Improving contaminated land data communication through the developing of an environmental indicator

Desenvolvimento de um indicador ambiental para aprimorar a comunicação de dados sobre áreas contaminadas

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ABSTRACT
Environment contamination is a widespread problem in all countries around the world. Contaminated sites are consequence of land use and occupation without environmental concerns, and it can cause contamination of superficial soil, subsoil, and groundwater. This issue affects urban planning, human health as well natural resource availability. The management of contaminated land data and its communication to stakeholders is a significant driver to achieve sustainable urban planning, promoting equally sustainable cities and communities. Therefore, tools to improve comprehension of environmental quality of cities is essential to face this challenge. Here, we develop an environmental indicator to analyze contaminated land data and communicate its complexity to non-technical stakeholders. The indicator developed, adopts 15 variables and considering three parameters: polluting substance concentration, affected environmental matrices, and the environmental behavior of the polluting substance. A dataset has been elaborated containing information about 25 contaminated sites of Lapa District, the pilot area of São Paulo city, and the environmental indicator was applied, resulting in four environmental contamination levels: low, moderate, high, and remarkably high degrees, existing in an individually site.

Keywords: contaminated land, environmental indicators, land use planning, sustainable development.

RESUMO
A contaminação ambiental é um desafio enfrentado globalmente. As áreas contaminadas são consequência da utilização e ocupação do solo sem as devidas preocupações ambientais, e podem provocar a contaminação do solo superficial, subsolo e águas subterrâneas. Esta questão pode afetar diferentes áreas, como o planeamento urbano, a saúde pública, bem como a disponibilidade de recursos naturais. A gestão de dados sobre

áreas contaminadas e a sua comunicação às partes interessadas são ferramentas chave para alcançar um planeamento urbano sustentável, promovendo cidades e comunidades sustentáveis. Portanto, ferramentas para melhorar a compreensão da qualidade ambiental nas cidades são essenciais para enfrentar esse desafio. Neste estudo, desenvolvemos um indicador ambiental que analisa dados sobre áreas contaminadas e visa comunicar sua complexidade às partes interessadas não técnicas. O indicador desenvolvido, adota 15 variáveis e considera três parâmetros: concentração da substância poluente, matrizes ambientais afetadas, e o comportamento ambiental da substância poluente. Foi elaborado um conjunto de dados contendo informação sobre 25 áreas contaminadas pertencentes ao Distrito da Lapa, a zona piloto da cidade de São Paulo. O indicador ambiental foi aplicado, resultando em quatro níveis de contaminação ambiental: baixo, moderado, alto, e muito alto, para cada área analisada.

Palavras-chave: áreas contaminadas, indicadores ambientais, planejamento e uso do solo, desenvolvimento sustentável.

1 INTRODUCTION

According to United Nations (2018), approximately 55 percent of the world's population lived in cities, whereby one in five people worldwide lives in a city with more than 1 million inhabitants. Megacities is a term that refers to cities with more than 10 million inhabitants. Of the world's 33 megacities identified until 2018, 27 are in less developed regions, labelled as "global South". São Paulo metropolitan region ranks fourth in this rating (United Nations, 2018).

São Paulo state presents, equally, the highest Gross Domestic Product (GDP) in 2019, and the Human Development Index (HDI), 0.783 in 2010, in Brazil. State is located on the southeast region of Brazil, with a 248,219.48 km² territorial area and an estimated population of 46,649,132 inhabitants in 2021. São Paulo city is the state capital and owns an area of 1,521.20 km² and a population of approximately 12,396,372 inhabitants in 2021 (Instituto Brasileiro de Geografia e Estatística, 2010, 2021b, 2021c). The state of São Paulo, through São Paulo Environmental Agency (Companhia Ambiental do Estado de São Paulo - CETESB), was a pioneer in the implementation of contaminated land management mechanisms. Consequently, state and city, lead the ranking of identified contaminated land in Brazil.

In countries around the globe, diffuse and local soil contamination is a widespread problem. These contamination means a mixture of contaminants in soil and, in groundwater. In contaminated land, building activities and urban development is hindered, due the investigation and remediation of such sites requires large time scales and substantial budgets (Swartjes et al., 2012).

