INDEX OF CONTAMINATED AREAS IN SÃO PAULO CITY, BRAZIL

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ABSTRACT
Environment contamination is a problem that most countries need to deal with in fields such as urban planning, public health, and availability of natural resources. Contaminated land, inside this topic, is a critical issue to discuss in the metropolis. Old areas have housed industrial activities, gas stations, and irregular waste disposal, can have the presence of toxic substances in the soil, underground, and in groundwater too, and this could lodge risk and a difficulty to change their land use and occupation, frequent in the dynamics of the societies. It is quite essential to create tools to handle this question, acknowledging the situation, and understanding how to achieve sustainable urban planning. Considering the existence of contaminated sites on the city and managing this, while The Sustainable Development Goals, as the Sustainable Cities and Communities, for instance, are applying. In this research, an index was developed of contaminated areas for the city of São Paulo, Brazil. The index was aimed to demonstrate in which districts are concentrated the contaminated sites and comprehend how the contamination it was spread at the city. The territorial unit used to divide the town was the district. The results indicated that the main contamination is concentrated near the downtown area and in older industrial districts. This data can be useful to define strategies on urban planning, because it can suggest which region is more indicated, or not, to receive different enterprises, around the city, like residential, commercial. Furthermore, the index can help to define what areas could need more specific environmental investigation and analysis to ensure the sustainability of the city and the citizens' safety.
Keywords: contaminated areas, urban planning, sustainable development.

1 INTRODUCTION

Ensuring a sustainable future for the next generations is a global concern, given by the Sustainable Development Goals (SDGs). However, this aim is a huge challenge, considering the fast growth in cities and the public policies of urban and land use. According to the UN in 2016, an estimated 54.5 percent of the world's population lived in urban areas, and by 2030, urban areas are projected to house 60 percent of people globally. Cities with more than 10 million inhabitants are often termed "megacities". Of the 31 megacities in the world, in 2016, 24 megacities were in less developed regions or the "Global South". In this ranking, the metropolitan region of São Paulo occupies the fifth position [1]. The city of São Paulo is located in the southeast region of Brazil, in the state of São Paulo, with a population of approximately 12,106,920 inhabitants an area of 1,521.11 km² [2]. In 2017, São Paulo city had 2,148 contaminated areas [3]. Contaminated land affects the soil quality and can also implicate the groundwater quality, giving the contaminant behavior. Thus, there is a strong relationship between contaminated land and SDGs. The purpose of this study is to develop an index of contaminated areas for São Paulo city. The index aims to demonstrate in which districts the contaminated areas are concentrated and comprehend how the contamination is spread around the whole city. The territorial unit used to divide the town was the district.

1.1 Scope

The scope of this study is developing an index for contaminated areas then, presents this information through spatial data in a map, in order to provide a helpful tool to improve the urban planning.

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2 LITERATURE REVIEW

The Sustainable Development Goals (SDGs) are a global blueprint for developing a sustainable future and these goals include different topics. Nevertheless, the environment issues are an essential point to achieve the goals. Environment contamination is a problem which most countries need to face. Anthropic activities have caused degradation, mainly in cities whose history has been marked by the development of the industry.

2.1 Sustainable development

Sustainable development has been defined in many ways, but according to the Brundtland Report, the definition is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [4]. In 2015 meeting, in New York, was announced the SDGs to the world [5]. The SDGs are goals to deal with the most urgent environmental, economics, and politicians challenges, that the world faces. Focusing on environmental problems are five goals:

1. Goal 2 end hunger achieve food security and improved nutrition and promote sustainable agriculture;
2. Goal 6 ensure availability and sustainable management of water and sanitation for all;
3. Goal 11 make cities and human settlements inclusive, safe, resilient and sustainable;
4. Goal 13 take urgent action to combat climate change and its impacts;
5. Goal 15, protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss [5].

Of the 05 targets identified, goal 02, 06, 11, and 15 can be directly impacted by the land use policy and the presence of soil contamination. Thereby the issues about contaminated land is not indicated in the SDGs, although their knowledge and management are essential to enforcement to goals.

