CARACTERIZAÇÃO DOS RESÍDUOS SÓLIDOS URBANOS DOS MUNICÍPIOS PAULISTAS POR SETOR CENSITÁRIO

RELATÓRIO FINAL DE PROJETO DE INICIAÇÃO CIENTÍFICA
(PIBIC/INPE/CNPq)
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RESUMO

O crescimento populacional acelerado e as mudanças no estilo de vida são os principais fatores que contribuíram para o rápido crescimento da geração de resíduos sólidos urbanos (RSU). Aterros sanitários são uma opção segura para a destinação final desses RSU, por serem áreas especialmente preparadas com o objetivo de minimizar impactos ambientais, além de evitar danos à saúde pública. A identificação apropriada da localização dos aterros sanitários pode evitar efeitos indesejáveis a longo prazo. Porém, encontrar novas áreas para a implantação de aterros sanitários está se tornando cada vez mais difícil devido à crescente conscientização ambiental, legislações rigorosas e oposição política e social. Sabe-se que adotar fatores ambientais restritivos é importante para evitar a contaminação dos recursos naturais, assim como adotar fatores socioeconômicos é necessário para reduzir os custos financeiros e a oposição pública. Neste trabalho foram elaborados cenários de restrições para o estado de São Paulo considerando as legislações dos Estados Unidos (US), Europa (EU), Brasil (BR) e World Bank (WB). Observou-se, dentre as quatro legislações analisadas que as leis do BR, WB, US e EU estão ordenadas da maior para a de menor restrições, e se adotadas restringem aproximadamente 90%, 43%, 29% e 15% do território paulista. Se considerarmos a legislação brasileira, que é a mais restritiva em comparação com as outras restrições, o critério adotado mais restritivo é distância de aeroportos. Este tipo de análise espacial permitiu comparar quais legislações internacionais ou nacionais são mais ou menos rigorosas para a implantação de aterros sanitários, bem como qual a porcentagem do território do estado de São Paulo onde a construção dos aterros é proibida. Estas informações serão de extrema importância para a próxima etapa do trabalho, que será mapear as áreas restritivas para localizações de aterros sanitário em uma escala mais abrangente, tendo como área de estudo todo o território brasileiro.

Palavras-chave: resíduos sólidos urbanos, aterros sanitários, áreas restritivas

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LISTA DE ABREVIATURAS

BR – Brasil

EU – Europa

GIS - Geographical Information System

IBGE – Instituto Brasileiro de Geografia e Estatística

INPE - Instituto Nacional de Pesquisas Espaciais

RSU - Resíduos Sólidos Urbanos

SICINPE - Seminário de Iniciação Científica e Iniciação em Desenvolvimento Tecnológico e Inovação do INPE

SIG - Sistema de Informações Geográficas

WB – World Bank

SW – Solid Waste

US - Estados Unidos

WB – World Bank

SUMÁRIO

1. INTRODUÇÃO

Este relatório tem por objetivo apresentar o progresso do projeto de iniciação científica intitulado “Caracterização dos resíduos sólidos urbanos (RSU) dos municípios paulistas por setor censitário”, desenvolvido pela bolsista Anna Isabel Silva Loureiro, no período de agosto de 2018 a julho de 2019.

Neste período do projeto foi realizada uma pesquisa sobre as legislações dos Estados Unidos (US), Europa (EU), Brasil (BR) e World Bank (WB) que citam as restrições para a construção de aterro sanitário. Com os resultados dessa pesquisa, obteve-se nove restrições ao todo, são elas distância de centros urbanos, distância de recursos hídricos, distância de águas subterrâneas, distância de unidades de conservação, distância de aeroportos, distância de rodovias, declividade máxima, permeabilidade do solo, distância de falhas geológicas. Foram escolhidos como área de estudo o estado de São Paulo para especializar os dados restritivos encontrados nas legislações. Para isso realizou-se uma busca por bases de dados espaciais a fim de determinar a porcentagem do território do estado que é restrita e na qual se pode construir aterros sanitários.

Com os resultados obtidos está sendo elaborado um artigo científico escrito em inglês o qual encontra-se na íntegra nesse relatório no Capítulo 3. Este estudo será apresentado na forma de pôster no Seminário de Iniciação Científica e Iniciação em Desenvolvimento Tecnológico e Inovação do INPE (SICINPE 2019), com o intuito de incorporar os comentários e sugestões recebidas pelos avaliadores, pesquisadores e alunos que estarão presentes no simpósio na análise em questão.

Este relatório está organizado da seguinte forma. O Capítulo 2 contém os objetivos do projeto de iniciação científica. O Capítulo 3 apresenta o artigo produzido ao longo desse período da pesquisa e que documenta o trabalho realizado. Por último, o Capítulo 4 apresenta as considerações finais deste relatório seguido pelas referências utilizadas ao fim deste documento.

2. OBJETIVO

2.1 Objetivo geral

O objetivo principal desta pesquisa foi identificar as áreas impróprias para construção de aterros sanitários a nível estadual, utilizando os dados de legislações de quatro países diferentes, tendo como área de estudo o estado de São Paulo.

2.2 Objetivos específicos

1. Analisar nas bibliografias nacional e internacional as restrições de acordo com os aspectos ambientais, econômicos e sociais que podem impedir a construção de um aterro sanitário;

2. Espacializar os resultados das restrições a nível estadual;

3. ARTIGO

Spatial assessment of landfill sites restrictions using Brazilian, European, North American and World Bank law in São Paulo state, Brazil

Introduction

Defining areas for landfill sites is an important issue due to growing urban population and urban growth areas causing land availability decrease for landfill sites. Furthermore, we are living an increase in waste generation. The world generates between seven and ten billion tons of solid waste (household, commercial, industrial and civil construction waste) per year (UNEP ISWA 2015), from which two billion tons per year is Municipal Solid Waste (MSW), and this rate increases with population growth. To make things worse, two billion people do not have regular access to solid waste collection (FRACALANZA AND BESEN 2016). So, the situation is: growing urban population leads to growing municipal waste and at the same time leads to growing urban areas; the larger the urban areas the smaller the area availability for

landfill sites. The decreasing available area must also comply with social, economic and environmental increase restrictions.

