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 aumento da urbanização e populacional, a industrialização e o estilo da produção em massa e do descartável, são os grandes responsáveis pelo aumento 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) e Revisão da Literatura Acadêmica (ALR). Os resultados demonstraram que dentre os cinco cenários, que as leis da ALR, BR, WB, EU e US estão ordenadas da maior para a de menor restrições, e se adotadas restringem aproximadamente 63%, 56%, 37%, 31% e 12% do território paulista. Também foi possível analisar a quantidade de aterros que estão dentro de áreas impróprias, dos 471 aterros do estado de São Paulo, 419 estão dentro de áreas impróprias segundo a ALR, 379 estão em áreas improprias segundo a legislação brasileira, 110 segundo WB, 82 segundo EU e 28 segundo US. 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. O estudo será continuado através do desenvolvimento de uma análise espacial de alternativas locacionais para aterros sanitários utilizando uma abordagem baseada em modelagem fuzzy para tratamento de incertezas no reconhecimento de padrões.

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

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ALR – Revisão Acadêmica da Literatura

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 setembro de 2020 a agosto de 2021.

Neste período do projeto foi realizado uma revisão bibliográfica sistemática global com o intuito de analisar estatisticamente as principais restrições para a construção de um aterro sanitário. Dessa etapa foi publicado o artigo intitulado “*A worldwide meta-analysis review of restriction criteria for landfill siting using Geographic Information System*” em 2020 pela revista internacional *Waste Management & Research*. Contudo, ainda que este estudo tenha levantado o estado da arte em relação as diferentes restrições para a construção de aterros sanitários adotadas em diversos artigos científicos, não se considerou as principais legislações relacionadas a este tema como a Europeia (EU), Norte Americana (US), Brasileira (BR) e adotada pelo World Bank (WB). Portanto, este trabalho realiza uma análise espacial para todo território do estado de São Paulo dos diferentes cenários de restrições para aterros sanitários usando as principais legislações mundiais através de um sistema de informações geográficas, utilizou-se também o valor médio das restrições encontradas no artigo publicado e, esse quinto cenário de restrição foi intitulado Revisão da Literatura Acadêmica (ALR), além de utilizar o valor médio das restrições encontradas no artigo publicado. Oito critérios restritivos foram selecionadoss, são eles distância de centros urbanos, distância de recursos hídricos, distância de unidades de conservação, distância de aeroportos, distância de rodovias, declividade máxima, áreas alagadas e distância de falhas geológicas.

Posteriormente considerando cada um destes critérios restritivos e os seus respectivos valores, foram elaborados os cinco cenários restritivos citados anteriormente e a partir deles foram obtidas as porcentagens de área imprópria para aterros sanitários dentro do estado de São Paulo. Toda essa análise, desenvolvimento e resultados foi apresentado no artigo científico escrito em inglês, o qual encontra-se na íntegra nesse relatório no Capítulo 3.

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. 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 para o estado de São Paulo utilizando cinco cenários de restrições diferentes baseados em legislações mundiais e nacional e na literatura cientifica.

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. Analisar qual cenário é mais restritivo;
4. Analisar se os aterros sanitários existentes estão dentro de áreas permitidas de acordo com cada cenário elaborado.

3. ARTIGO

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

Introduction

Defining landfill sites is an important issue due to decreasing land availability caused by the population and urban growth (Rezaeisabzevar et al. 2020). Consequently, the amount of solid waste is also increasing (Osra and Kajjumba 2020).

The world population generates about seven to ten billion tons of solid waste (household, commercial, industrial, and civil construction waste) per year (UNEP ISWA 2015). From this amount, two billion tons per year corresponds to municipal waste and this rate increases in line with population growth (Fracalanza and Besen 2016).

In Brazil, the largest economy in Latin America, proper disposal in landfills received almost 60% of all municipal solid waste collected. The remainder, 40%, was dumped in inappropriate places by 3,001 cities, more than half of Brazilian municipalities. Currently, 29.5 million tons of MSW went to dumps or uncontrolled landfills, which do not have a set of systems and measures necessary to protect the people’s health and the environment against damage and degradation (ABRELPE 2019).

To define which areas in the state are suitable or unsuitable for landfill Geographic Information System (GIS) was used. Geoprocessing is essential for optimizing municipal performance due to data collection, problem diagnosis, decision making, planning, design execution of actions, and results measurement. In general, knowing where problems occur and visualizing them spatially facilitates their understanding greatly and shows us the possible solution, if not the only one (Cordovez 2002).

One of the powerful methods for suitable landfill sites selection involves GIS use (Aksoy and San 2017). Applying GIS for landfill siting process includes selecting 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).

Several studies using GIS were done in the past. For example, Soroudi et al. (2018) analyzed the restrictions for constructing a landfill in the southeast of Tehran province in Iran and concluded that 71% of the area is unsuitable. Khan et al. (2018) analyzed the restrictions for constructing a landfill in Alberta, Canada, and the constraint screened out 45% of the total study area. Yıldırım and Güler (2016) analyzed the restrictions for the construction of a landfill in Mersin province in Turkey, and 84% of the study area was classified as unsuitable. Gbanie et al. (2013a) analyzed the restrictions for constructing a landfill in Bo, Southern Sierra Leone, and 83% of the study area was considered unsuitable. Eskandari et al. (2012) analyzed the restrictions for constructing a landfill in Marvdasht, Iran, and 87% of the study area was classified as unsuitable.

So, as can be seen, usually in several studies, the size of the study area is considered restricted larger than 70% of the territory, which makes finding a suitable site for a new landfill a challenge.

This study aims to first spatial assess several worldwide landfill siting legislation in the São Paulo state in Brazil.

Afterward, analyze if the existing landfills are located in a suitable or unsuitable area accordingly to the United States (US), European (EU), Brazil (BR), and World Bank (WB) scenarios.

This paper is organized as follows. First, a review of laws and regulations for landfill site selection is presented, then the study area and the method are described in further detail. Afterward, the results are then presented and discussed, followed by the conclusions section.

Methods and study area

Study area

São Paulo is the most populous state in Brazil, with approximately 46,3 million inhabitants in 2020, living in 645 municipalities, with a total area of 248.219,481 km^2 (IBGE 2020). The state is also the biggest municipal solid waste producer in Brazil, generating approximately 40.8 thousand tons per day, disposed of in 612 official landfills (CETESB 2020)

The restrictions for landfill sites were applied for Sao Paulo state in Brazil because it is the most populous state in the country. With approximately 22% of the total of the country’s total inhabitants, being the highest concentration of economic activities of the country (Dalmo et al. 2019), it represents almost one-third of the Brazilian GDP (31.5%) (IBGE 2019).