2.2 Contaminated areas

According to United Stations Environmental Protection Agency (USEPA) contaminated land is a result from a diversity of intended, accidental, or naturally occurring activities and proceedings such as manufacturing, mineral extraction, abandonment of mines, national defense activities, waste disposal, accidental spills, illegal dumping, leaking underground storage tanks, hurricanes, floods, pesticide use, and fertilizer application. These areas can present of varying size and significance in sceneries ranging from abandoned buildings in inner cities to large areas contaminated with toxic materials from past use. Contaminated lands include sites contaminated by inappropriate handling or disposal of toxic and hazardous materials and wastes, also sites where toxic materials may have been deposited as a result of natural disasters or acts of terror [6].

In Brazil, contaminated land is defined as places where there is the presence of chemical substances above the reference values and due to anthropic activities which limit the use of this environmental resource either for current or future use [7]. According to federal law, there are three reference values: reference quality, is the concentration of a substance that defines the natural quality of the soil; prevention, is the limit concentration of a substance in the soil, such that soil is capable of sustaining its main functions; investigation, is the concentration of a given substance in soil or groundwater above which there are potential direct or indirect risks to human health [7]. These values are defined by international

standards and considering two tools: the exposure scenarios and Human Health Risk Assessment. The exposure scenarios can be Rural, Residential, and Industry. Each one has different reference values. Then, when an area has a concentration of a substance above the investigation reference values, is a contaminated area.

In Brazil there is no federal database regarding contaminated areas, however in 2016, Institute for Technological Research (IPT), a public research institute linked to the Secretariat for Economic Development, Science, Technology and Innovation of the State of São Paulo published an inventory of contaminated areas in Brazil, based on consultations with state environmental agencies and environmental consulting firms [9]. Table 1 shows the numbers found by IPT, about contaminated land in 17 states. Still, Brazil has 27 federal units.

Table 1: Contaminated land in Brazil in 2016. *(Source: Teixeira et al., 2016 [9].)*

State	Contaminated land
Pará	2
Amazonas	3
Pernambuco	1
Piauí	5
Sergipe	5
Paraíba	9
Bahia	23
Tocantins	1
Distrito Federal	1
Mato Grosso	5
Espírito Santo	1
Rio de Janeiro	271
Minas Gerais	578
São Paulo	5351
Paraná	4
Santa Catarina	10
Rio Grande do Sul	18

2.3 Contaminated areas in São Paulo city

Despite the lack of a federal database for contaminated land, São Paulo State, through Environmental Company of the State of São Paulo (CETESB), is the pioneering State in Brazil that have been publishing yearly information about contaminated areas. According to the Report, published in 2017 by CETESB, São Paulo State had 5942 contaminated areas [10]. In São Paulo State, also has a specific law to contaminated land, providing guidelines and procedures for soil quality protection and management of contaminated areas [11]. Moreover, there is a decree too, to regulate actions, as the CETESB definition as the agency responsible for planning and managing the process of identifying contaminated areas [12].

Even with the data provided by CETESB, the master plan of São Paulo city does not include in its aims and targets tackle the questions about contaminated land. The master plan only foresees actions aimed at the conservation and reforestation of degraded public areas, as parks, springs, and areas of environmental protection, [13]. Then, the information regarding contaminated land is not used as a strategic way to improve the land use policy in the city.

3 METHODOLOGY

This research used public data, obtained from secondary sources e available by official sources. For identifying the number of contaminated areas and the location, was used data from the Environmental Agency of São Paulo State (Companhia Ambiental do Estado de São Paulo-CETESB) [10]. The territorial unit used was the district, and São Paulo city currently has 96 districts. Information regarding the size, in kilometers, and boundaries of each district, was collect by the prefecture of the city of São Paulo [14].