The term contaminated land, according to the first Brazilian document on the subject, the Management Manual of Contaminated Areas, published by the Environmental Agency of the State of São Paulo (CETESB) is defined as "local where there is proven pollution caused by any substances or waste that have been deposited, accumulated, stored, buried or infiltrated in it, and that determines negative impacts on the assets to be protected" (CETESB, 2001). The Brazilian standard ABNT NBR 15515-1, entitled Environmental Liabilities in Soil and Groundwater, published in 2011, provides a more current concept of the term contaminated land as "an area where the concentrations of chemical substances of interest are above a reference value in force in the region, in the country or, in the absence of this, that internationally accepted, which indicates the existence of a potential risk to safety, human health or the environment" (ABNT, 2011). Contaminated land does not refer only to the source of contamination, the soil that received the contaminants, contaminated land is a concept that encompasses the set of environmental compartments (air, water, soil, vegetation) which were impacted, in addition to buildings, facilities and equipment on the site. In these spaces, pollutants and contaminants may be present on the ground surface or in the subsurface, in different environmental matrices: soil, water, air, biota, also in the built environment, material used for landfill, and thus it justifies the name, contaminated land, not just contaminated soil (RISSO GÜNTHER, 2006). The definition for site is provided for Van-Camp et al., meaning a particular area of land related to a specific ownership or activity (Van-Camp et al., 2004).

In Brazil, is absent an official inventory presenting contaminated land data. However, São Paulo State, annually, publishes the document Report of Contaminated and Rehabilitated Areas of the State of São Paulo, by CETESB. According to this publication, in the year 2020 there were 6,434 contaminated lands in the state (CETESB, 2020). Once a contaminated site is identified, the Management of Contaminated Land Process begins, including several measures and steps, which seek to comprehend the characteristics of the site and define which will be the most appropriate intervention measures to be adopted, aiming to eliminate or minimize the damage and/or risks to the assets to be protected, arising from the contaminants contained therein (SÃO PAULO (State), 2013).

The report published by CETESB is the official communication tool between the environmental agency and stakeholders and community. Inside this document it is described the information about the site address, stages that a site has already fulfilled, facing the management process, plus summarized information about the affected environmental matrices, groups of contaminants present in the site and the remediation technologies used. Despite the disclosure of these data, there is no use of them from the perspective of environmental quality indicators. Kwatra et al. (2020), recognize indicator as a tool that allows information to be obtained about a particular reality, which can be individual data or an aggregate of information, efficiently communicating the state of the observed phenomenon. According to Verma and Raghubanshi, measuring the progress of nations toward sustainable or unsustainable development requires quantifying the phenomena that represent this progress. This process is done using indicators (Kwatra, Kumar, & Sharma, 2020; Verma & Raghubanshi, 2018).

Here, we attempt to make a step towards to environmental quality assessments of cities and its communication process to non-technical stakeholders. with the use of indicators. The proposed approach is to contribute to a better understanding of the problem of contaminated land, and their impacts on cities, by developing an environmental indicator. The indicator were developed considering Bellagio's principles and applying the following Gibson's criteria: Socio-ecological system integrity, Resource maintenance and efficiency, and Socio-ecological civility and democratic governance (R. B. Gibson, 2006; R. Gibson, Hassan, Holtz, Tansey, & Whitelaw, 2005; Pintér, Hardi, Martinuzzi, & Hall, 2012).

2 MATERIALS AND METHODS

The present work begins with exploratory research, outlined through literature review, to provide a broader view of the subject addressed, increasing the level of understanding of the same and allowing us to delimit our focus (Cervo, Bervian, & Da Silva, 2007; Gil, 2022). The work advances to documental research, to obtain quantitative and qualitative secondary data to elaborate the dataset.

The dataset was built up based on the Report of Contaminated and Rehabilitated Areas, published by CETES, and the geographic information was provided by São Paulo City Hall (CETESB, 2017; Prefeitura de São Paulo, 2019). The dataset was elaborated by analyzing the investigation, monitoring, and environmental licensing processes of contaminated sites in Lapa district, a pilot area of São Paulo city, and make available for CETESB. These reports are produced by environmental consultants and duly delivered to CETESB, during the contaminated land management process. Acquiring this data had two main objectives: to identify the main information collected in the investigations of contaminated sites, assisting in the selection mechanism of the parameters adopted in the indicator; and a dataset elaboration, to implement the proposed indicator.

