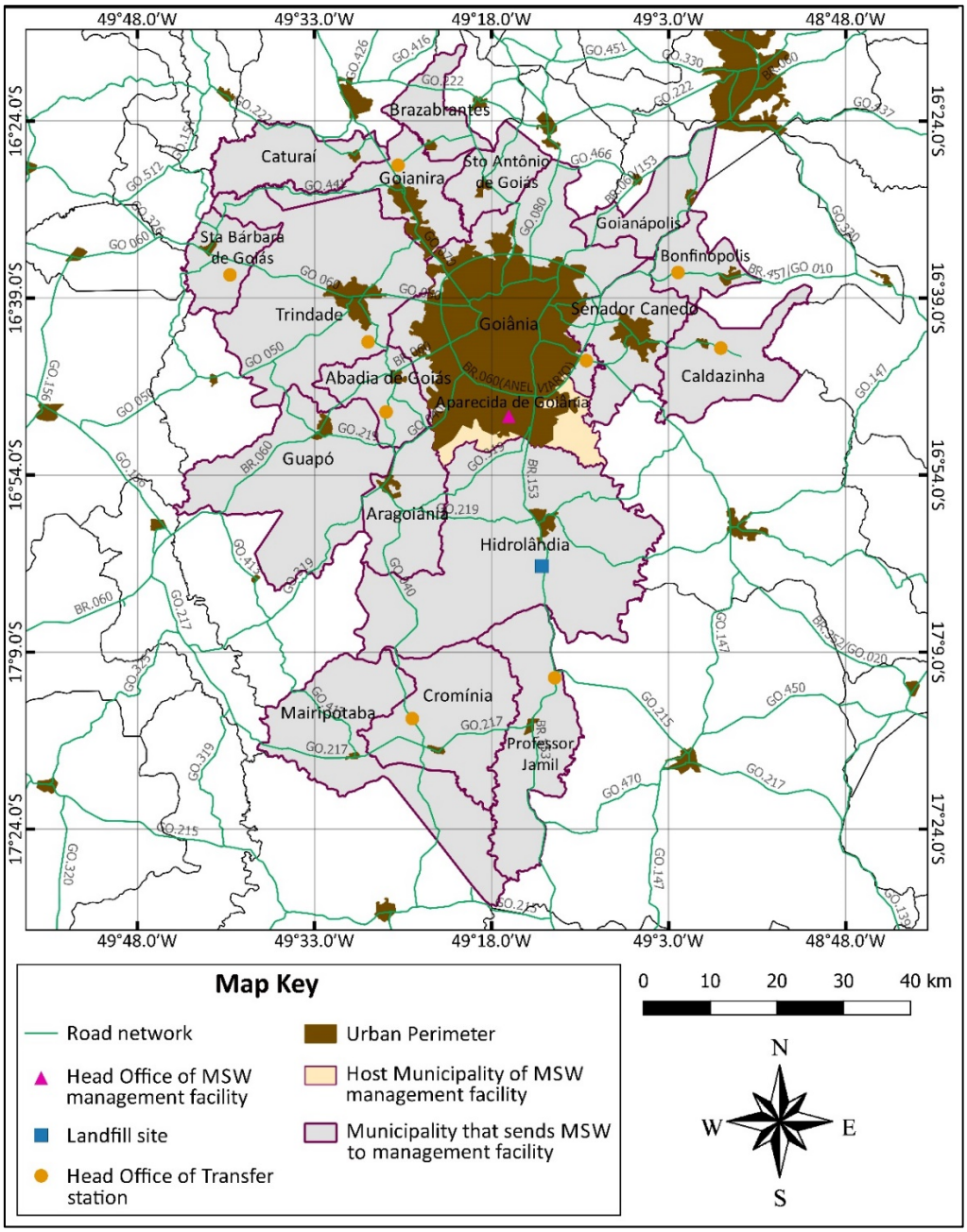
Regarding the "Geometric population growth", a positive association with the *per capita* solid waste generation was found in MGyn, in the 10% confidence interval, considering the calculated coefficient ($\tau = 0.33$). In a study conducted in Can Tho city, in the Mekong Delta, Vietnam, Thanh et al. (2010) reported that the *per capita* MSW generation was positively correlated with the demographic variable, population density. Thus, it is possible to infer that higher rates of population growth are associated to higher MSW generation levels, in particular, as the population of a municipality grows, so does the *per capita* MSW generation (Colvero et al. 2017a). Similarly, Johnstone & Labonne (2004) provided evidence of the relationship between demographic factors and the MSW generation in member countries of the Organization for Economic Cooperation and Development (OECD).