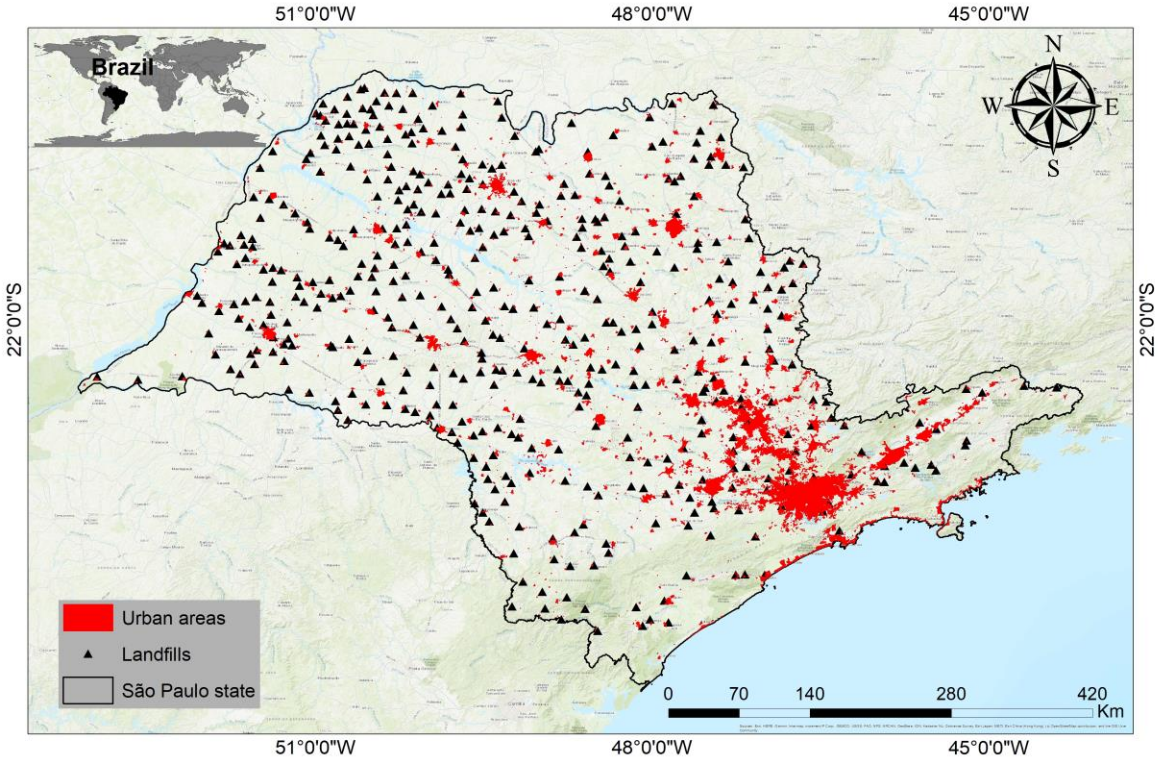

Figure 01 - Map of the state of São Paulo, Brazil

Methods

To spatial assess the landfill restriction scenarios in the São Paulo state, five significant steps were followed: (1) first step was to search and select the most essential worldwide laws and regulations dealing with landfill site selection to generate the scenarios restrictions; (2) second step was to search and collect spatial data for the study area to integrate them into a GIS database; (3) third step was to create each one of the restrictions selected in the scenarios; (4) fourth step was the union of the restrictions according to each scenario; (5) fifth step was the assessment of the currently landfills accordingly to each scenario.

Step 1: Selection of restrictions and scenarios

In this study, several worldwide laws and regulations for landfill site selection were found in the literature. In order to create and compare some of them, we elaborated on five scenarios which are explained in this section.

The first scenario was based on a North American country, specifically the United States (US). The restrictions in the US were taken from the "Solid Waste Disposal Facility Criteria: Technical Manual" published by the *Environmental Protection Agency* (EPA) (US EPA 1993). The US scenario was chosen because this country is one of the largest economies in the world, notably due to the high income of a large population, capital investments, high consumer consumption, and technological innovation (Directorate of Intelligence 2019).

The second scenario was based on a European country, specifically Germany. The "Guidelines for an Appropriate Management of Domestic Sanitary Landfill Sites" published by (Mutz and Oeltzschner 1994) was used to construct the EU restriction scenario. The German regulation was chosen because the country is internationally recognized for its environmental concern, and it is a pioneer in applying sustainable policies (Correio and Rezende 2015). Also, Germany is the biggest economy in Europe (Directorate of Intelligence 2019).

The third scenario was based on the Brazilian regulations and norms that take into consideration landfill restrictions, such as the Brazilian Association of Technical Standards (ABNT 1997), Brazilian Environment Council (CONAMA, 2010), and Air Force Command (COMAER, 2018). For example, ABNT presents three Brazilian restriction criteria in this study, the distance from residential areas, water bodies, and values related to the slope. At the same time, the distance from protected areas were established in CONAMA and the distances from airports in COMAER. The Brazilian scenario (BR) was created because our study area is located in the country.

In addition, to the three-country case scenarios mentioned before, two more were created based on global studies. The first one uses the "Sanitary Landfill Siting and design Guidance" published by the World Bank (WB) initially in 1996 and updated in 2004 (Cointreau, 2004). The WB scenario was chosen because of its importance as an international financial institution, one of the world's most significant funding sources for developing countries (World Bank 2014).

The last global restriction scenario was based on a scientific review article entitled "A worldwide meta-analysis review of restriction criteria for landfill siting using geographic information systems" (Nascimento et al. 2020). This article systematically reviewed and statistically analyzed the most environmental, economic, and social restrictions used in the academic literature from 1996 to 2018. Our study used the Median values found in that article to create the academic literature review scenario (ALR) to represent the state of the art of restrictions for landfill siting.

Afterward, the most significant restrictions were selected based on the United States (US), Europe (EU), Brazil (BR), World Bank (WB), and the Academic Literature Review (ALR) scenarios. A total of eight restrictions were organized in (**Table 02**) and described in further detail.

Table 01 - Landfill siting restrictions

Aspects	**Parameter**	**Scenarios**				
		US	**BR**	**EU**	**WB**	**ALR**
Environmental	Distance from water bodies (m)	-	<200	-	<300	<300
	Floodplains areas	Within	Within	Within	Within	-
	Slope (%)	-	<1 and >30	-	-	>20
	Distance from faultlines (m)	<60	-	-	<500	<160
	Distance from protected areas (m)	-	Within	Within	<500	<500
Economic	Distance from roads (m)	-	-	>5000	>10000	<275
	Distance from airports (km)	<3	<10	<5	<3	<3
Social	Distance from residential areas (m)	-	<500	<200	<250	<1000

Environmental restrictions

Distance from water bodies and Floodplains

The primary purpose of these criteria is to avoid surface water pollution by solid waste. By creating leachate and gaseous pollutants, landfills pose a risk to lakes, wetlands, ponds, and rivers, necessitating creating a buffer zone away from surface waterways (Rezaeisabzevar et al. 2020).

Only BR, WB, and ALR presented the restriction "distance from water bodies," and WB and ALR share the most restricted value (300m). The only criterion that all four scenarios have, except the ALR, is "floodplains areas," and it presents equal values is considering within the areas unsuitable for landfill siting.