Each country has its own laws and regulations for landfill sites to cope with their specific characteristics. This study analyses the legislation from United States (US), Brazil (BR), Europe (EU) and World Bank (WB). We applied these restrictions to Sao Paulo state and presented which areas are suitable or unsuitable for landfill sites, by using Geographic System Information (GIS). Practically all areas of municipal management can find in geoprocessing an important ally in dealing with spatial data collection, problem diagnosis, decision-making, planning, actions execution, and results measurement. In general, knowing where problems occur and being able to visualize them spatially facilitates their understanding greatly and shows us the possible solution if not the only one (CORDOVEZ 2002).

This paper aims to define the suitable and unsuitable landfill siting areas in Sao Paulo State. This overall objective is obtained by the following this method: (i) selection of regulations restrictions, based on legislations, norms, and guidelines; (ii) spatial data acquisition and integration into a GIS database, using a variety of sources of environmental, economic and social data at different scales; (iii) application of each restrictions in the study area, assigned considering the spatial data availability and the best spatial resolution; (iv) union and comparison of each scenario restriction.

This paper is organized as following. This Introduction section is followed by a literature review, then the study area is defined and the study method is described in further detail. Results are then presented and discussed followed by conclusions.

Review of Literature

Finding areas for landfills using GIS

One of the powerful methods for suitable landfill sites selection involves the use of GIS (AKSOY AND SAN 2017). Applying GIS for landfill siting process include selection of objective zone exclusion processes according to a set of provided screening criteria, zoning and buffering, handling and correlating large amounts of complex geographical data, and visualization of the results through mapping and graphical representation (CHENG AND THOMPSON 2016). (SOROUDI ET AL. 2018) analyzed the restrictions for the construction of a landfill in the southeast of Tehran province, in

Iran and concluded that 71% is unsuitable, (KHAN ET AL. 2018) analyzed the restrictions for the construction of a landfill in Alberta, Canada and the constraint screened out 45% of the total study area. (YILDIRIM AND GULER 2016) analyzed the restrictions for the construction of a landfill in Mersin province in SE Turkey and 84% of the study area was classified as unsuitable. (GBANIE ET AL. 2013a) analyzed the restrictions for the construction of a landfill in Bo, Southern Sierra Leone and 83% of the study area was considered unsuitable. (ESKANDARI ET AL. 2012) analyzed the restrictions for the construction of a landfill in Marvdasht city, Iran and 87% of the study area was classified as unsuitable.

Review of laws and regulations for landfill site selection

The laws and regulations for landfill site selection used in this study are shown in (**Table 01**).The US restrictions for landfill site selection were found in (US EPA, 1993), the BR restrictions were found in (ABNT, 1997 and BRASIL, 2012), the EU restrictions were taken from (MUTZ AND OELTZSCHNER 1994) and the WB restrictions were taken from (COINTREAU 2004).

Table 1 - Regulations and laws for landfill site selection

Area	Title	Year
United States (US)	Solid Waste Disposal Facility Criteria: Technical Manual (Sub-B: Location Criteria Chapter 2 EPA/530-R-93-017.)	1993
Brazil (BR)	ABNT – Associação Brasileira de Normas Técnicas	1997
	BRASIL. Lei N° 12725, 16 de outubro de 2012	2012
European Union (EU)	Guidelines for an Appropriate Management of Domestic Sanitary Landfill Sites	1994
World Bank (WB)	Sanitary Landfill Siting and design Guidance	1996 (Updated in 2004)

Methods and study area

Study area

São Paulo state, in Southeastern Brazil, is located between 19º and 25º South latitude and 53º West longitude. It borders the Minas Gerais state to the north, Rio de

Janeiro state to the northeast, the Atlantic Ocean to the east, Paraná state to the south, and Mato Grosso do Sul state to the west (**Figure 01**). São Paulo is the most populous Brazilian state, with approximately 45,5 million inhabitants in 2018 living in 645 municipalities with a total area of 248.219,481 km^2 (IBGE, 2018). São Paulo is also the biggest producer of municipal solid waste in Brazil, generating approximately 40.7 thousand tons per day, which are disposed in 612 official municipal solid waste disposal sites (CETESB 2018).

