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MULTI-CRITERIA ANALYSIS AND GEOPROCESSING IN THE SELECTION OF AREAS FOR SANITARY LANDFILLS IN THE SOUTHERN AREA OF RIDE/DF

MULTICRITERIA ANALYSIS AND GEOPROCESSING IN THE SELECTION OF AREAS FOR LANDFILLS IN THE SOUTHERN AREA OF RIDE/DF

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SUMMARY
Population growth and changes in consumption patterns are the main activities that have contributed to the increase in the generation of Urban Solid Waste (MSW). With the significant increase in MSW generation, these in turn, in the vast majority of Brazilian cities, are disposed of in a totally inadequate manner, that is, in open-air dumps, putting the environment as a whole at risk. This situation is evident in the Integrated Region of the Federal District and Surrounding Area (RIDE), a region composed of 22 municipalities and the Federal District. This research sought to select suitable areas for sanitary landfills in the South of RIDE/DF to assist in the management of MSW in the region. For this purpose, maps of land use and coverage were produced on a multitemporal scale, criteria were defined, and weighted by experts through the application of questionnaires; the weights of the criteria were calculated using the Hierarchical Process Analysis (HPA) methodology. The criteria, represented as a geographic data plan, were standardized and aggregated using Weighted Linear Combination (WLC) to produce a map of potential landfill sites. Four alternatives for landfill sites were defined and, using a multicriteria methodology, alternative 1, located 27 km south of Luziânia, was selected. The results indicate that the proposed objectives were achieved and the AHP method integrated with GIS provides a procedure for the precise location of landfill sites that should satisfy all interested parties. **Keywords:**Solid waste. Sanitary landfill. Hierarchical Process Analysis.

ABSTRACT
Population growth and changes in consumption patterns are the main activities contributing to the increase in the generation of Urban Solid Waste (USW). With the significant increase in USW generation, these wastes, in most Brazilian cities, are disposed of in an entirely inadequate manner, such as in open-air dumps, putting the environment as a whole at risk. This situation is evident in the Integrated Region of the Federal District and Surrounding Areas (RIDE), a region consisting of 22 municipalities and the Federal District. This research aimed to select suitable areas for sanitary landfills in the southern part of RIDE/DF to assist in the management of USW in the region. For this, maps of land use and land cover on a multi-temporal scale were produced, and criteria were defined, which were weighted by experts through the application of questionnaires. The weights of the criteria were calculated using the Analytic Hierarchy Process (AHP) methodology. The criteria, represented as geographic data layers, were standardized and combined using the Weighted Linear Combination (WLC) method to produce the map of potential areas for sanitary landfills. Four alternatives for landfill areas were defined, and through multi-criteria methodology, alternative 1, located 27 km south of Luziânia, was selected. The results indicate that the proposed objectives were achieved, and the AHP method integrated with GIS provides a procedure for the precise location of areas for landfills that should meet the needs of all stakeholders.
Keywords: Solid waste. Sanitary landfill. Analytic Hierarchy Process.

INTRODUCTION

Population growth and changes in consumption patterns are the main activities that have contributed to the increase in the generation of Urban Solid Waste (MSW). Therefore, the issue of MSW generation and its final disposal has been growing gradually and is therefore gaining more and more space in technical discussions and research in the sanitation area.

According to SNIS (2017), in Brazil, only 66.8% of the urban solid waste collected was properly deposited in landfills, the remainder, 33.2%, was sent to dumps and controlled landfills. In the Brazilian Midwest, 67.2% of the collected waste was deposited in an appropriate manner.

irregular, in controlled landfills and dumps, thus presenting itself as the region with the highest rate of inadequate disposal of solid waste. The problem is also noticeable in RIDE/DF (Integrated Region of Economic Development of the Federal District and Surrounding Area), located in the Brazilian Midwest, where there are only three sanitary landfills.

Despite continuous advances, the problem of solid waste is still a major challenge for environmental management today, especially in relation to adequate final disposal, since, with the expansion of urban centers, it becomes increasingly difficult to find areas that meet the technical, environmental and economic conditions necessary for the implementation of sanitary landfills (SHAHABI et al., 2013).

To facilitate and reduce costs, the process of selecting areas for landfills has increasingly been based on spatial analysis and mathematical modeling, that is, through the integration of Geographic Information Systems (GIS) with multicriteria analysis methods, with AHP being one of the most widely used methods. Hierarchical Process Analysis (AHP) is a multicriteria decision-making support method developed by Thomas Saaty in 1980 (Saaty, 1980) for resolving negotiated conflicts and problems with multiple criteria, and can help decision-makers establish priorities and make the best decision when faced with a problem. To use the AHP method and make comparisons between criteria, Saaty's fundamental scale is used, which indicates how many times an element is more important or more dominant than the other in relation to the criterion or property in relation to which they are compared.

In the integration process, the maps of interest are georeferenced and superimposed in layers (*layers*or information plans), so that spatial analysis based on Boolean logic and/or logic *fuzzy* resulting produces possible candidate and/or unsuitable areas, which can be separated by clear boundaries (Chang*et al.*, 2008).