PROPOSAL OF A HOST MUNICIPALITY FOR THE MSW MANAGEMENT FACILITIES

Based on the identification of the CM of each municipality of the MGyn microregion and the five neighboring microregions, it was possible to identify the HM for each of the six microregions. Thus, the location of the proposed MSWMF for MGyn, which will be composed of 19 municipalities

(Figure 4), will be defined, as described in item *Restricted, subject to approval or available areas for construction of a final waste disposal facility in the microregions*.

Figure 4. Urban waste management facility proposed for Metropolitana de Goiânia microregion and neighboring municipalities, Goiás State.



Source: Authors.

Although the CM of the MGyn microregion indicated the municipality of Goiânia, instead the municipality of Aparecida de Goiânia was selected to host the proposed MSWMF (Figure 4). The reason is that this municipality has four industrial clusters that integrate the largest Industrial District of Goiás State (FIEG 2015). So, the proposed MSWMF will be located at the Industrial District, which is

the best located cluster in the area. It is located beside roadway BR 153, the fourth most extensive highway in Brazil and which crosses Goiás State (SEPLAN 2010; Lauria 2012). Thus, the proposed management facility could promote MSW recovery, which would be burned at special waste-to-energy plants to generate electricity and/or steam for the large industries installed in this industrial district. Another positive aspect is the fact that Aparecida de Goiânia is conurbated with Goiânia (Anjos 2009; SEGPLAN & SEPIN 2011), which reduces the travelling distances to transport the MSW from the capital to the proposed MSW management facility. Moreover, in 2015, Aparecida de Goiânia had the second largest population of Goiás (more than 500 thousand inhabitants - IBGE (2016) and it is estimated that the city had produced more than 465 $t \cdot day^{-1}$ of MSW, in 2016.

Moreover, the closest place to the CM, where there is an area available to construct a landfill (to receive waste from processed MSW at the MSWMF of Aparecida de Goiânia), is Hidrolândia. Therefore, a waste management facility with two HM was proposed: (1) Aparecida de Goiânia, to be the HM of the MSWMF where the MSW treatment technology will recover the waste and generate electricity and/or steam, and (2) Hidrolândia, for the construction of the landfill that will receive the waste from the management facility of Aparecida de Goiânia. This landfill will be located along the BR-153 highway, 29.3 km away from the MSWMF. The way between Aparecida de Goiânia and Hidrolândia's landfill will be characterized by paved highways.

Thus, the proposed MSWMF will count on a MSW treatment facility in Aparecida de Goiânia. It will also have a landfill in Hidrolândia and in other nine TS to interconnect the municipalities that are farthest from the Aparecida de Goiânia HM.

TRAVEL DISTANCES FOR MSW TRANSPORTATION

The MSW transportation distances were crucial to determine the municipalities to be included in the proposed MSWMF. In addition, the distance criteria detailed in item *Geographically centralized municipalities* were important to determine whether the municipalities would send their MSW directly to the proposed management facility directly, or to a TS, first.

The proposed MSWMF, located in Aparecida de Goiânia, will receive MSW from 18 municipalities (in addition to MSW from its own HM). The MSW transport distances from each non-HM to the MSWMF headquarters of Aparecida de Goiânia are shown in Table 6.

Table 6. Transport distances of MSW from the 19 municipalities of Goiás to the MSW management facilities or to the TS.