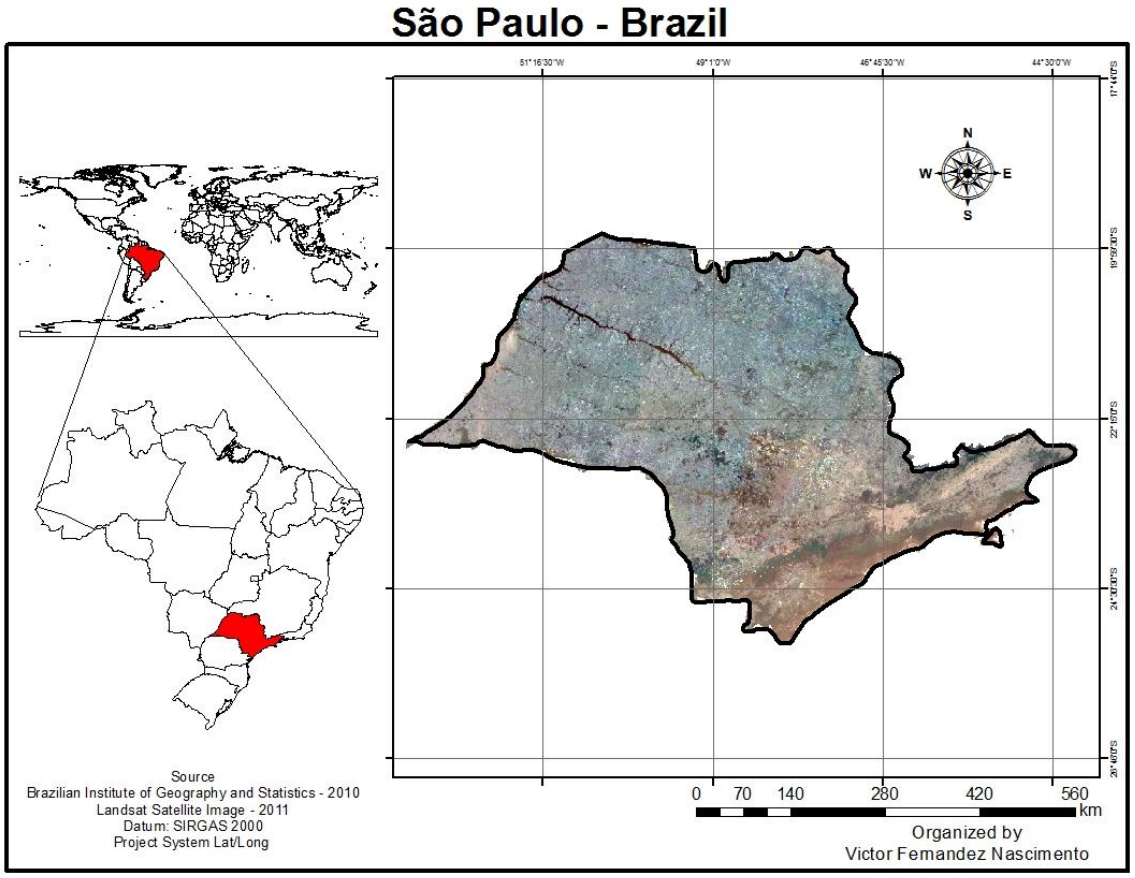

Figure 01 - Map of the state of São Paulo, Brazil

Methods

To spatial assess the landfill sites restrictions we considered four major steps: (1) selection of the most important regulations restrictions for landfill site selection in the world; (2) collection of spatial data and integration into a GIS database; (3) application of each restrictions in the study area; and (4) Union of the restrictions according with each regulation (**Figure 02**). Each step is described as follows:

Figure 02- Flowchart of the methodology

Step 1: Selection of regulations restrictions

In this step, the most worldwide important restrictions were selected based on legislations, norms, and guidelines for Europe, United States, Brazil, and worldwide (**Table 02**). To simplify our discussion, we will call them regulations henceforth. Overall, a total of nine restrictions were found.

Table 2 - Landfill siting restrictions

Parameter	**Area**			
	US	**BR**	**EU**	**WB**
Distance from residential areas (m)	-	500	200	250
Distance from water bodies (m)	-	200	-	300
Distance from groundwater line (m)	-	1,5	1	1500
Distance from protected forest (m)	-	-	Within areas	500
Distance from airport location (km)	9,5	20	5	3
Distance from road line (m)	-	-	>5000	>3000
Maximum slope (%)	-	>30	-	-
Soil permeability (cm/s)	-	<10-6	<10-7	<10-9
Distance from fault line (m)	60	-	-	500

Step 2: Spatial data acquisition and integration into a GIS database

Through GIS it is possible to assess, storing, retrieving and analyzing a considerable amount of disaggregated data from various sources and displaying the results on maps (GBANIE ET AL. 2013B; KALLEL ET AL. 2016). Several studies have used GIS to identify areas for new landfills for example (BABAN AND FLANNAGAM 1998) study identified suitable areas in UK by using GIS, and (HATZICHRISTOS AND GIAOUTZI 2006) used GIS to find suitable areas in Egypt

and both studies used a Boolean analysis. Which is a form of algebra in which all values are reduced to either 1 or 0, which means that the land is arranged as suitable or unsuitable for landfills sites (CHENG AND THOMPSON 2016).

The spatial database used in this study was created using a variety of data sources at different scales (**Table 03**). All data layers were stored, projected, manipulated, analyzed, and visualized using ArcGIS version 10.5. The data were georeferenced using the UTM System Datum SIRGAS 2000 (Zone 22 and 23 South).

166
167 **Table 3** Spatial data used to create the Boolean restriction for landfill sites in the state of São Paulo, Brazil
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Parameter	Sources	Scale or Resolution	Date
Distance residential areas	(Embrapa 2015)	1:250.000	2015
Distance from water bodies	(IBGE 2017)	1:250.000	2017
Distance from protected forest	(MMA 2014)	-	2014
Distance from airport location	(ANAC 2013)	-	2013
Distance from road line	(Open Streetmap 2019)	-	2019
Maximum slope	(IGC 2010)	1:50.000	2010
Distance from fault line	(CPRM 2006)	1:1.000.000	2006

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Step 3: Application of each restrictions in the study area

Each one of the parameters from all regulations used in this study for landfill site selection were grouped for the US, BR, EU, and WB regulations and intersected into a GIS presented in (**Figures 03, 04, 05 and 06**), respectively. The specific restrictions values used in this study were assigned considering the spatial data availability and the best spatial resolution for the state of São Paulo, for other Brazilian states or even another region in the world this can change according with the data and resolution available.

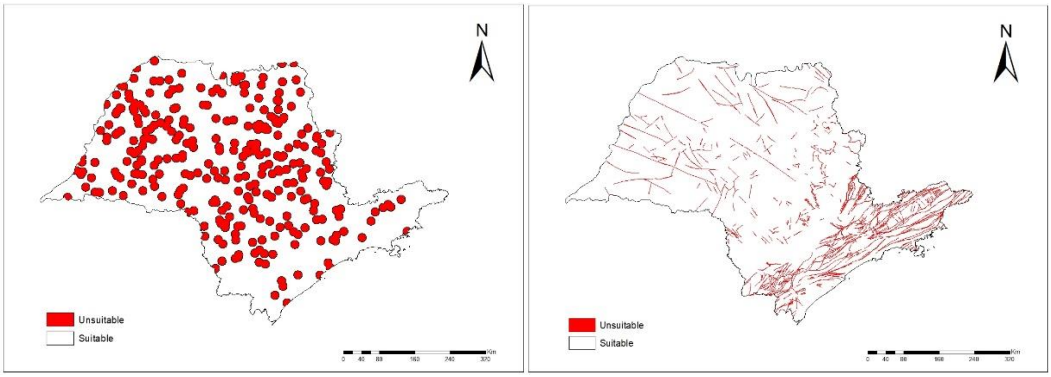

Figure 03 - Maps for each parameter using the United States regulation for landfill site selection. a) distance from airports and b) distance from faultlines