There are several studies that have integrated GIS with multicriteria analysis, such as that of Maguri et al. (2016), who used GIS, multicriteria decision support analysis, remote sensing and several criteria, such as solid waste production, distance from homes, groundwater, land use, among others, to produce a map of potential areas, which allowed proposing three areas for landfill for the city of Mohammedia, in Morocco.

In a study on urban solid waste management, Khan and Samadder (2014) used the integration of GIS with AHP and concluded that the integration of the two methods provides an effective tool in multicriteria analysis and in the evaluation of more suitable locations for landfills.

Thus, this research had as its main objective the development of a methodological proposal using a multicriteria method and Geographic Information Systems for the analysis and selection of areas for the implementation of a sanitary landfill in the South of RIDE/DF and surrounding areas.

1. MATERIAL AND METHOD

The research was developed in the South of RIDE/DF and surrounding areas, located in the Central-West Region of Brazil, in the Southeast portion of the State of Goiás. The study area is composed of the municipalities of Águas Lindas de Goiás, Santo Antônio do Descoberto, Novo Gama, Cidade Ocidental, Valparaíso de Goiás, Luziânia and Cristalina. Figure 1 shows the location of the study area.

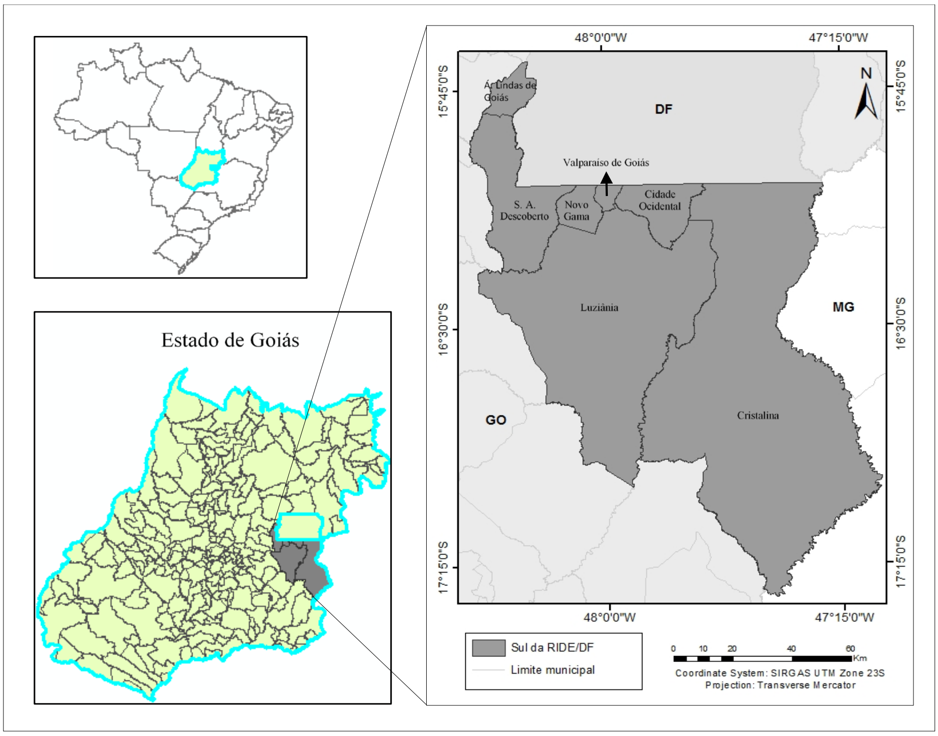

Figure 1 - Location of the study area.

RIDE/DF and Surrounding Areas, within the scope of CORSAP/DF-GO, for better management, is divided into four strategic planning regions: the North region, with seven municipalities; the West region, with five; the Federal District; and the South region, with seven municipalities (CORSAP, 2013). After analyzing the four regions, it was decided to choose the South region for the development of the research, which is of a scientific nature and free from external interference, since it is the region, among the four, that has the most critical situation regarding the final disposal of MSW, with the current deposits in landfills located near urban areas and sources of water collection for public supply, and because it is the region that has the best geographical conditions for the shared management of MSW, including with the premise of future import of part of the solid waste from the Federal District.

The research was divided into three stages (Figure 2), the first of which consisted of analyzing the temporal evolution of land use and coverage, and the second of which consisted of identifying potential areas for landfills. and in the third, an area was selected for a regional landfill in the South of RIDE/DF.