Slope

The slope affects drainage, soil water content, erosion potential, and overland and subsurface flow velocity (Donevska et al. 2012; Gorsevski et al. 2012; Nascimento et al. 2017). A steep slope increases drainage from the landfill to the downstream, which raises downstream water pollution hazards, intensifies engineering work, and increases the risk of landslides (Djokanović et al. 2016; Nascimento et al. 2017). A flat location, on the contrary, would have an impact on runoff drainage.

BR and ALR scenarios presented "slope" as a landfill siting restriction. For BR, areas with a slope of less than 1% and more than 30% are considered unsuitable, while for ALR, areas greater than 20% are considered inappropriate.

Distance from faultlines

Fault lines and fracture zones increase rock permeability, which increases the danger of groundwater pollution (Saatsaz et al., 2018). The primary purpose of this criterion is to prevent landfill damage and pollution leakage that earthquakes could cause and earth movement. Hence avoiding faults is also vital for landfill siting (Rezaeisabzevar et al. 2020). This criterion was found in the US, ALR, and WB scenarios but with different values. The most restricted is the WB (500m).

Distance from protected areas

The purpose of this criterion is to ensure that the landfill site is far from sensitive areas to keep free threatened or endangered species from landfill pollution and any negative human activities (Nascimento et al. 2020; Mahmood et al. 2021).

The criterion "distance from protected areas" was found in BR, GE, WB, and ALR scenarios, in which BR and GE have the same value (within areas), also WB and ALR have the same and the most restricted value (500m).

In addition to these environmental restrictions mentioned before in (**Table 02),** other ones were not considered because there is no spatial data available in the studies area. For example, our study did not use the wetlands, groundwater depth, seismic impacts zones, and the unstable regions restrictions mentioned in the US regulation. However, we used floodplains areas that represent some wetlands areas. In the WB scenario, areas within the landfill boundaries that are part of the 10-year groundwater recharge area for current or pending water supply development, wetlands, open spaces of high winds, seismic impact zones are also considered unsuitable for a landfill site. In the BR scenario, areas with less than 1,5 meters from groundwater, a soil permeability bigger than 10^{-6} are also location restriction criteria and were not used. In contrast, São Paulo and other Brazilian states don't present high seismic zones, making an area unstable to construct a landfill.

Economic restrictions

Distance from roads

The primary goal of this criterion is to find a balance between logistics needs and regulatory distance from transportation infrastructures when establishing a landfill, which should be located at a reasonable distance from existing roads to save money on road building (Nascimento et al. 2020).

In the WB scenario, the distance from roads must be less than 10 km for large landfills serving metropolitan areas and less than 3 km for small landfills serving secondary cities. We chose the most restrictive values because using the highest value also covers areas with smaller landfills.

"Distance from roads" restriction was found in EU, WB, and ALR scenarios. The big difference between the ALR scenario and the others was the "distance from roads" restriction which restricted any area less than 275 m from the roads. The other two scenarios limited spaces with more than 5 km (EU) and 10 km (WB).

Distance from airports

The landfill site should be located far from any airport/airbase to prevent birds from disrupting aircraft during landing and take-off (Mallick 2021). Furthermore, airplane traffic may cause waste dust to rise (Ahmad et al., 2013). However, the primary goal of this criterion is to guarantee that the landfill site is located far enough away from the airport to prevent aircraft crashes.

The US and WB scenarios mention that a landfill must not be constructed within 3 km of a turbojet airport and 1.6 km of a piston-type airport. It used the 3 km restriction because using the most restricted value also covers the area with the less restricted and was the same restriction value of the ALR scenario.

Meanwhile, the EU scenario says that areas nearer than 2-5 km to airports must be excluded, while the BR scenario was the most restrictive from all regulations and used 10 km buffer because the legislation (COMAER 2018) says that existing landfills or one to be implemented will have a favorable technical opinion if there is a distance greater than 10 km from airports.

The criterion "distance from airports" was found in all five scenarios. The US, WB, and ALR scenarios have the same and the less restricted value (3km). BR presents the most restricted value (10km).

Social restrictions

Distance from residential areas

This criterion aims to determine the permissible distance for a landfill, taking into account waste logistics and the welfare of inhabitants. The chosen place should be close enough to the city for convenient disposal and low transportation costs, yet far enough away to avoid causing health or environmental issues (Aksoy and San 2017). The chosen land should not be too far away from the waste generation source. This will increase transportation costs and clean-up times, which are important in disaster recovery (Cheng and Thompson 2016). A landfill is considered to have a significant impact on those living near a site due to excessive noise, traffic, odor, litter, and the presence of scavengers (Ghobadi et al., 2013).

Furthermore, in the US regulation, some social restrictions related to historical, religious, or other important cultural sites or heritages are also areas considered unsuitable for landfill sites but were not considered because there is no spatial data available in the studies area. In the WB scenario, siting within 1 km of socio-politically sensitive sites where public acceptance might be unlikely are also areas considered unsuitable for a landfill site.

BR, EU, and US scenarios present the restriction “distance from residential areas.” Still, with different values, BR has the most restricted value (500m), and EU has the less restricted value (200m).

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

Using GIS, it is possible to access, store, retrieve, and analyze a considerable amount of disaggregated data from various sources and display 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 Flannagan (1998) identified suitable regions in the UK using GIS and Hatzichristos, and Giaoutzi (2006) used GIS to find appropriate areas in Egypt. Both studies also used a Boolean analysis, a form of algebra in which all values are reduced to either 1 or 0. This means that the land is arranged as suitable or unsuitable for landfills sites (Cheng and Thompson 2016). Our study used Boolean analysis, considering suitable landfill sites, all areas without restriction, and unsuitable areas within any restriction criteria.

The spatial database used in this study was created using several 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 World Azimuthal Equidistant.

Table 02- Spatial data used to create the restriction for landfill sites in the state of São Paulo, Brazil

Parameter	Sources	Scale or Resolution	Date
Distance from residential areas	(Embrapa 2015)	1:250.000	2015
Distance from water bodies	(IBGE 2017)	1:250.000	2017
Distance from protected areas	(MMA 2016)	1:250.000	2016
Distance from airports	(ANAC 2013)	-	2013
Distance from roads	(Open Streetmap 2019)	-	2019
Slope	(IGC 2010)	1:50.000	2010
Distance from faultlines	(CPRM 2006)	1:1.000.000	2006
Floodplains areas	(SÃO PAULO 2014)	1:50.000 and 1:75.000	2014

Step 3: Application of each restriction in the study area

Each of the restrictions was created for all the five scenarios US, EU, BR, WB, and ALR presented in (**Figures 02, 03, 04, 05, and 06**), respectively. The buffer tool was used for all restrictions except for the slope. It is essential to highlight that the specific restrictions values used in this study were assigned considering the best spatial data for the São Paulo state. However, this can change according to the available data and resolution for other study regions in Brazil or the world.