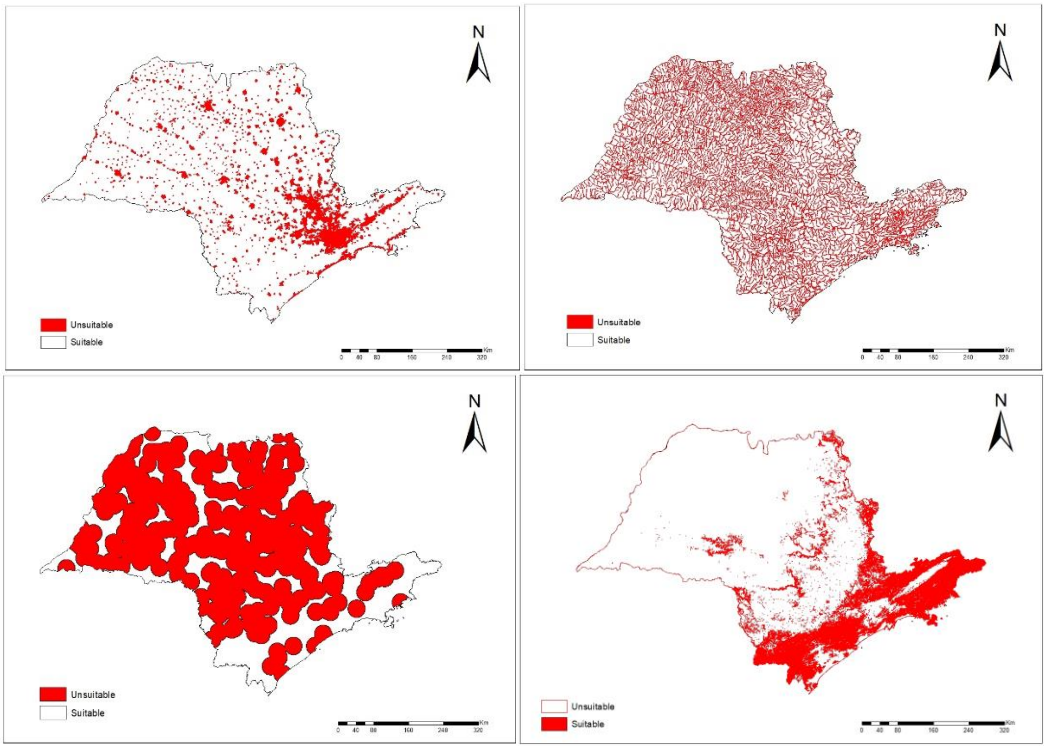

Figure 04 - Maps for each parameter using the Brazilian regulation for landfill site selection. a) distance from residential areas, b) distance from water bodies, c) distance from airports and d) slope

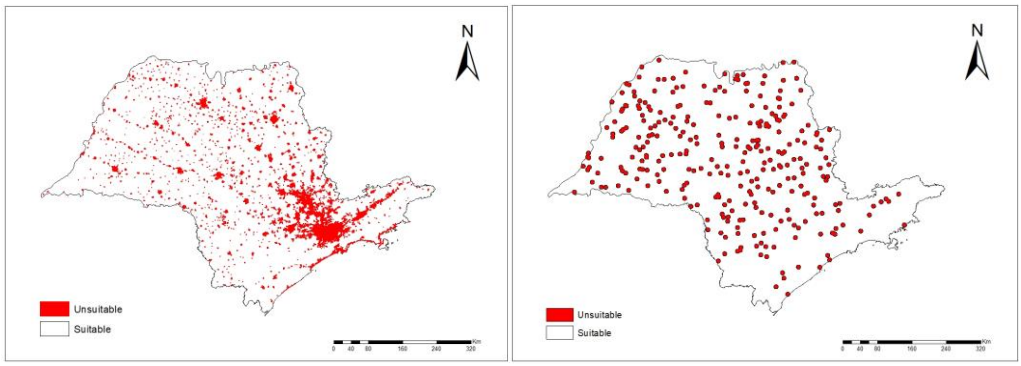

Figure 05 - Maps for each parameter using the European Union regulation for landfill site selection. a) distance from residential areas and b) distance from airports