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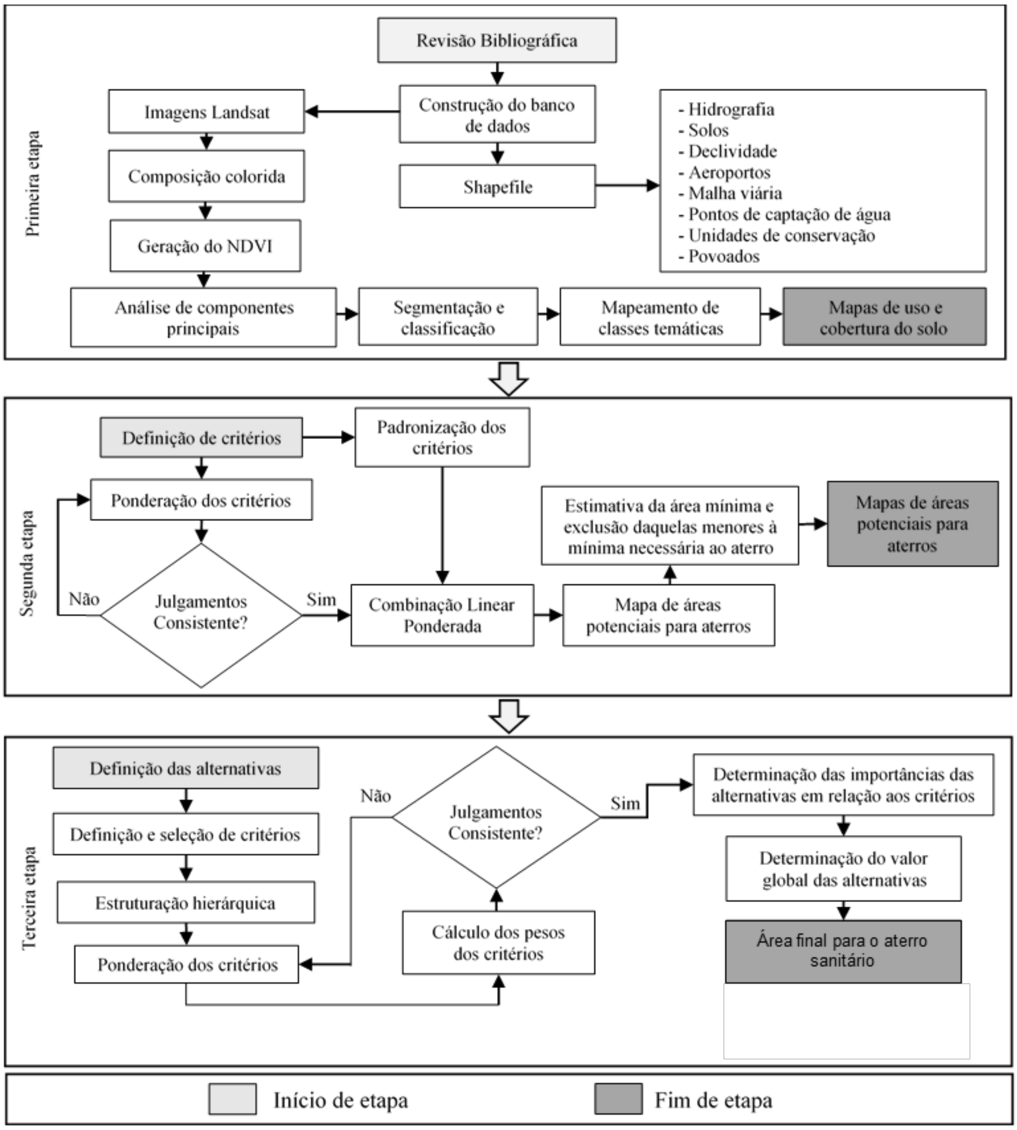

Figure 2 - Flowchart of activities carried out.

Thematic classification of land use and land cover

The thematic classification of land use and land cover was carried out with images from the Landsat 5 satellite for the years 1986, 1996, 2006 using the green, red and near infrared spectral bands (bands 2, 3 and 4), in a false-color composition, which according to Almeida*et al*(2012) allows the separation of soil and vegetation, with a spatial resolution of 30 meters, and with images from the Landsat 8 satellite for the year 2016, using the red, near and mid-infrared spectral bands (bands 3, 4 and 5) with a spatial resolution of 30 meters, and the panchromatic band (band 8), with a spatial resolution of 15 meters.

The Georeferenced Image Processing System (SPRING), developed by the National Institute for Space Research (INPE), was used for thematic image classification. The land use and land cover maps were classified into eight classes: urbanized area, agriculture, gallery forest, field, savannah, pasture, exposed soil and water bodies.

Location of potential landfill sites

For this stage, a survey of criteria for identifying potential areas was carried out.
for the implementation of sanitary landfills. The survey was based on ABNT NBR 13.896/97, Resolutions of the National Environmental Council (CONAMA), National System of Conservation Units (SNUC), dissertations, theses and articles related to studies of areas for sanitary landfills. The objective of this survey was to select the most important and most used criteria and subcriteria today, such as

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shows Figure 3.