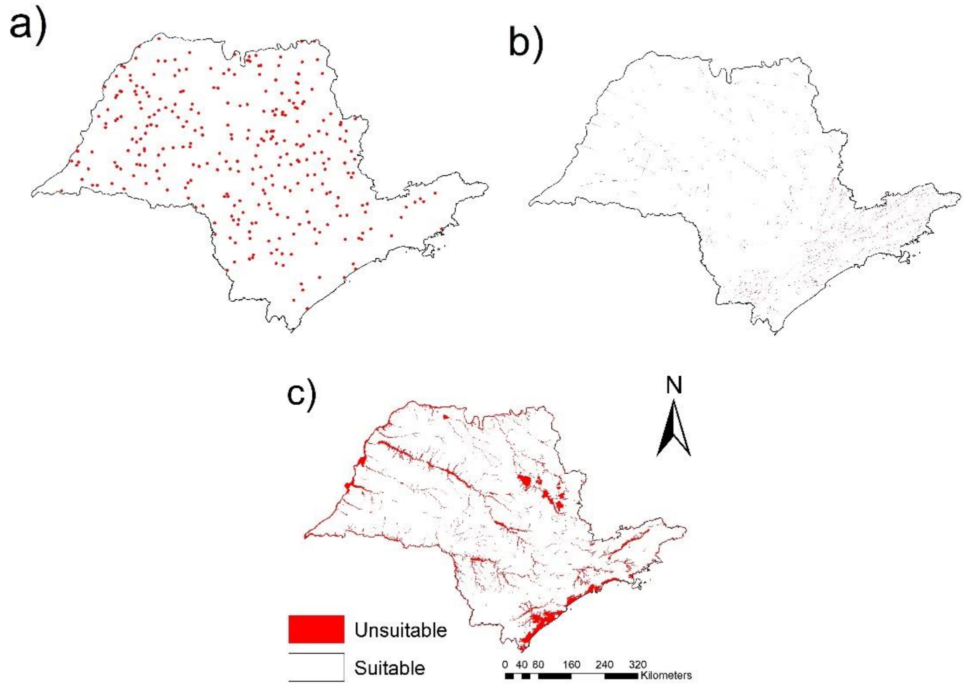

Figure 02 - Maps for each restriction considering the United States scenario for landfill site selection. a) distance from airports, b) distance from faultlines, and c) floodplains areas

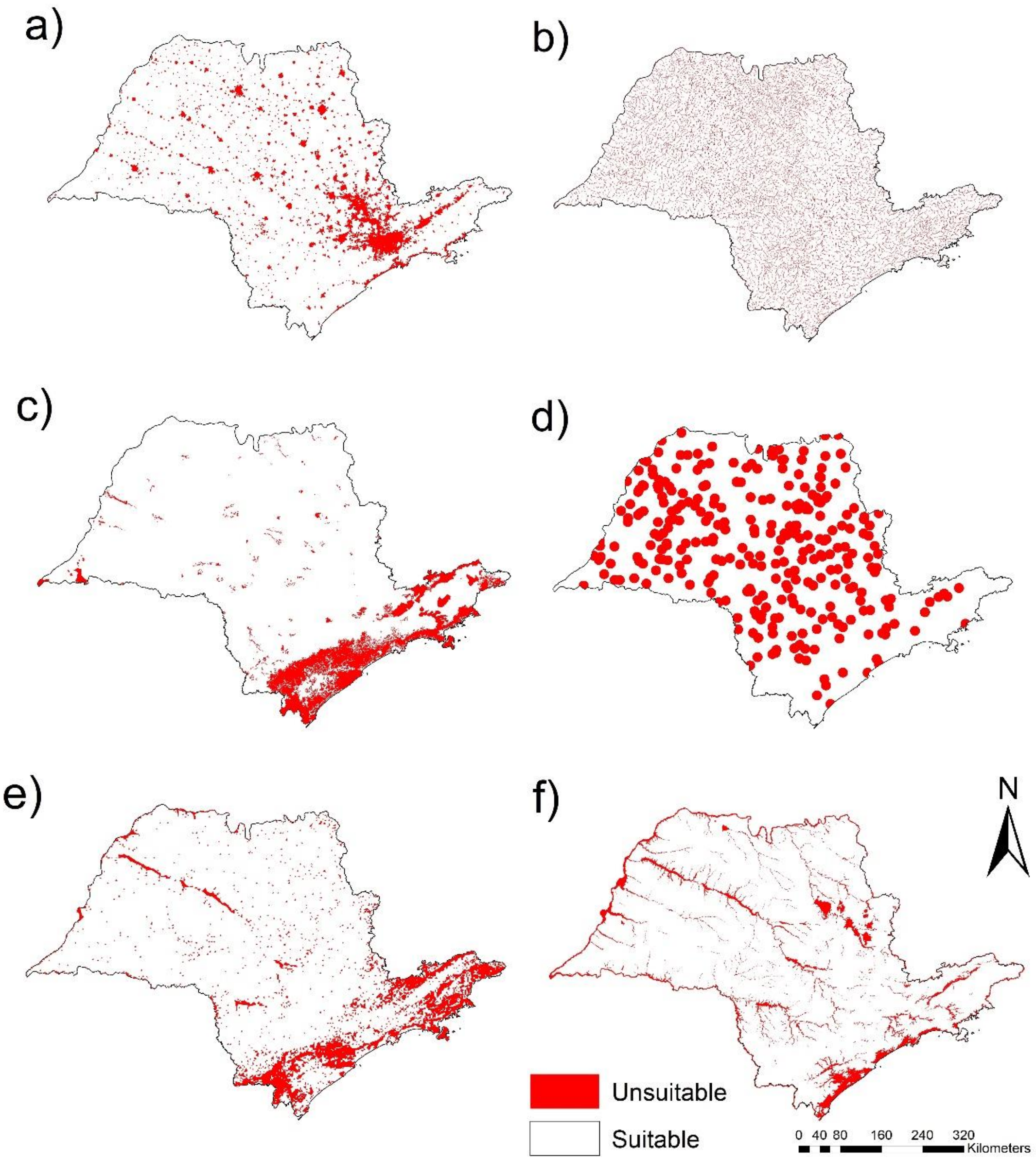

Figure 03 - Maps for each restriction considering the Brazilian scenario for landfill site selection. a) distance from residential areas, b) distance from water bodies, c) distance from protected areas, d) distance from airports, e) slope, and f) floodplains areas