3.1 Data processing

The data provided by CETESB include information about the contaminated area location, without the district. Then, in this first part, for all 2148 areas, was added information about the district. The software used for this step was Microsoft Excel 365. By including this data, it was possible identify which district had the highest number of contaminated areas in the whole city.

3.2 Calculation of the index

For the calculation of the index (I), was adopted the same methodology used for calculation of demographic density. It was used two variables, the number of contaminated areas per district (CA) and the value of district area (A), in kilometers. The following equation was applied, and the index is the result of the quotient of the variables:

$$I = \frac{CA}{A}. \tag{1}$$

3.3 Separating the index in classes and viewing data

Following the calculation of the Index, the results were inserted in software ArcGIS 10.5. Then, the data were classified in 06 grades, using the Equal Interval as methodology. Equal interval divides the series of attribute values into equal-sized subranges [15]. Finally, was produced a map, showing the different grades in a color scale. To draw up the map was used a shapefile with the boundaries and divisions of the São Paulo city, available in an official source, the prefecture of the city of São Paulo website [16].

4 ANALYSIS RESULTS

The first result founded it was regarding the district with the higher number of contaminated lands. Santo Amaro has 83 areas, followed by Ipiranga with 72 areas and Lapa, 70 areas. All three are former industrial districts. Santo Amaro has already been addressed in a previous study, about the revitalization process and changes in urban land use [17]. Ipiranga district has several studies in order to identify and delimits the contamination [18]–[20]. Regarding Lapa district, were not founded published studies.

Table 2 presents data concerning the districts code, district name, number of contaminated areas, size in kilometers as well the calculated index.

Table 2: Districts, contaminated areas and index.

District code	District	Contaminated areas	Area km^2	Index
1	Água Rasa	28	6.9	4.06
2	Alto de Pinheiros	20	7.7	2.60
3	Anhanguera	1	33.3	0.03
4	Aricanduva	18	6.6	2.73
5	Artur Alvim	16	6.6	2.42
6	Barra Funda	35	5.6	6.25
7	Bela Vista	19	2.6	7.31
8	Belém	32	6	5.33
9	Bom Retiro	23	4	5.75
10	Brás	32	3.5	9.14
11	Brasilândia	4	21	0.19
12	Butantã	27	12.5	2.16
13	Cachoeirinha	11	13.3	0.83
14	Cambuci	29	3.9	7.44
15	Campo Belo	37	8.8	4.20
16	Campo grande	65	13.1	4.96
17	Campo Limpo	15	12.8	1.17
18	Cangaíba	12	16	0.75
19	Capão Redondo	16	13.6	1.18
20	Carrão	24	7.5	3.20
21	Casa Verde	17	7.1	2.39
22	Cidade Ademar	26	12	2.17
23	Cidade Dutra	20	29.3	0.68
24	Cidade Líder	8	10.2	0.78
25	Cidade Tirandentes	3	15	0.20
26	Consolação	13	3.7	3.51
27	Cursino	27	12.8	2.11
28	Ermelino Matarazzo	14	8.7	1.61
29	Freguesia do Ó	17	10.5	1.62
30	Grajaú	9	92	0.10
31	Guaianases	3	8.6	0.35
32	Moema	37	9	4.11
33	Iguatemi	11	19.6	0.56
34	Ipiranga	72	10.5	6.86

Table 2: Continued.