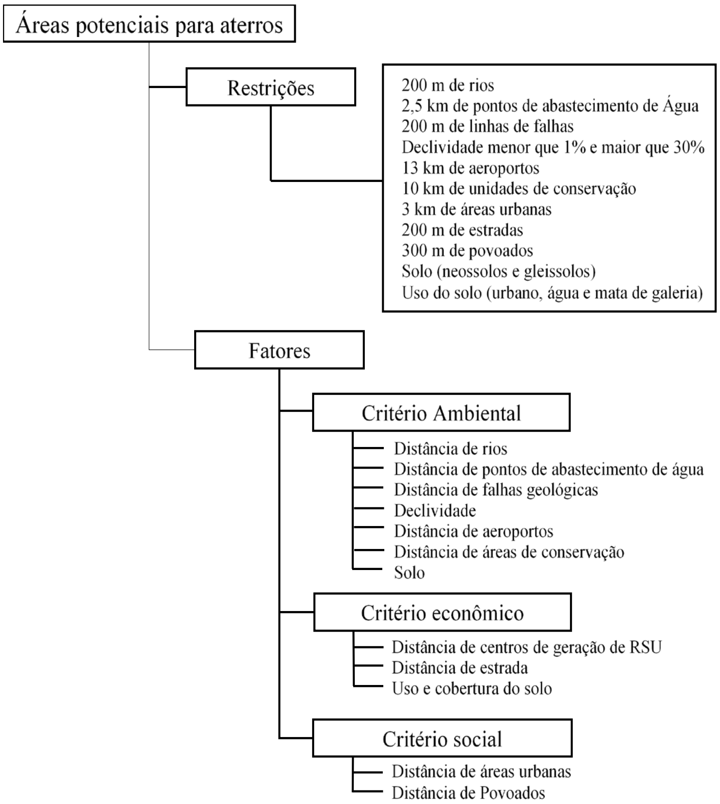

Figure 3 - Criteria and factors for locating areas for sanitary landfills (modified from NBR 13.896/97; Shahabi *et al.* (2013); *et al.* (2015) and Maguri *et al.* (2016).

Standardization was achieved by reclassifying the maps, in matrix format, using the ArcGIS Reclassify tool, and applying scores on a scale of 0 to 10. A score of 0 was assigned to areas that did not meet the legislation criteria, creating a *buffer* protection around these areas and excluding them from the analysis process. On the other hand, a score of 10 was given to the areas considered suitable, producing maps with suitable and unsuitable areas. Within the standardization scale, suitability bands were created, which vary according to the scores assigned.

After the criteria and factors were standardized, they were weighted by means of paired comparison, which was carried out by experts, through the application of questionnaires, where, using the fundamental scale for paired comparison (Saaty, 1980), the experts assigned weights to the criteria. The paired comparison was made within their respective levels (environmental, economic and social). After the pair comparison, the judgments of the different experts were grouped by the Individual Judgment Aggregation (IJA) method using Equation 1, which made it possible to obtain the global matrix of judgments.

(1)

Where:

s: Number of experts.

w: Weight assigned in pairwise comparison.

m: Number of criteria.

After grouping the global matrix of judgments, the normalized matrix was constructed by applying Equation 2, which consisted of dividing each value in the matrix column by the sum of the weights in that column.

(2)

Where:

W: Weight assigned in the pairwise comparison of criteria.

m: Number of criteria.

From the normalized matrix, the final weight of each criterion was calculated by the arithmetic mean of each row of the normalized matrix using Equation 3.

(3)

Where *m* is the number of criteria.

The choice of the AHP method for this research is justified by the fact that it allows the assignment of priority levels through the determination of weights. It is one of the most widely used methods for multicriteria decision support, and has been widely integrated into GIS for the identification of potential areas for landfills. In addition, the method is based on the knowledge and experience of experts from different areas.

Selection of alternatives for landfill

To determine the potential areas, four Weighted Linear Combinations (WLC) were performed, three at the third level of the hierarchy and one at the second level. For the weighted linear combinations, the extension *Spatial Analyst Tools* and the tool for weighted overlay, the *Weighted Overlay*. The Weighted Linear Combination of the maps was performed by Equation 4.

(4)

Where:

PLC: Map resulting from the weighted linear combination. *W*: Criterion or factor. *w*: Weight of the criterion or factor.

Selection of alternatives for landfill

To carry out this stage, it was necessary to define the alternatives, a new group of criteria, determine the relative importance of the criteria in relation to the alternatives and obtain the priority and decision vectors. To define the alternatives, from a set of numerous alternatives, and apply the AHP method, it was necessary to eliminate several alternatives. To do this, areas smaller than the minimum required for the sanitary landfill and those located far from the MSW generation centers were eliminated, thus leaving only four viable areas.

To define the new set of criteria, these were first pre-defined through literature research and adapted to the local reality of the study area according to their importance and data availability. Six criteria were pre-selected, and the experts selected four for analysis: urban solid waste generation, landfill lifespan, transportation costs and access conditions.

The determination of the relative importance of the criteria was made through expert judgments, carried out by applying questionnaires, comparing the criteria with each other. The experts consulted have knowledge in the areas of solid waste, environment and geography.

The priority vectors were obtained by normalization for the landfill life criterion, and by harmonization followed by normalization for the other criteria. Normalization is done by dividing the value of the criterion for each alternative by the sum of the values of the alternatives. Harmonization is done by dividing the sum of the values of the criteria for the alternatives by the value of each of the alternatives, and then normalization is done to obtain the priority vector of the alternatives in relation to this criterion. After this, the global evaluation of each alternative was done by Equation 5, which allows generating the final values of the alternatives.

tives, classifying them in order of preference of the judges.

(5)

Where:

m: number of criteria. *n*: number of alternatives. *w*: weight of the criterion.

v: priority vector of the alternative.

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And finally, sensitivity analysis was performed to assess the stability in the ordering of the alternatives obtained regarding changes in the weights of the criteria.