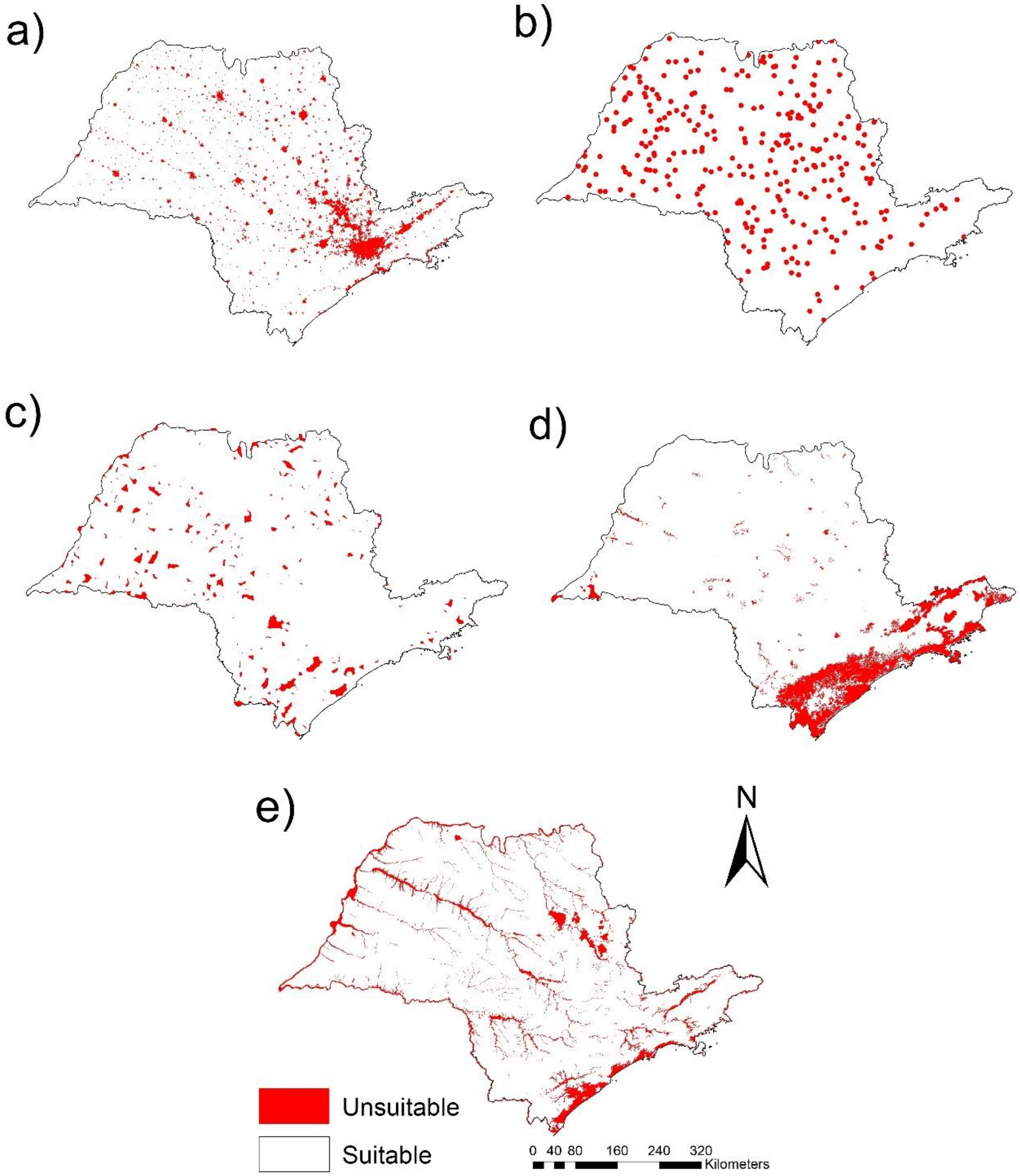

Figure 04 - Maps for each restriction considering the European scenario for landfill site selection. a) distance from residential areas, b) distance from airports, c) distance from roads, d) distance from protected areas, and e) floodplains areas

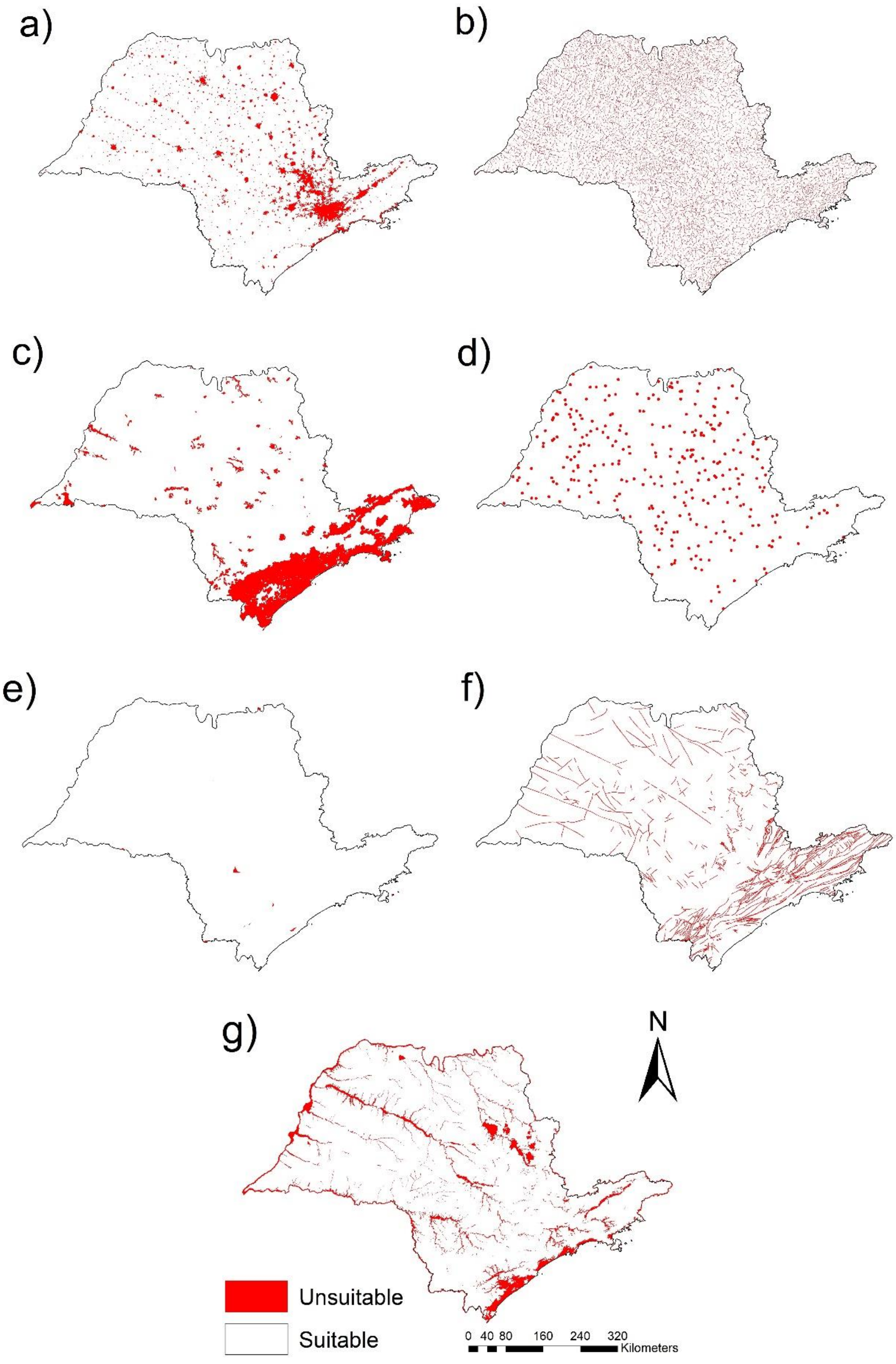

Figure 05- Maps for each restriction considering the World Bank scenario for landfill site selection. a) distance from residential areas, b) distance from water bodies, c) distance from

protected areas, d) distance from airports, e) distance from roads, f) distance from faultlines, and g) floodplains areas