2.1 DEVELOPING AN ENVIRONMENTAL CONTAMINATION INDICATOR (ECI)

During the elaboration of the indicator, that we named Environmental Contamination Indicator (ECI), classification methodologies for contaminated sites were analyzed, as the one developed by CABERNET for brownfields, the Hazardous Ranking System (United States Environmental Protection Agency, 1992), the National Classification System for Contaminated Sites (Canadian Council of Ministers of the Environment's, 2008), CETESB Prioritization System (CETESB, 2001; Gloeden, Oliveira, & Pereira, 2021) and the Classification adopted by the São Paulo State Health Surveillance Center (CVS, 2019b).

The scope of the soil contamination indicators studied for the development of the ECI is to assess soil contamination by heavy metals. The Single Pollution Index (PI) is an indicator that assesses the degree of individual heavy metal contamination in topsoil. It is calculated by dividing the value found for a given metal by the expected reference value for the metal evaluated. The Contamination factor (Cf) is an indicator that aims to evaluate the contamination of the soil, adopting two parameters, the values found for heavy metals in the surface soil and the preindustrial reference levels, previously defined for these same metals. The Sum of contamination (PIsum), on the other hand, assesses global contamination generated by heavy metals. It is the sum of all the determined heavy metal contents in the soil, expressed in the indicator PI. The Pollution Load Index (PLI) is used to assess the degree of deterioration caused by soil contamination because of heavy metal accumulation. It is calculated as a geometric mean of the PI indicator (Abasi, Inengite, Abasi, & Walter, 2015; Kowalska, Mazurek, Gąsiorek, & Zaleski, 2018; Kwatra et al., 2020).

Furthermore, literature on the process of indicator construction, has been analyzed (Nardo et al., 2008). According to the classification suggested by Quiroga-Martínez, indicators can be divided into 3 classes. In this work, a 1st generation environmental sustainability indicator is proposed (Quiroga-Martinez, 2001). The designed indicator used 15 variables, consolidated into 3 parameters. ECI was used in a dataset consisting of 25 contaminated sites. The results were aggregated using a categorical scale, by quartiles. Each quartile represents a level of contamination of the area: low for the first quartile, moderate for the second, high for the third and remarkably high for the upper values.

3 RESULTS

3.1 ENVIRONMENTAL CONTAMINATION INDICATOR

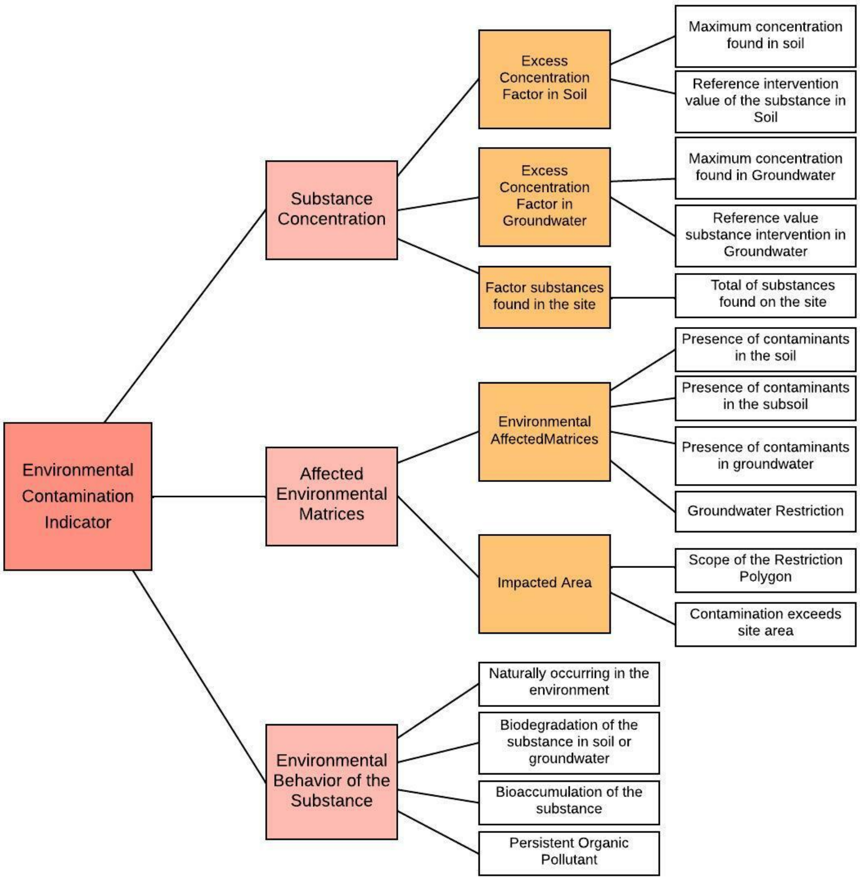
For the development of the Environmental Contamination Indicator (ECI), 15 primary variables were used, which correspond to the data present in the environmental investigations or consulted in databases. The next step adopts 05 secondary variables, calculated based on the primary variables. Following, 3 parameters have been calculated, Substance Concentration, Affected Environmental Matrices, and the Environmental Behavior of the Substance. The variables chosen, measurement unit, and the sources containing the data are indicated in table 1. In figure 1, below, the flowchart of the indicator elaboration process is showed.