District code	District	Contaminated areas	Area km^2	Index
35	Itaim Bibi	48	9.9	4.85
36	Itaim Paulista	13	12	1.08
37	Itaquera	19	14.6	1.30
38	Jabaquara	25	14.1	1.77
39	Jaçanã	17	7.8	2.18
40	Jaguara	10	4.6	2.17
41	Jaguaré	28	6.6	4.24
42	Jaraguá	8	27.6	0.29
43	Jardim Angela	9	37.4	0.24
44	Jardim Helena	8	9.1	0.88
45	Jardim Paulista	19	6.1	3.11
46	Jardim São Luís	23	24.7	0.93
47	José Bonifácio	7	14.1	0.50
48	Lapa	70	10	7.00
49	Liberdade	22	3.7	5.95
50	Limão	19	6.3	3.02
51	Mandaqui	10	13.1	0.76
52	Marsilac	0	200	0.00
53	Mooca	58	7.7	7.53
54	Morumbi	12	11.4	1.05
55	Parelheiros	4	153.5	0.03
56	Pari	13	2.9	4.48
57	Parque do Carmo	10	15.4	0.65
58	Pedreira	12	18.7	0.64
59	Penha	33	11.3	2.92
60	Perdizes	29	6.1	4.75
61	Perus	3	23.9	0.13
62	Pinheiros	31	8	3.88
63	Pirituba	13	17.1	0.76
64	Ponte rasa	11	6.4	1.72
65	Raposo Tavares	18	12.6	1.43
66	República	14	2.3	6.09
67	Rio pequeno	18	9.7	1.86
68	Sacomã	53	14.2	3.73

Table 2: Continued.

District code	District	Contaminated areas	Area km^2	Index
69	Santa Cecília	38	3.9	9.74
70	Santana	32	12.6	2.54
71	Santo Amaro	83	15.6	5.32
72	São Lucas	27	9.9	2.73
73	São Mateus	19	13.2	1.44
74	São Miguel	14	7.5	1.87
75	São Rafael	8	13	0.62
76	Sapopemba	24	13.5	1.78
77	Saúde	38	8.9	4.27
78	Sé	9	2.1	4.29
79	Socorro	33	12.9	2.56
80	Tatuapé	64	8.2	7.80
81	Tremembé	10	56.3	0.18
82	Tucuruvi	9	9	1.00
83	Vila Andrade	14	10.3	1.36
84	Vila Curuçá	10	9.7	1.03
85	Vila Formosa	20	7.4	2.70
86	Vila Guilherme	36	6.9	5.22
87	Vila Jacui	14	7.7	1.82
88	Vila Leopoldina	41	7.2	5.69
89	Vila Maria	30	11.8	2.54
90	Vila Mariana	36	8.6	4.19
91	Vila Matilde	16	8.9	1.80
92	Vila Medeiros	15	7.7	1.95
93	Vila Prudente	43	9.9	4.34
94	Vila Sonia	24	9.9	2.42
95	São Domingos	8	10	0.80
96	Lajeado	5	9.2	0.54

As is possible to realize, only 01 district in São Paulo city does not have contaminated land, Marsilac, on the other hands, this district is located at the south end of town, in an environmental protection area [21], with a lower demographic density [14].

Considering the results of the index is quite relevant because it is not intuitive, allows to realize different districts, then those present the more significant number of contaminated areas. The values of the results varied among 9.74 and 0. The higher result, 9.74 belong to Santa Cecília, district code 69, with 38 contaminated land, in an area of 3.9 km^2. Further, the

index results also have been classified in 06 grades, using Equal Intervals. The grades are available in Fig. 1.