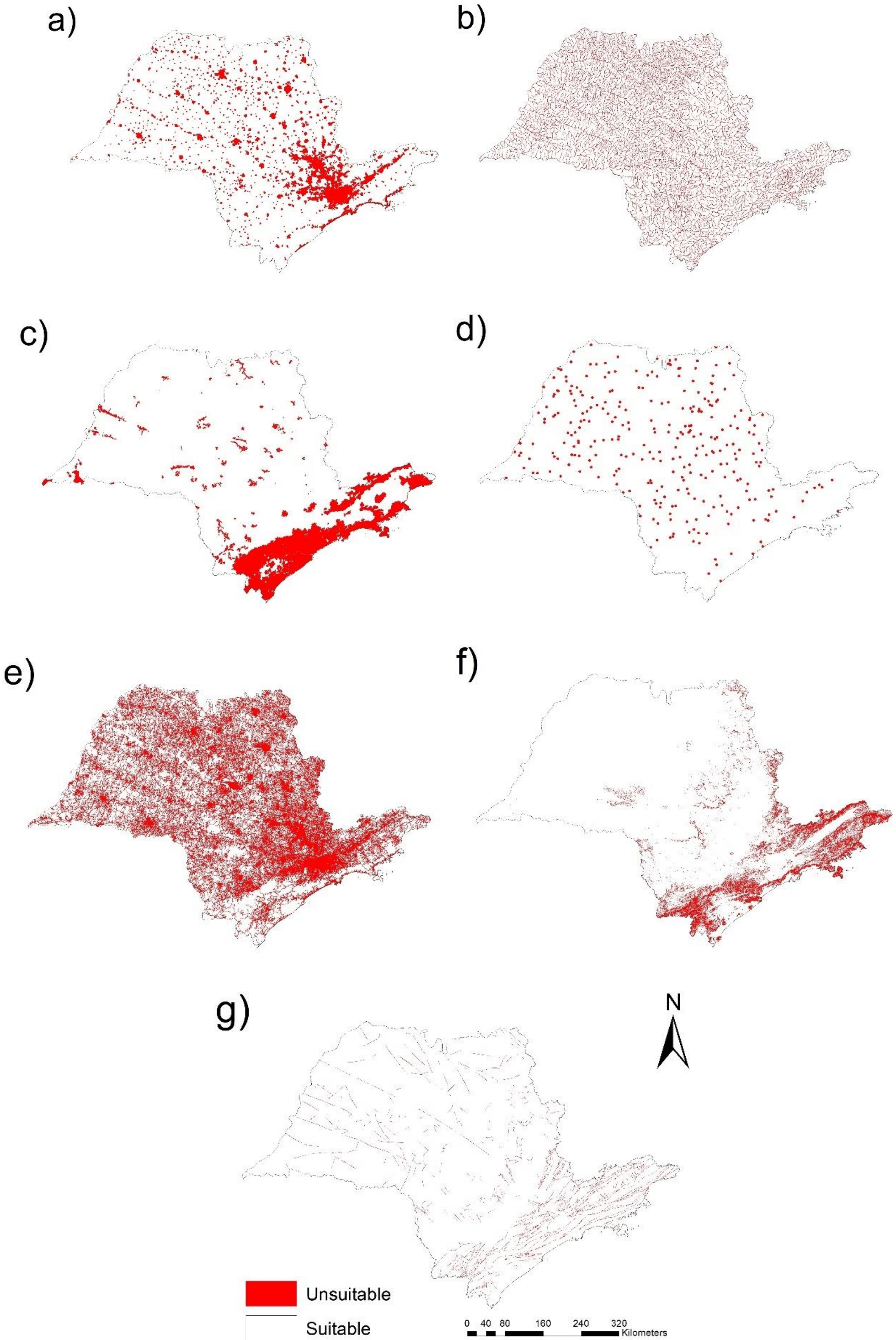

Figure 06- Maps for each restriction considering the academic literature review scenario (ALR) for landfill site selection. a) distance from residential areas, b) distance from water

bodies, c) distance from protected areas, d) distance from airports, e) distance from roads, f) slope, and g) distance from faultlines.

Step 4: Union and comparison of the restrictions

To compare the areas restricted for a landfill in the São Paulo state, each one of the restrictions was merged, considering the values for all scenarios (**Table 02**). To achieve this step, it was used the Merge and the Dissolve tool. The dissolve tool was used so that areas covered by two or more restrictions were not counted more than once. After that, the assessment was conducted for US, EU, WB, BR, and ALR and presented in the results section.

Step 5: Analysis of the existing landfills

Finally, using the merged scenarios elaborate in the step before, we did a spatial analysis to check if the landfills in the São Paulo State landfills used between 2011 and 2019 are located in a suitable or unsuitable area according to the five restrictions scenarios. This procedure was done by overlaying the restrictions scenarios with the existing landfills areas. It is worthwhile to mention that when a landfill area is inside of any scenario restriction, the entire landfill was classified as restricted. This methodology was selected for a conservative analysis.

Results and Discussion

Restrictions Analysis

This section presents the results of each of the five restriction scenarios US, EU, WB, BR, and ALR used in this study for the São Paulo state (**Figure 07**). In addition, the total area of state restricted as well each one of the restriction areas is presented in (**Table 04**).