2. RESULTS AND DISCUSSION

Thematic classification of land use and land cover

To verify the changes that occurred over time in each of the classes (urban area, agriculture, field, cerrado, gallery forest, pasture, exposed soil and water), the areas of each class were calculated for each year analyzed, and the difference between them shows the gain or loss of area in each class. The land use and land cover maps for the years 1986, 1996, 2006 and 2016 are presented in Figures 4.

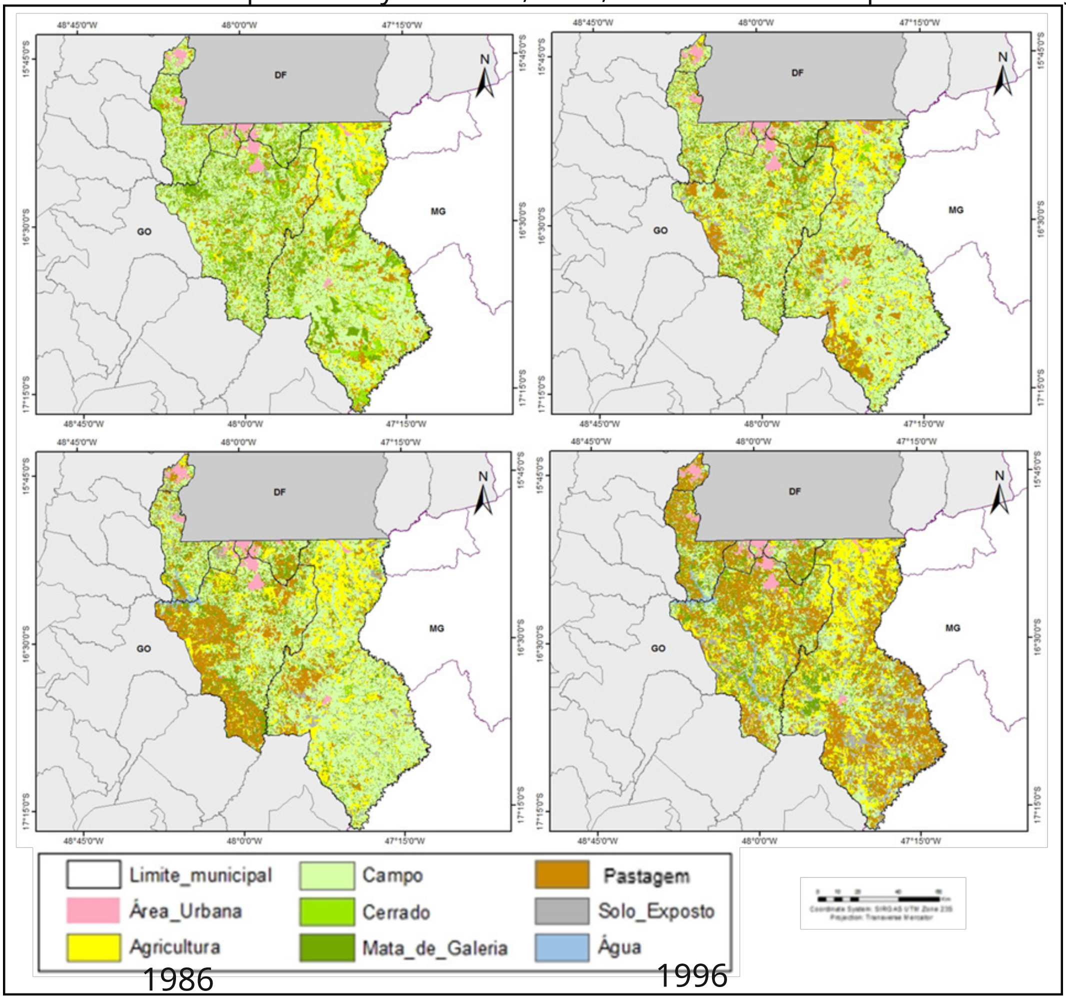


Figure 4 - Land Use and Cover Map for the years 1986, 1996, 2006 and 2016.

Over the thirty years analyzed, the greatest changes occurred in the following classes: field, which had an area of approximately 6,371 km² in 1986 and was reduced to approximately 2,484 km², i.e., a reduction of approximately 156%; pasture, which had an area of 1,073 km² in 1986 and now has approximately 3,604 km² in 2016, registering an increase of approximately 70%. In percentage terms, the greatest change occurred in the cerrado class, where a reduction of approximately 1,225% was observed. Mapping the land use and land cover classes and understanding their dynamics, carried out by thematic classification of digital sensor images remote, are preponderant factors in the location of potential areas for the implementation of sanitary landfills, whose exposed soil class is prioritized, as suggested by the National Solid Waste Policy.

2006 2016

Location of potential landfill sites

The location of potential areas for landfills was carried out through the weighted linear combination of maps of environmental, social and economic criteria. Figure 5 shows the sequence of combinations of factors and criteria for producing the map of potential areas for landfills.