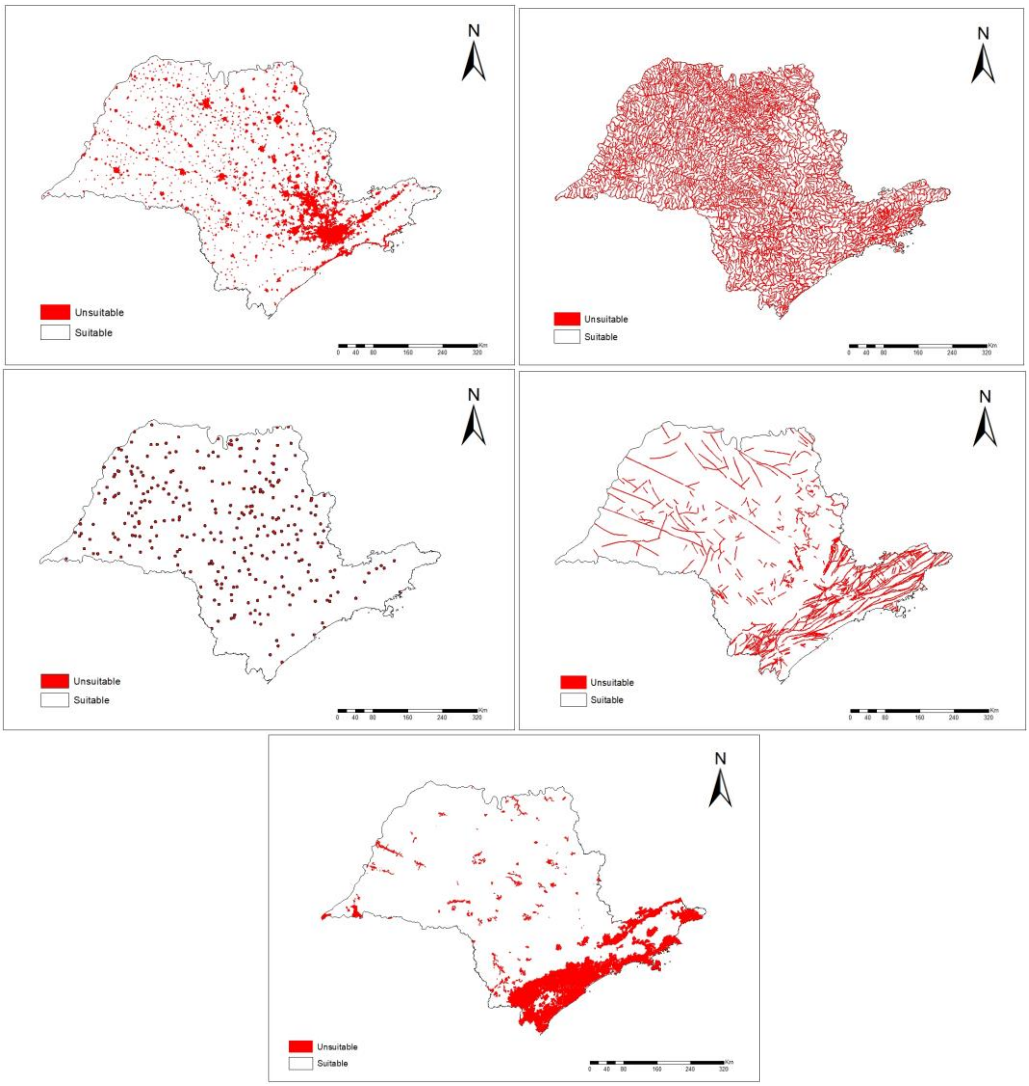

Figure 06 - Maps for each parameter using the World Bank regulation for landfill site selection. a) distance from residential areas, b) distance from water bodies, c) distance from airports, d) distance from faultlines and e) distance from protected areas

Step 4: Union and comparison of the restrictions

In order to conduct the spatial analysis for the landfills sites all EU, US, BR and WB restrictions regulation were merged.

Results and Discussion

Spatial analysis was performed by overlaying the restrictions in the state of São Paulo.

Restrictions Analysis

United States regulation scenario

The results of the United states regulation scenario using all parameters with spatial data available for São Paulo state using the Boolean restrictions for landfills sites is presented in (**Figure 07**). The area for each restriction is included in (**Table 04**) and can also be visualized in (**Figure 03**).

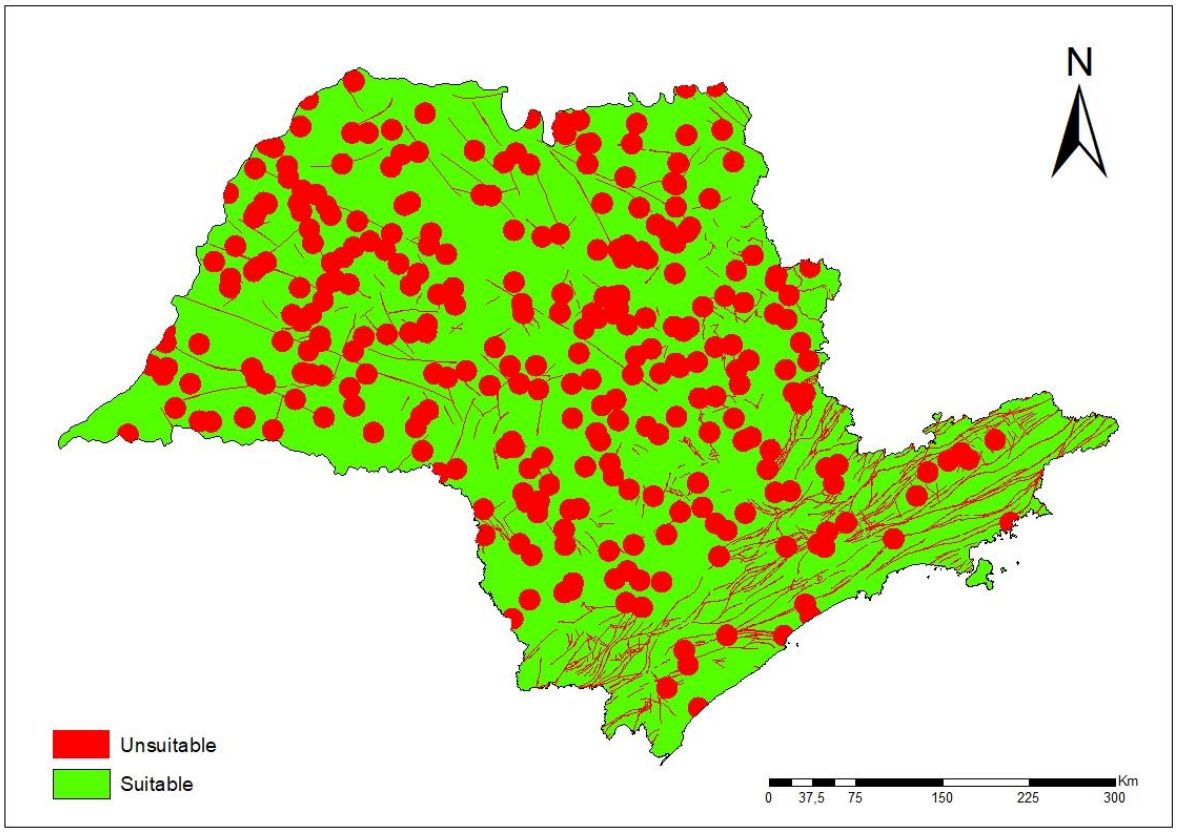

Figure 07 – United States landfills restrictions regulation applied in São Paulo State