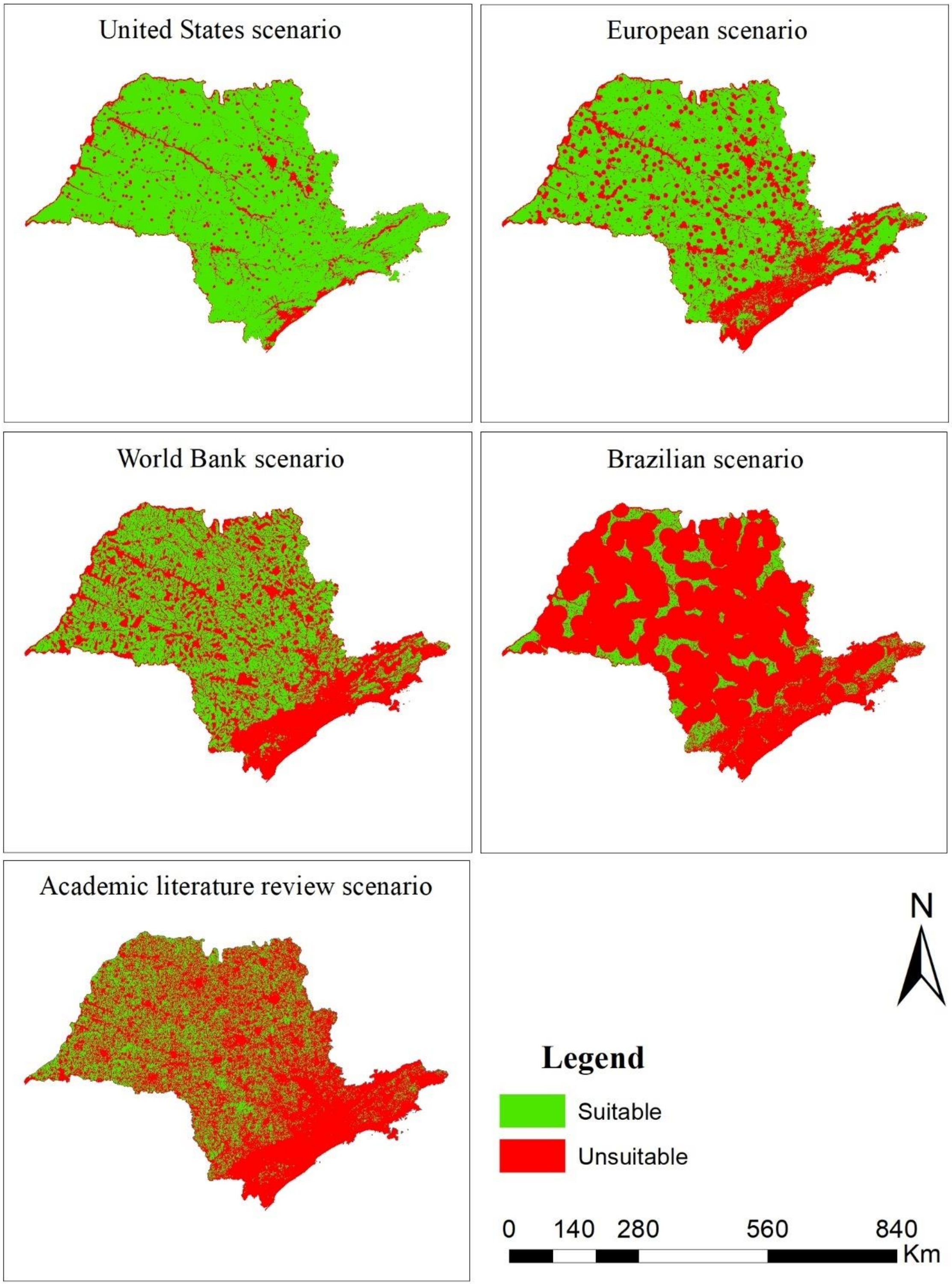

Figure 07 – Landfill restriction scenario applied to São Paulo State

Table 03 – Landfill restriction areas using US, EU, WB, BR, and ALR scenario

US	**Areas with restriction**		**Areas without restriction**	
Restriction	**km²**	**%**	**km²**	**%**
Floodplains areas	20272,7	8,2	227946,7	91,8
Distance from faultlines	1734,6	0,7	246484,8	99,3
Distance from airports	8246,8	3,3	239972,6	96,7
Total	29524,4	11,9	218695	88,1
EU	**Areas with restriction**		**Areas without restriction**	
Restriction	**km²**	**%**	**km²**	**%**
Floodplains areas	20272,74	8,17	227946,74	91,83
Distance from protected areas	25127,505	10,12	223091,98	89,88
Distance from roads	8398,266	3,38	239821,22	96,62
Distance from airports	22059,68	8,89	226159,8	91,11
Distance from residential areas	14959,83	6,02	233259,65	93,98
Total	77077,4	31,05	171142,08	68,95
WB	**Areas with restriction**		**Areas without restriction**	
Restriction	**km²**	**%**	**km²**	**%**
Floodplains areas	20272,74	8,17	227946,74	91,83
Distance from water bodies	22651,4	9,13	225568,08	90,87
Distance from faultlines	14480,3	5,83	233739,18	94,17
Distance from protected areas	35895	14,46	212324,48	85,54
Distance from roads	240,016	0,1	247979,47	99,9
Distance from airports	8246,85	3,32	239972,63	96,68
Distance from residential areas	15906,5	6,41	232312,98	93,59
Total	92177,68	37,14	156041,8	62,86
BR	**Areas with restriction**		**Areas without restriction**	
Restriction	**km²**	**%**	**km²**	**%**
Distance from water bodies	22651,4	9,13	225568,08	90,87
Floodplains areas	20272,74	8,17	227946,74	91,83
Slope	26767,4	10,78	221452,08	89,22
Distance from protected areas	25127,505	10,12	223091,98	89,88
Distance from airports	75659,87	30,48	172559,61	69,52
Distance from residential	20629,61	8,31	227589,87	91,69

areas				
Total	138807	55,92	109412,48	44,08
ALR	**Areas with restriction**		**Areas without restriction**	
Restriction	**km^2**	**%**	**km^2**	**%**
Distance from water bodies	33912,7	13,66	214306,78	86,34
Slope	21430,19	8,63	226789,29	91,37
Distance from faultlines	4637,32	1,87	243582,16	98,13
Distance from protected areas	35895	14,46	212324,48	85,54
Distance from roads	104410	42,06	143809,48	57,94
Distance from airports	8248,08	3,32	239971,4	96,68
Distance from residential areas	30295,4	12,2	217924,08	87,8
Total	155735	62,74	92484,481	37,26

United States restriction scenario (US)

The United States restriction scenario for landfill sites in São Paulo state is presented in (**Figure 07)**. The area for each restriction inside this scenario is shown in (**Table 04**) and visualized in (**Figure 02)**

According to the United States scenario, almost 12% of the São Paulo state is considered restricted for landfill sites, areas presented in red in (**Figure 07**). It's worth mentioning that although this scenario only presented two environmental restrictions and one economic restriction, some societal constraints relating to historical, religious, or other important cultural places or heritages are also considered unsuitable for landfill sites in the US legislation. Still, they were not taken into account because no spatial data was provided in the study area. It was observed that the distance from faultlines represents less than one percent of the total state area. At the same time, the distance from airports and floodplain areas together covers more than 11% of the São Paulo state territory. This scenario presented two environmental restriction and one economic restriction

It is essential to mention that the total sum of the percentages for each restriction's areas is more than the whole area considered restricted in the state. This happens because the same site can be part of different restrictions simultaneously but only once for the final restriction scenario.

European restriction scenario (EU)

The European restriction scenario for landfills sites in São Paulo state is presented in (**Figure 07)**. The area for each restriction inside this scenario is shown in (**Table 04)** and visualized in (**Figure 05)**.

According to the European scenario, more than 31% of the São Paulo state is considered restricted for landfill sites, areas presented in red in (**Figure 07**). This scenario was obtained using two environmental restrictions, two economic restrictions and one social restriction, from the most to the least restrictive we found: distances from protected areas, airports, floodplains areas, distances from residential areas and, roads, with approximately 10%, 9%, 8%, 6%, and 3% of the São Paulo state territory, respectively.

World Bank restriction scenario (WB)

The World Bank restriction scenario for landfill sites in São Paulo state is presented in (**Figure 07)**. The area for each restriction inside this scenario is shown in (**Table 04)** and visualized in (**Figure 06)**.

The World Bank restriction scenario for landfill siting comprises more than 37% of the São Paulo state territory. This scenario was obtained by using four environmental restrictions, two economic restrictions and one social restriction. The most relevant restrictions were distances from protected areas, water bodies, residential and floodplains areas. The other three restrictions corresponded to less than 6% of unsuitable regions each.