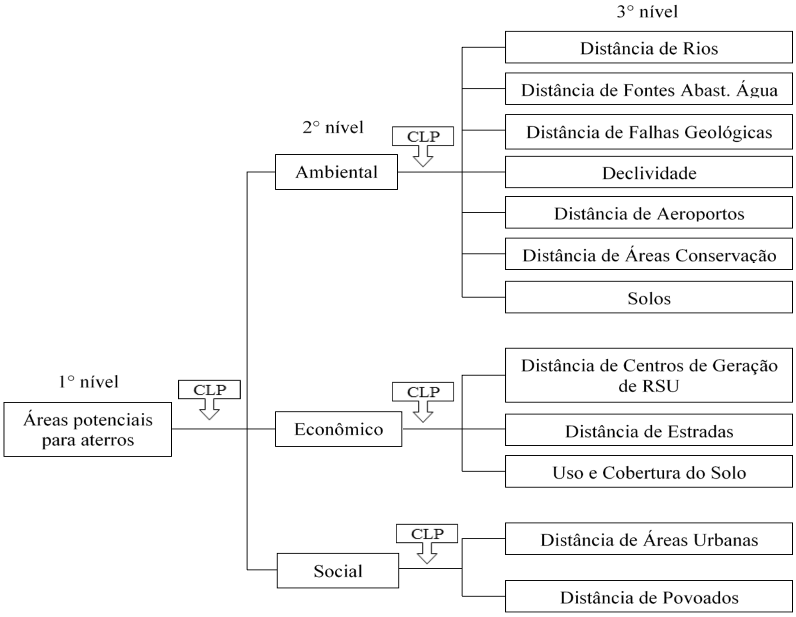


Figure 5 – Flowchart of combinations of factors and criteria.

Figure 6 shows the map of potential areas for sanitary landfills in the South of RIDE/DF and surrounding areas.

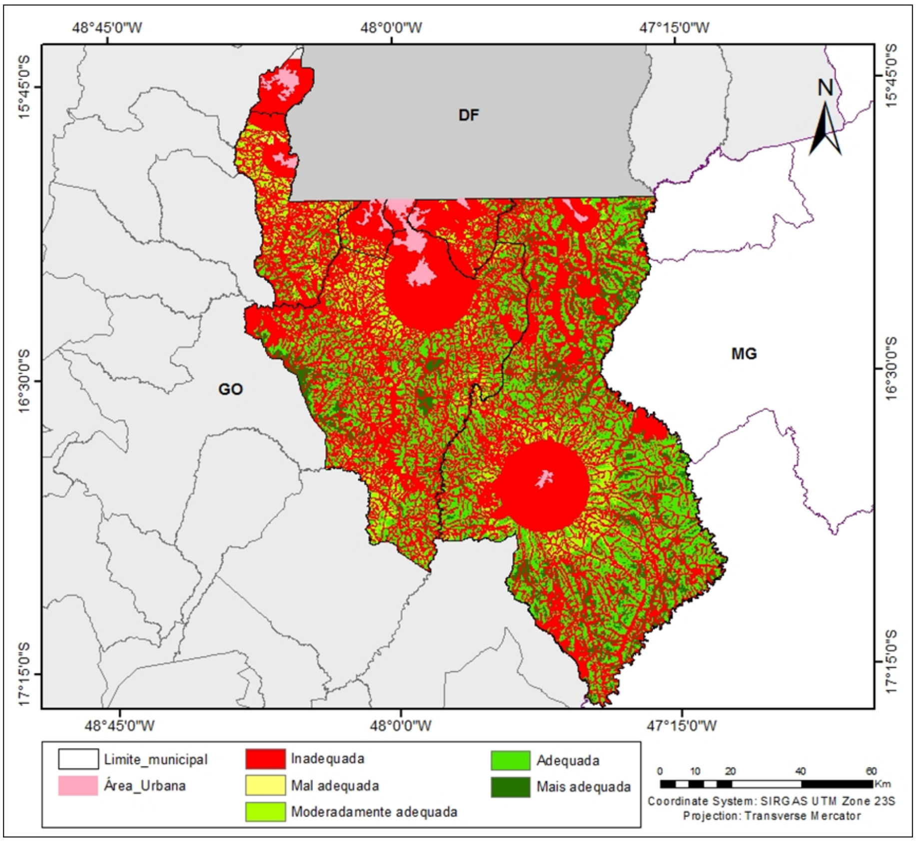


Figure 6 - Map of potential areas for landfills in the South of RIDE/DF.

The map of potential areas for sanitary landfills was reclassified into five classes (inadequate, poorly adequate, moderately adequate, adequate and most adequate). Among the seven municipalities in the South of RIDE/DF and Surrounding Area, Águas Lindas de Goiás and Valparaíso de Goiás do not have areas suitable for sanitary landfills. The absence of areas that meet the minimum requirements for the implementation of sanitary landfills can be justified by the fact that these two municipalities have the smallest territorial area (190.56 and 61.20 km_2) and the highest density demographic of the South of RIDE/DF, with 1,004.46 and 2,555.79 inhabitants/km^2 for the municipalities of Águas Lindas and Valparaíso, respectively, making their areas completely restricted for the implementation of sanitary landfills.

On the other hand, the municipality of Cristalina has the largest territorial area (6,169.02 km^2), lower population density (8.81 inhabitants/km^2) and more potential areas for sanitary landfills (249,596.33 ha). The South of RIDE/DF, when considering only the most restrictive class, the "most suitable" class, presents approximately 62,363.23 ha of potential areas for sanitary landfills.