Table 2 Adopted variables

Variable	Unit	Source	Variable response
Maximum concentration found in soil from CS1 and CS2	mg/kg	Files	Maximum concentrations presented by contaminant substances 1 and 2, in milligrams per kilogram of soil.
Reference intervention value of the substance in Soil	mg/kg	CETESB, 2016	Intervention value adopted for the contaminant substance. The intervention value is considered for the residential scenario, when there is a change of use, to residential; industrial when it comes to gas stations or maintenance of industrial activity in the site.
Excess Concentration Factor in Soil	not applicable	calculated	By how many times the value found in the site exceeds the reference values consulted. It is the division of the value found by the reference value.
Maximum concentration found in Groundwater from CS1 and CS2	μg/L	Files	Maximum concentrations found of contaminant substances 1 and 2, in micrograms per liter.
Reference value substance intervention in Groundwater	μg/L	CETESB, 2016	Intervention value adopted for the contaminant substance. The intervention value is considered for the residential scenario, when there is a change of use to residential; industrial when it comes to gas stations or maintenance of industrial activity in the site.
Excess Concentration Factor in Groundwater	not applicable	Calculated	How many times the value found is above the reference values. It is the division of the value found by the reference value.
Total of substances found on the site	not applicable	Files	Is the sum of the total contaminant substances found at the site

Variable	Unit	Source	Variable response
Factor substances found in the site	not applicable	Files	It is applying normalization, in a range of 0 and 1 to the results of the variable total of substances found on the site
Presence of contaminants in the soil	not applicable	Files	Are there contaminants in the soil? yes=01/no=0
Presence of contaminants in the subsoil	not applicable	Files	Are there contaminants in the subsoil? yes=01/no=0
Presence of contaminants in groundwater	not applicable	Files	Are there contaminants in the groundwater? yes=01/no=0
Groundwater Restriction	not applicable	Files	Has a groundwater use restriction measure been defined? yes=01/no=0
Environmental Affected Matrices	not applicable	Calculated	The sum of variables: presence of contaminants in soil, subsoil, groundwater, and groundwater restriction
Scope of the Restriction Polygon	not applicable	Files	Does the area of the restriction polygon for groundwater use exceed the site? yes=01 / no= 0
Contamination exceeds site area	not applicable	CETESB, 2017a; CVS, 2019a	Does the contamination plume exceed the area of the site? yes=01 / no=0
Impacted Area	not applicable	calculated	Sum of variables: extent of restriction polygon and contamination exceeds land area
Naturally occurring in the environment	not applicable	(Agency for Toxic Substances and Disease Registry, 2022; Companhia Ambiental do Estado de São Paulo, n.d.; Organisation for Economic Co-operation and Development, 2022; TOXNET, 2018),	Does the contaminant found occur naturally in the environment in which it was identified? yes=0 / no= 01
Biodegradation of the substance in soil or groundwater	not applicable	(Agency for Toxic Substances and Disease Registry, 2022; Companhia Ambiental do Estado de São Paulo, n.d.; Organisation for Economic Co-operation and Development, 2022; TOXNET, 2018)	Is the contaminant expected to biodegrade in the environment where it is present? yes=0 / no= 01
Bioaccumulation of the substance	not applicable	(Agency for Toxic Substances and Disease Registry, 2022; Companhia Ambiental do Estado de São Paulo, n.d.; Organisation for Economic Co-operation and Development, 2022; TOXNET, 2018)	Is the contaminant expected to bioaccumulate in organisms present in the environment? yes=1 / no=0
Persistent Organic Pollutant	not applicable	(Brasil, 2005; United Nations, 2019)	Is the substance classified as a persistent organic pollutant? yes=01/no=0.