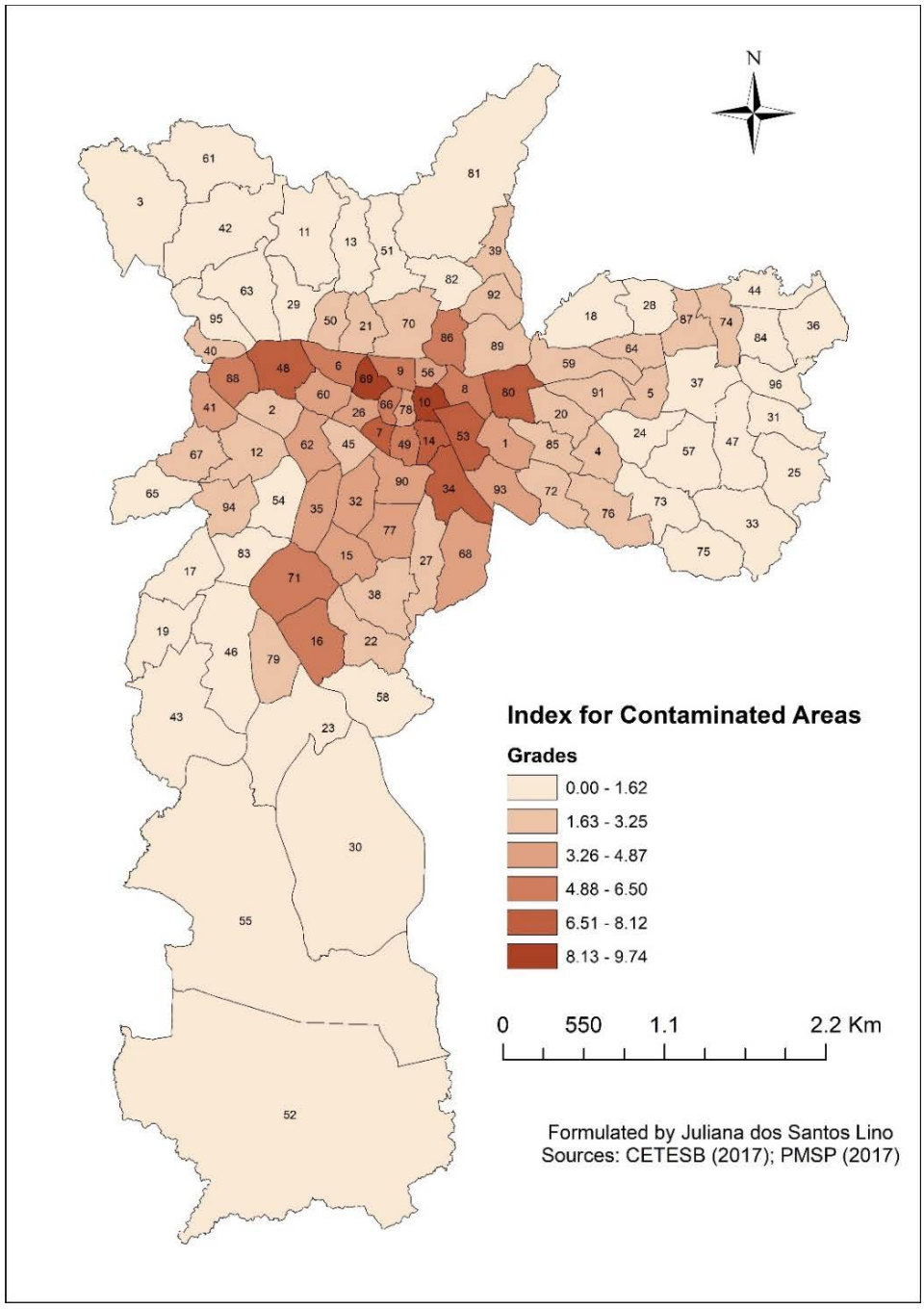

Figure 1: Index for Contaminated Areas in grades.

5 CONCLUSION

Sustainability is about thinking in the future, discussing now, what and how are people are managing the planet, to ensure the resources are available to the next generations. Urban land use is an essential topic inside this context because it can impact issues related to housing, also food production and availability of natural resources.

To develop sustainable public policies, the governments should base the actions on data. Then it is necessary the existence of tools to provide data regarding the environmental city health to help the urban planning.

The city of São Paulo is a huge city and offers guidelines for all cities in Brazil. Also, the city has a significant number of contaminates sites, and it is required to improve the management of this information. The research evinced that districts of Santo Amaro, Ipiranga, Lapa, and Campo Grande have the highest number of contaminated sites in the city. However, through the developed index was possible observed that other districts, as Santa Cecília, with a small number of contaminated areas and small area, presents a large concentration of contaminated sites if considering the size. Therefore, these places need more careful in issues refers to zoning law and use of groundwater.

A way to achieve the SDGs and guarantee sustainable use of the city is raising the ability of manager environmental data and use for planning the future, this index was done with this aim, providing information to a sustainable city.

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