Selection of alternatives for landfill

The definition of alternatives took into account the most suitable class areas, the minimum area required for the landfill, where the 20-year project horizon was considered, through which the minimum area of 230 ha for the implementation of the sanitary landfill was determined. Therefore, areas smaller than 230 ha, areas of difficult access and areas located at great distances from solid waste generation centers were excluded. Thus, four alternatives remained that met the established criteria. Figure 7 shows the four alternatives for the implementation of the sanitary landfill.

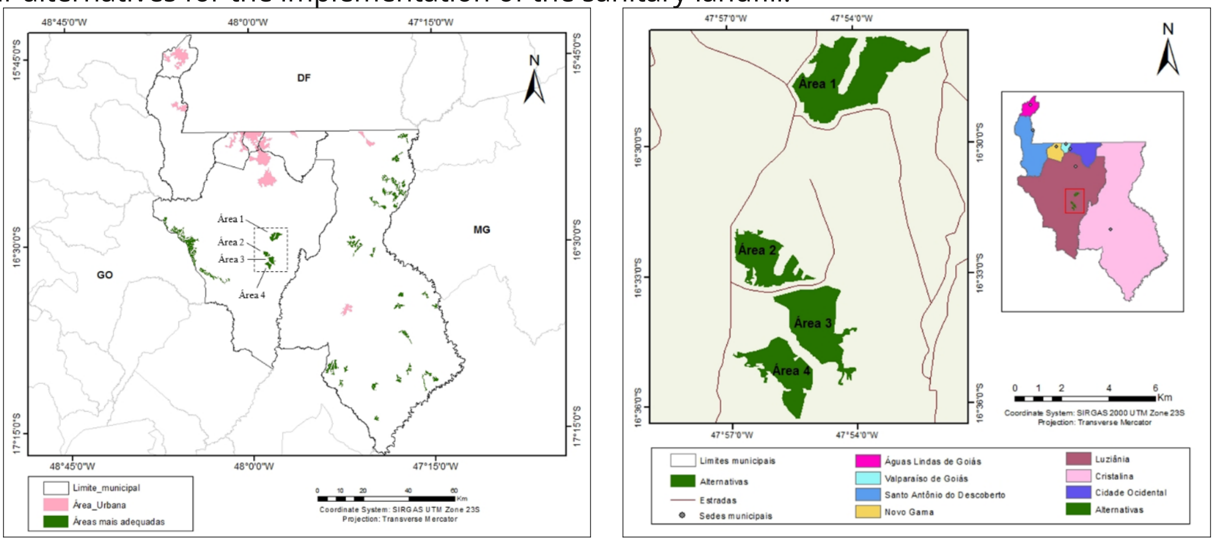


Figure 7 - Alternatives for sanitary landfill in the South of RIDE/DF.

According to the assessment of land use and coverage, the four alternatives present the classes of field, pasture, exposed soil and agriculture and, with the exception of alternative 1, all the others consist, for the most part, of rural areas. For the four alternatives, the areas were calculated, the useful life, the distance to the center of mass of MSW, the percentage of paving of access roads and the distance to the center of solid waste generation of the headquarters of each municipality were estimated. Table 1 presents the area, useful life, distance from the center of mass of waste in the region and the percentage of paving of access roads.

Table 1 - Area, useful life, distance from the center of mass of waste in the region and percentage of paving. tion of access routes.

Alternative	Area (ha)	Useful life (year)	Distance from the Center of Mass of MSW (km)	Paving of access routes (%)
Area 1	1059.5	50.9	53.8	16.7
Area 2	410.5	29.2	63.6	14.7
Area 3	643.6	38.7	68.2	13.2
Area 4	458.4	31.4	67.6	13.0

Table 2 presents the optimized distances between the alternatives and the municipal headquarters.

Table 2 - Distance of alternatives to municipal headquarters.

Municipality/headquarters	Distance (km)			
	Area 1	Area 2	Area 3	Area 4
Beautiful Waters of Goiás	141	150	155	154
Saint Anthony of the Discovered	108	118	123	122
New Range	57	67	71	71
Valparaiso of Goiás	52	61	66	65
Western City	51	60	65	64
Luziania	27	37	42	41
Crystal clear	71	74	79	79

According to Table 2, it can be seen that all alternatives are located at distances greater than 20 km from all municipal headquarters, which requires transfer stations to reduce transportation costs. Transfer stations are the facilities where the MSW is transferred from a collection vehicle to another vehicle with a higher load capacity, such as trailers and trucks (NUNES and SILVA, 2015).

The alternatives were subjected to a new multicriteria evaluation to rank them and thus select the best area, according to the experts' assessment. The experts, through paired comparison, assigned weights to the criteria. Table 3 Overall matrix of experts' judgment and weight of the criteria.