Figure 1 Flowchart ECI



The association between the adopted variables and other existing classifications and indicators are listed in the supplementary material.

3.1.1 Calculating ECI parameters

In equation 2 the calculation of the environmental concentration parameter (EC) of the substance is displayed.

Equation 2 EC parameter

$$EC= \frac{\sum Factor\ exc\ Soil+\sum Factor\ exc\ groundwater+Factor\ substances}{3}$$

Equation 3 demonstrates the calculation of the environmental affected matrices (EAM) parameter.

Equation 3 AEM parameter

$$AEM= \frac{Environmental\ Affected\ Matrices+Impacted\ Area}{2}$$

Equation 4 is the calculation for the parameter environmental behavior (EB) of the substance.

Equation 4 EB parameter

$$EB=\frac{\sum Naturally\ occurring+\sum Biodegradation+\sum Bioaccumulation+\sum POP}{4}$$

In equation 5 the calculation for the Environmental Contamination Indicator is showed, which is formed using the data from the 3 parameters described above.

Equation 5 ECI

$$ECI=\frac{EC+EAM+EB}{3}$$

In calculation process of the Environmental Concentration parameter, we used variables with quantitative data. To calculate equally, Environmental Affected Matrices and Environmental Behavior, the data are of qualitative nature, represented in 0 and 1 scale. In this work we chose not to assign weights to the variables found, because it would require a more complex data analysis, which can be performed in future works. In the cases of EC and EB, two chemical contaminants substances were considered for each analyzed site.

3.1.2 Data normalization

To perform the calculations related to the proposed ECI, the normalization process was adopted for quantitative data. According to Nardo et al., normalization is necessary before any data aggregation, because indicators in a data set usually have different measurement units (Nardo et al., 2008). The normalization technique used was the resizing (Re-scaling) or Min-Max normalization, the equation for applying this technique is showed below.

Equation 6 Normalization min-max

$$x' = \frac{x - \min(x)}{\max(x) - \min(x)}$$

Fonte: BORKIN et al., 2019

3.1.3 Applying ECI to a pilot area

The ECI developed was used to our pilot area, containing 25 contaminated sites on Lapa district, in São Paulo city. Following, in table 3, we present the results, equally, for the three parameters, calculation of the ECI, and the rating assigned. The results for each of the variables are available in the supplementary material.

Table 3 ECI Results

Site ID	EC	EAM	EB	ECI	Rating
1	0.073	2.5	0.00	0.86	moderate
2	0.061	0.5	0.25	0.27	low
3	0.095	1.5	0.25	0.62	low
4	0.000	1.5	1.00	0.83	moderate
5	0.037	2.0	0.50	0.85	moderate
6	0.576	2.5	1.25	1.44	remarkably high
7	1.072	3.0	1.00	1.69	remarkably high
8	0.007	1.5	0.50	0.67	low
9	0.003	2.5	1.00	1.17	remarkably high
10	0.096	2.5	0.50	1.03	high
11	0.100	2.5	0.75	1.12	high
12	0.091	1.0	1.00	0.70	low
13	0.000	3.0	0.50	1.17	remarkably high
14	0.521	2.5	0.50	1.17	remarkably high
15	0.068	2.0	0.25	0.77	low
16	0.096	1.5	0.75	0.78	moderate
17	0.336	2.5	0.50	1.11	high
18	0.083	2.0	0.75	0.94	moderate
19	0.432	2.0	0.75	1.06	high
20	0.093	2.0	0.25	0.78	moderate
21	0.434	2.5	0.75	1.23	remarkably high
22	0.063	0.5	0.75	0.44	low
23	0.260	2.5	0.75	1.17	remarkably high
24	0.102	2.5	0.75	1.12	high
25	0.116	2.0	0.75	0.96	high