Table 04 – United States regulation scenario restrictions areas

Restriction	Areas with restriction		Areas without restriction	
	km²	%	km²	%
Distance from airport	69559	28,02	178660,481	71,98
Distance from fault line	1735	0,70	246484,481	99,30
Total	71394	28,72	176825,481	71,28

The red spots in **Figure 07** refer to the unsuitable areas for landfill sites in São Paulo state according to United States regulations. These areas were obtained by using only two restrictions “distance from airport” and “distance from fault line”. It was noticed that the restriction “distance from fault line” has not presented itself as relevance once less than one per cent of unsuitable area was due to this restriction. On the other hand, the restriction “distance from airport” caused more than 28% of the total state area to become unsuitable. In other words, according to the United States regulations, more than 71% of the São Paulo state area is suitable for landfill siting.

Brazilian regulation scenario

The results of the addition of all Brazilian restrictions for landfills sites in the state of São Paulo is presented in (**Figure 08**). The area for each restriction is included in (**Table 05**) and can also be visualized in (**Figure 04**).

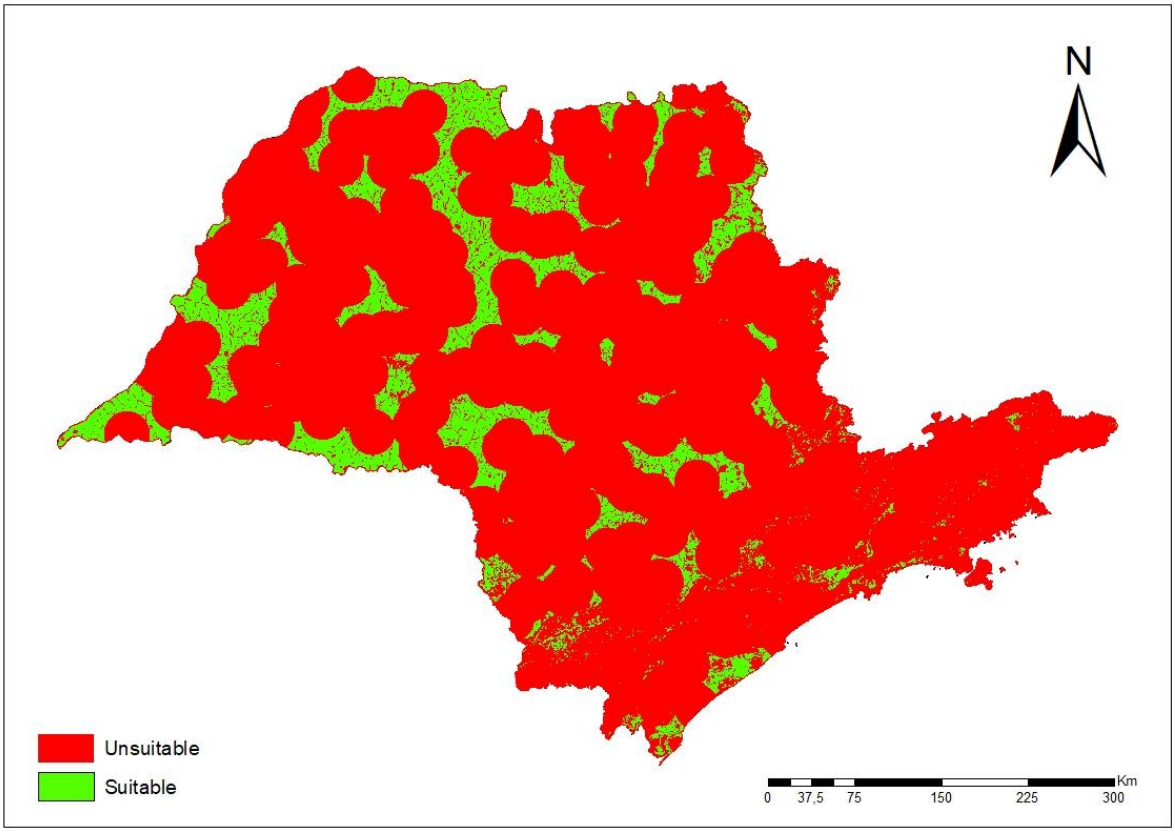

Figure 08 - Brazilian landfills restrictions regulation applied in São Paulo State

Table 5 - Brazilian regulation scenario restriction areas

Restriction	Areas with restriction		Areas without restriction	
	km²	%	km²	%
Distance residential areas	20630	8,31	227589,481	91,69
Distance from water bodies	22651	9,12	225568,481	90,88
Distance from airport location	180677	72,79	67542,481	27,21
Maximum slope				
Total	223958	90,22	24261,481	9,78

More than 90% of the São Paulo state map in **Figure 08** is painted in red meaning that, according to Brazilian regulations, the vast majority of the state is considered unsuitable for landfill siting due to the restrictions “distance from residential areas”, ‘distance from bodies”, “distance from airport location” and “maximum slope”. It was

noticed that the restriction “distance from airport location” contributed with more than 72% of the restricted area. The other two restrictions contributed with approximately 9% each. In other words, according to the Brazilian regulations, less than 10% of the São Paulo state area is suitable for landfill siting. It must be said that there is no analysis data for the restrictions “distance from ground water line” and “soil permeability”.

European regulation scenario

The results of the addition of all social restrictions for landfills sites in the state of São Paulo is presented in (**Figure 09**). The area for each restriction is included in (**Table 06**) and can also be visualized in (**Figure 05**).