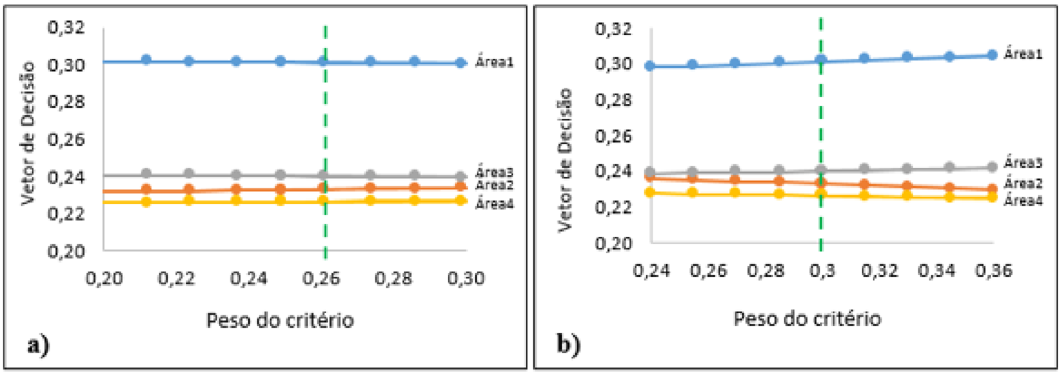
Table 3 - Global matrix of expert judgment and weight of criteria.

Criteria	Generation of RSU	Useful life from the landfill	Cost of transport	Conditions access	Weight of criteria
MSW generation	1	0.880	0.880	1,732	0.249
Landfill lifespan	1,136	1	0.809	3,201	0.300
Transportation cost you	1,136	1,236	1	3,482	0.340
Access conditions only	0.577	0.312	0.287	1	0.111

The experts' judgments showed inconsistency within the acceptable limit, with *RC*=0.015, since the maximum allowed for the comparison of four criteria is 0.08 (Saaty, 1980). With the information on the criteria weights, the priority vectors were determined to calculate the general classification values of the four alternatives. Figure 8 shows the decision vectors of the alternatives.

Figure 8 - Decision vector of alternative areas for sanitary landfill.

According to Figure 8, the alternative selected for the implementation of a sanitary landfill in the South of RIDE/DF was area 1, which is the largest of the four alternatives and, consequently, the one with the longest useful life, with 50.9 years and, in addition, it is located closest to the large waste generating centers.
solid duos, which can minimize transportation costs. Figure 9 presents the sensitivity analysis.



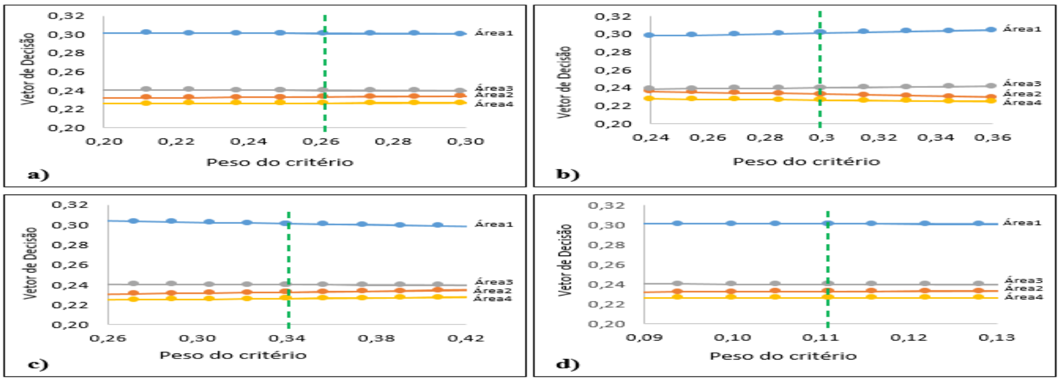


Figure 9 - Sensitivity in the ranking of alternatives to changes in the weight of the criterion: a) MSW generation, b) Landfill useful life, c) Transportation cost and d) Access conditions.

According to Figure 9, it is observed that even changing the weights of the criteria by 20%, either upwards or downwards, there are no inversions in the overall evaluation of the alternatives. Thus, the sensitivity analysis, therefore, indicates that the classification values are stable, showing the preference for area 1 in all evaluation scenarios, which is considered by experts to be the most suitable location for the construction of the regional landfill in the South of RIDE/DF.

3. FINAL CONSIDERATIONS

The multitemporal analysis for the 30-year period showed that there was an expansion of agricultural areas, urban areas, pasture areas and exposed soil, with high variation values. On the other hand, there were reductions in the areas of field, cerrado and gallery forest, reflecting the current model of land use that probably occurs in an unplanned manner, with land use and coverage being one of the criteria used to select areas for landfills.

The establishment and aggregation of environmental, economic and social criteria and their respective factors produced a map of potential areas suitable for sanitary landfills, with the “most suitable” class comprising approximately 20,135.60 hectares, from which four alternatives for sanitary landfills were defined.

Through multicriteria analysis it was possible to select an area for sanitary landfill, the alternative 1, located 27 kilometers south of the municipality of Luziânia, is considered the best area for the installation of a sanitary landfill, according to experts, and the sensitivity analysis proved to be robust, with the ordering of the alternatives remaining unchanged when the original weights of the criteria were changed by 20%, either upwards or downwards.

In general, the results obtained show that the geoprocessing algorithms existing in a GIS integrated with AHP are useful and efficient tools in the process of selecting potential areas for landfills, as they allow for the analysis of existing data in a precise and rapid manner, reducing costs and the number of areas to be analyzed, in addition to assisting in interdisciplinary diagnostic studies.

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