4 DISCUSSION

4.1 DEVELOPING AND APPLYING THE ENVIRONMENTAL CONTAMINATION INDICATOR

The proposed indicator was developed composed of three parameters, aiming to measure the environmental commitment of a given area, allowing a classification for each site.

The variables used, termed as natural occurrence, biodegradation, bioaccumulation, and persistent organic pollutant, sought to capture information about the environmental behavior of the substances analyzed, transmitting these conditions in yes or no answers (0 and 1). This information was consulted in official databases, which describe each substance in detail, based on numerous studies and scientific evidence. We emphasize that the variable Natural occurrence, meets the mentioned by Kowalska et. al

(2018), which explains that the calculation of soil pollution indices requires an assessment of the geochemical background, evaluating and distinguishing the natural concentrations of heavy metals in the soil, from abnormal concentrations. The existence of this variable is intended to increase the score for substances that do not occur naturally in the environment in which they have been identified (Kowalska et al., 2018).

It is important to note that information about the carcinogenic potential of the substances was not included, since the objective of this indicator is not to consider the risk to human health, but communicating the environmental alteration caused to a site because of existing contamination. Additionally, in the Human Health Risk Assessment, which is a consolidated and widely used tool in the management of contaminated areas, this information is already contemplated.

The indicator developed here seeks to function as a sustainability tool, expressing and communicating the environmental alterations found in every single site, caused by the activities that have been developed there. The indicator differs from the prioritization tool adopted by CETESB, since its objective is to evaluate the degree of risk that contamination in a site can generate to the assets to be protected, considering the possible exposure routes (CETESB, 2001).

The Organization for Economic Cooperation and Development (OECD), in a report published in 2017, considers soil resources to be essential components of the natural asset base of the economy and ecosystems. They are critical to produce food and other biomass, support recreational activities, and more generally provide a physical basis for all economic activities. How soil is used and managed influences everything in the environment, generating impacts on biodiversity as well as ecosystem services (Diogo & Koomen, 2016). However, consulting the database of indicators, the OECD.Stat, and searching for environmental indicators, two indicators are found within the class soil, Land resources: land cover and land use. The first refers to the form of land cover, offering data as spatial occupation, buildings, surface water, and forests. The second deals with agricultural land use. In neither indicator is available contaminated land data (OECD, 2022).

Currently, there are already studies that relate soil quality indicators to contaminated land, as in the present study, however these works are inserted in the theme of ecosystem services. A study conducted by Drobnik et al., (2018), considers contaminated land as one of the variables involved in the soil quality indicator. The study uses the BOKS index methodology and employs six attributes, used to characterize soil quality. The author highlights that the differential of this methodology lies in the fact that it considers natural and anthropogenic factors in the composition of the final soil quality index. There are two anthropogenic attributes: contaminated sites and soil sealing level (Drobnik, Greiner, Keller, & Grêt-Regamey, 2018).