Brazilian restriction scenario (BR)

The Brazilian restriction scenario for landfill sites in São Paulo state is presented in **Figure 07**. The area for each restriction inside this scenario is shown in **Table 04** and visualized in **Figure 03**.

According to the Brazilian restriction scenario, almost 56% of the São Paulo state territory is considered unsuitable for landfill siting due to the six spatial restrictions. Four were environmental restrictions, one was economical, and the other one was social. Three of them are responsible for more than 10% of the area restricted. However, the distance from airports alone is responsible for more than 30%.

Academic literature review scenario (ALR)

The scientific article literature review scenario for landfill restriction sites in São Paulo state is presented in (**Figure 07)**. The area for each restriction inside this scenario is shown in (**Table 04)** and visualized in (**Figure 06)**.

This restriction scenario was obtained by using four environmental, two economic, and one social restriction. It is the only scenario that didn’t use the floodplain restriction. Almost 63% of the São Paulo state territory is considered unsuitable for landfill siting. The distance from roads alone was responsible for more than 42%.

Currently Landfills analysis

Between 2011 and 2019, the state of São Paulo had 471 landfills, and the sum of their areas totaled 45,82101km². **Table 05** presents how many landfills are in restricted areas according to each scenario.

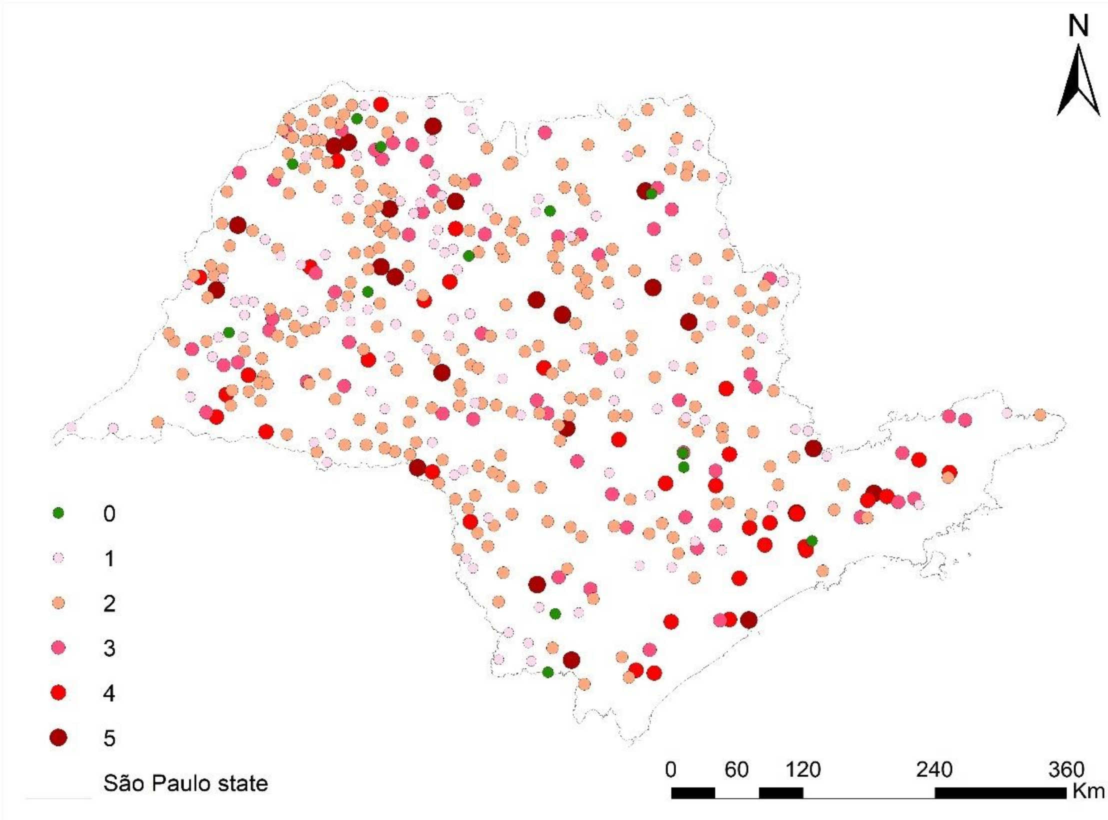

Figure 08 - Number of times that the landfill appeared in the restriction scenarios

As shown in figure 8, there were 13 landfills in appropriate areas, 105 landfills in one restriction scenario, 234 in two restriction scenarios, 60 in three restriction scenarios, 35 in four restriction scenarios, and 24 in all the five scenarios.

Table 04 – Number and size of landfills within and without restricted areas

Landfill Restriction Scenarios	Landfills within a restricted area		Landfills in appropriate areas	
	Number	**Area (km²)**	Number	**Area (km²)**
US	28	8,837796	443	36,983214
EU	82	19,5759	389	26,24511
WB	110	25,3431	361	20,47791
BR	379	42,7861	92	3,03491
ALR	419	44,59288	52	1,22813

The ALR had the highest number of landfills in inappropriate areas, followed by BR, WB, EU, and finally, the US scenario.

Conclusions

This study presents the importance of spatial data analysis for the restriction scenarios for landfill siting. This type of spatial analysis can help decision-makers promote the mitigation of environmental impacts and assist in identifying areas for new landfills.

In this article, we presented the suitable and unsuitable landfill siting areas in Sao Paulo State. The novelty of our study is first to do this spatial analysis for a significant region, such as the São Paulo state, and second, to consider different scenarios accordingly different regulations in the same study to compare them. Our findings showed that the United States scenario is less restrictive when compared to the other ones. In increasing order, we have the United States scenario, which presented a restriction with approximately 12% from São Paulo territory, followed by the European (31%), Word Bank (37%), Brazilian (56%) scenarios, and the Academic Literature review (63%).

Also, only 13 of the 471 landfills were in appropriate areas according to all five scenarios.

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", neste período 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. Além dessas, também foi feito um cenário utilizando os valores restritivos encontrados na Revisão de Literatura Acadêmica (ALR). 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. O cenário que se mostrou mais restritivo foi a Revisão de Literatura Acadêmica em que aproximadamente 63%, esse valor mais alto deu-se pela restrição distância de rodovias, em que diferente dos demais cenários, a restrição proibia rodovias a uma distância menor de 275 metros de aterros sanitários. A menos restritiva mostrou-se ser a legislação americana, com aproximadamente 12% da área de estudo considerada inapropriada.

Considera-se o método utilizado efetivo para prover uma ferramenta de planejamento urbano. A obtenção, análise e disponibilização de dados espaciais das restrições devem ser objetivos constantes desse processo, bem como o aprimoramento da qualidade dos dados.

Com os resultados obtidos foi elaborado o artigo científico, que foi apresentado no Capítulo 3 e encontra-se em aperfeiçoamento antes de ser submetido. A partir da finalização desse artigo o estudo será continuado através do desenvolvimento de uma análise espacial de alternativas locacionais para aterros sanitários utilizando uma abordagem baseada em modelagem fuzzy para tratamento de incertezas no reconhecimento de padrões.

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