Host municipality of the MSW management facility (MSWMF)	Distance from the urban center of the host municipality to the MSWMF - Maximum 25 km	Municipality that sends its MSW directly to the MSWMF	Distance from the urban center to the MSW management facility headquarters - Maximum of 25 km	Host municipality of the Waste Transfer Station (WTS)	Distance from the WTS to the HM of the MSWMF - maximum of 100 km (preferably with a minimum distance of 25 km)	Distance from the urban center of the host municipality of the WTS to the WTS - Maximum of 25 km	Municipality that sends its MWS directly to the WTS	Distance from the urban center of the municipality to the WTS - Maximum of 25 km
Aparecida de Goiânia	3.8							
		Hidrolândia	22.5					
				Abadia de Goiás	32.4	5.8		
							Guapó	21.1
							Aragoiânia	13.5
				Caldazinha	49.6	3,2		
				Santa Bárbara de Goiás	60.9	10.3		
				Goiânia	27.1	24.9		
							Senador Canedo	13.2
				Bonfinópolis	43.9	8.3		
							Goianápolis	21.1
				Cromínia	70.1	6.9		
							Mairipotaba	17.2
				Professor Jamil	47.2	9.1		
				Goianira	50.7	6.2		
							Caturaí	11.7
							Brazabrantes	6.5
							Santo Antônio de Goiás	22.8
				Trindade	33.8	8.9		

Source: Authors.

CONCLUSION

Approximately 81% of the total area of the 19 municipalities of the proposed MSWMF is off limits for the construction of MSW disposal facilities. Nine of those have no available areas for the construction of these facilities, mainly because of urban occupation and the presence of airfields. Moreover, three of the four most populated municipalities have almost 100% of their area restricted for the construction of landfills: Aparecida de Goiânia, Goiânia and Senador Canedo.

Another issue identified in this region concerns the 21 existing MSW disposal facilities. Of these, there are 14 dumps and three unlicensed landfills. Also, the four licensed landfills by the OAL are located in restricted areas for landfill construction.

Regarding the MSW production sent to these final solid waste disposal facilities, 2 163 $t \cdot day^{-1}$ of MSW were produced in the region of the proposed MSWMF, in 2015. Only Goiânia and Aparecida

de Goiânia produced 89% of the total amount of MSW. The application of the correlation test by the Kendall coefficient (τ) allowed to identify the association of socioeconomic and demographic factors with the *per capita* MSW generation. The *per capita* MSW generation in the municipalities that integrate the proposed MSWMF was found to be strongly associated with electricity consumption, and moderately correlated with income and population growth levels of the municipalities investigated in this study.

Regarding the proposed MSWMF, based on the identification of the CM of each municipality of the MGyn microregion and the five neighboring microregions, the HM for each of the microregions were defined. The management facility that comprises the capital of Goiás State will include 19 municipalities, of which 13 belong to MGyn and six other municipalities belong to three neighboring microregions. This MSWMF will have Aparecida de Goiânia as the treatment facility's HM that will handle most of the MSW in the region. The landfill will be in the municipality of Hidrolândia, 29.3 km away from the management facility. Moreover, because there are municipalities that are more than 25 km away from the proposed MSWMF, there will be nine TS to send the MSW of 17 municipalities to Aparecida de Goiânia. To conclude, the proposed MSWMF for the MGyn microregion and neighbor municipalities can be an alternative to change the MSW management panorama in this region.

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Proposta de Localização de um Sistema de Gestão de Resíduos Sólidos Urbanos para uma Região Metropolitana

RESUMO

Apenas 16 dos 246 municípios do Estado de Goiás, Brasil, dispõem seus resíduos sólidos urbanos (RSU) em aterros licenciados. Assim, este estudo propôs o município sede (MS) do futuro sistema de gestão de RSU (SGRSU) compartilhado para a microrregião Metropolitana de Goiânia (MGyn). Primeiramente identificaram-se potenciais áreas para instalar sistemas de disposição final de RSU (aterros). Posteriormente, utilizando-se a metodologia da geometria das massas, definiu-se o MS do SGRSU proposto para a MGyn. Os resultados mostram que apenas 19,4% da área dos municípios estudados é livre ou sujeita à anuência para instalar aterros. O MS será Aparecida de Goiânia, que tratará a maior parte dos RSU e enviará os rejeitos dos RSU tratados para o município vizinho de Hidrolândia. Além disso, este SGRSU servirá 19 municípios e terá nove estações de transferência que receberão os resíduos de 17 municípios, para minimizar os custos com o transporte dos RSU.

Palavras-Chave: Município Sede; Centro de Massa; Análise Estatística; País em Desenvolvimento.

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