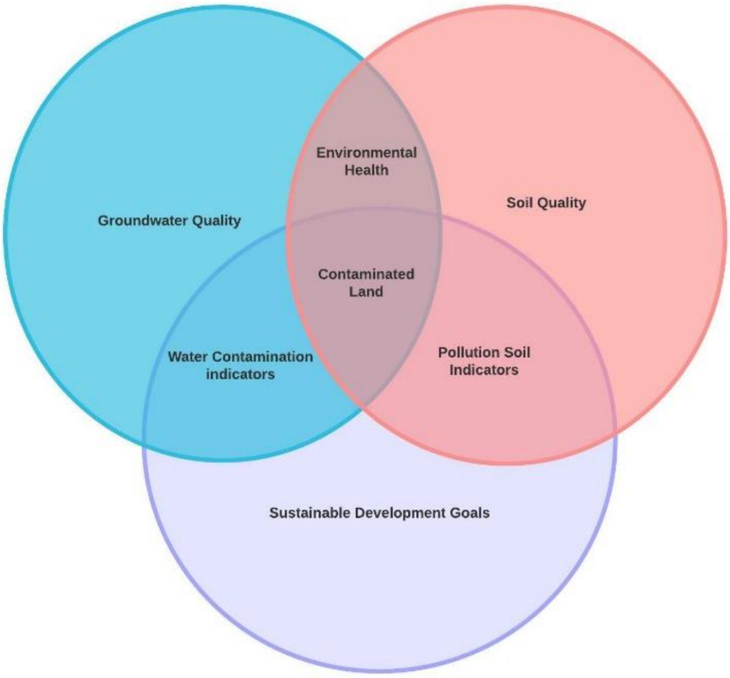
In a review work on pollution indices for assessing the degree of soil contamination, Kowalska et al., clarifies that pollution indices are widely considered as a useful tool for holistic assessment of the degree of contamination. In addition, they can be of great importance in assessing soil quality and predicting the future sustainability of an ecosystem (Kowalska et al., 2018).

The European Environment Agency (EEA) has designed a set of environmental indicators to answer policy questions and provide scientific support to decision makers. According to the EEA Indicators report, there are currently 120 environmental indicators, covering 22 topics, aimed at providing a manageable and stable basis for assessing progress against the priorities set in EU environmental policy. Among this set of indicators, soil-related indicators are the following: land cover; soil moisture; soil impermeability and changes in soil impermeability; soil organic carbon; and progress in the management of contaminated land. Soil contamination is then seen as an integral part of environmental quality assessments, not an isolated problem. (EEA, 2019; Paya Perez & Rodriguez Eugenio, 2018).

The theme of contaminated areas is strongly associated with the SDGs. Consequently, the indicators developed in this work can contribute significantly, as a measurable tool to the advances in the management of contaminated areas of cities, facing the goals set by the SDGs. We can cite association with 5 SDGs: 3 Good Health, as mentioned before; 6 Clean water and Sanitation, which is committed to protecting and restoring aquifers; 11 Sustainable Cities and Communities, although it does not make direct mention of soil contamination, it does address the need to reduce the environmental impact caused by cities; 12 Responsible consumption and production, brings reflection about the management of chemical substances and the disposal of residues in an environmentally correct way, preventing their release into the soil; and, finally, 15 life on land, although contamination is not present in every degraded soil, in every contaminated site the soil is degraded (Sánchez, 2004; United Nations, 2021).

Finally, we created a Venn diagram, in figure 2, that illustrates the several relationships of the contaminated land and thus the possibilities fields of applying the indicator developed in this study.

Figure 2 Relationships between topics associated Contaminated land



4.2 UNCERTAINTIES OF THE RESEARCH APPROACH AND CHALLENGES IN IMPLEMENTING THE PROPOSED INDICATORS

The developing of Environmental Contamination Indicator was based on a literature review that aimed to identify key references. Although, we do not claim to have exhaustively identified all literature on the contaminated land classification or soil indicators.

We admit that at this stage our study is of theoretical nature. A challenge in implementing the proposed indicator is the data availability. Some of the analyzed parameters vary regarding data availability and data collection complexity. Nowadays, environmental agency publishes summarized information of contaminated sites.

5 CONCLUSION

Urban land use planning is a driver toward sustainable cities. Hence, it is essential developing tools that provide environmental data concerning to health city to improve urban planning. São Paulo city is a megacity and offers guidelines for all Brazilians cities, through CETESB. However, despite the progress made in the subject of contaminated sites, it is important to improve the environmental management information.

The ECI aims to present contaminated sites information in a simple and objective method, contributes to the understanding of the distinct levels of contamination found in contaminated sites. Likewise, it is favoring the communication with stakeholders who are not involved in the processes of management and remediation of these sites. Additionally, may contribute as a parameter in the composition of future urban soil quality indicators, nonexistent so far in the Brazilian scenario.

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