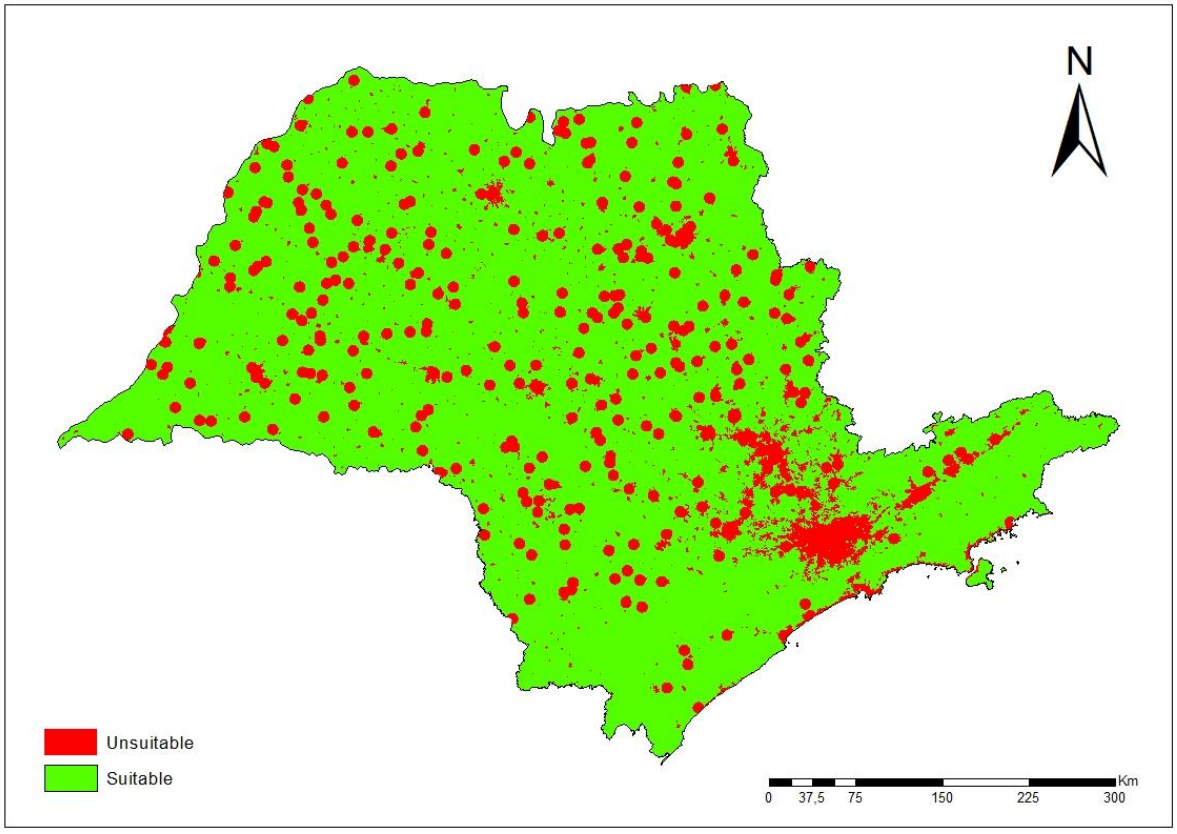

Figure 09 – European landfills restrictions regulation applied in São Paulo State

Table 6 – European regulation scenario restriction areas

Restriction	Areas with restriction		Areas without restriction	
	km²	%	km²	%
Distance residential areas	14960	6,02	233259,481	93,98
Distance from airport location	22321	9,00	225898,481	91,00
Total	37281	15,02	210938,481	84,98

The red spots in **Figure 09** refer to the unsuitable areas for landfill sites in São Paulo state according to European regulations. These areas were obtained by using only the two restrictions "distance from airport location" and "distance residential areas". It was observed that the restriction "distance from residential areas" contributed with 6% of unsuitable area and "distance from airport location" contributed with 9% over a total of 15% of the total state area being considered unsuitable for landfill siting according to European regulations. In other words, according to the European regulations, nearly 85% of the São Paulo state area is suitable for landfill siting. It must be said that there is no analysis data for the restrictions "distance from road line", "distance from ground water line" and "soil permeability"

World Bank regulation scenario

The union for all the environmental, economical and social restrictions for landfills sites in the state of São Paulo is presented in (**Figure 10**). The area for each restriction is included in (**Table 07**) and can also be visualized in (**Figure 06**).

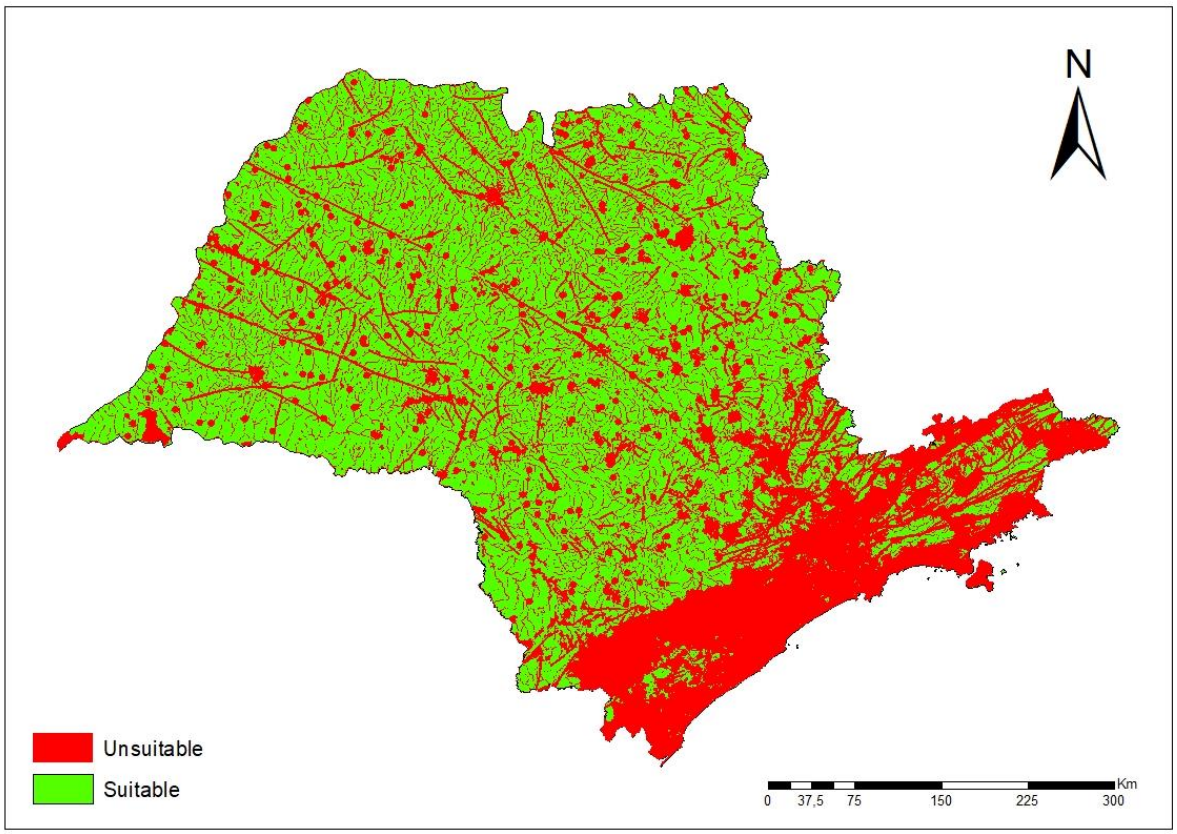

Figure 10 – World Bank landfills restrictions regulation applied in São Paulo State

Table 7 – World Bank regulation scenario restriction areas

Restriction	Areas with restriction		Areas without restriction	
	km²	%	km²	%
Distance residential areas	15907	6,41	232312,481	93,59
Distance from water bodies	33913	13,66	2143066,481	86,34
Distance from airport location	8247	3,32	239972,481	96,68
Distance from protected areas	35895	14,46	212324,481	85,54
Distance from road line	-	-	-	-
Distance from fault line	14480	5,83	233739,481	94,17
Total	108442	43,68	139777,481	56,32

The area painted in red in **Figure 10**, which comprises for approximately 44% of the total São Paulo state area, is considered unsuitable for landfill siting according to the restrictions “distance from residential areas”, “distance from water bodies”, “distance from airport location”, “distance from protected areas” and “distance from fault line” in the World Bank regulations. The most relevant restrictions were “distance from water bodies” and “distance from protected areas”, each contributing with 14% of the unsuitable areas. The other three restrictions accomplished for around 5% each of the unsuitable areas. In other words, according to the World Bank regulations, more than 56% of the São Paulo state total area is suitable to landfill siting. It must be said that there is no analysis data for the restrictions “distance from road line”, “distance from ground water line” and “soil permeability”.

Conclusions

This paper aims to define the suitable and unsuitable landfill siting areas in Sao Paulo State. This objective was fulfilled by analyzing restrictions from United States, Europe, World Bank and Brazilian regulations. Environmental, economical and social

restrictions were applied to Sao Paulo state spatial data by using GIS. The conclusions are that the Brazilian regulations are the most restrictive in terms of suitability of landfill sites. The Brazilian regulations considered that more than 90% of the São Paulo state area is unsuitable. In other words, if considered all restrictions, the unsuitable area would be even larger than 90% according those regulations. World Bank regulations considered that more than 29% of the Sao Paulo state area was unsuitable. United States regulations considered that approximately 28% was unsuitable. If considered all restrictions, the percentage of unsuitable areas would be larger for any of the regulations analyzed. Therefore, the study concludes that the less restrictive regulations, if applied to Sao Paulo state, are the European regulations and the most restrictive are the Brazilian regulations. Further studies must be done in order to acquire, treat and analyze data to cover all restrictions in all regulations. In any case, this study presents a method to perform such analysis and the method presented itself as an effective analysis tool. This type of spatial analysis can help decision makers promote the mitigation of environmental impacts and also assist in the process of identifying areas for new landfills.

4. CONCLUSÃO

Este relatório apresentou o progresso do projeto de iniciação científica intitulado "Caracterização dos resíduos sólidos urbanos (RSU) dos municípios paulistas por setor censitário" foram analisadas as legislações dos Estados Unidos (US), Europa (EU), Brasil (BR) e World Bank (WB) que citam as restrições para a construção de um aterro sanitário. Essas restrições foram aplicadas à área geográfica do estado de São Paulo utilizando SIG. Dependendo da regulamentação escolhida, diferentes porcentagens do território do estado foi considerada inapropriada e apropriada para construção de aterros sanitários. A regulamentação que se mostrou mais restritiva foi a brasileira em que mais de 90% da área de estudo foi considerada inapropriada. A menos restritiva mostrou-se ser a legislação europeia, com aproximadamente 15% da área de estudo considerada inapropriada.

Apesar de não haver dados espaciais disponíveis para todas as restrições encontradas, o que causaria um aumento na área considerada inapropriada para a construção de aterros sanitários, considera-se o método utilizado como efetivo para prover

uma ferramenta de planejamento urbano. A obtenção, análise e disponibilização de dados sobre as outras restrições devem ser objetivos constantes desse processo, bem como o aprimoramento da qualidade desses dados.

Este estudo é necessário para a próxima etapa do projeto que é a espacialização dos dados a nível nacional, tomando como área de estudo, todo o território brasileiro.

Com os resultados obtidos foi elaborado um artigo científico, que foi apresentado no Capítulo 3 e encontra-se em aperfeiçoamento antes de ser submetido. Além disso, este estudo será apresentado na forma de pôster no Seminário de Iniciação Científica e Iniciação em Desenvolvimento Tecnológico e Inovação do INPE (SICINPE) em agosto de 2019, com o intuito de incorporar os comentários e sugestões recebidas pelos avaliadores, pesquisadores e alunos que estarão presentes no simpósio na análise em questão, pretendemos melhorar o nosso artigo antes de submete-lo.

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