Contaminated soils in Southeastern Brazil: Review of the current scenario and opportunities for improvement

Solos contaminados no Sudeste do Brasil: revisão do cenário atual e oportunidades de melhoria

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Vitor Augusto Cordeiro Milagres
Master in Forest Engineering
A.W. Faber-Castell
Rua Tenente Reis, 1287, Rodoviário. Prata, MG. CEP: 38140-000. Brazil
vitor.acmilagres@gmail.com

ABSTRACT
The objective of this work is to present the management actions carried out by the states in southeastern Brazil after the creation of CONAMA Resolution No. 420, and to propose points of improvement for the management of these regions. This work was prepared from a literature review based on reports and data provided by the State Environmental Foundation of Minas Gerais (FEAM), by the Environmental Company of the State of São Paulo (CETESB) and by the State Environmental Institute of the State of Rio de Janeiro (INEA). In São Paulo and Minas Gerais, the states that have older records, the numbers of rehabilitated areas have gone through constant growth, unlike Rio de Janeiro, which has a younger record. The lack of standardization in the provision of state data makes it difficult to understand the process at regional and national level. It is worth noting the activities of gas stations due to the high number of contaminated areas. The presence of landfills and dumps has the potential to be better addressed in the states of Southeastern Brazil. This region, in addition to being the most populous, has numerous illegal dumps scattered throughout the cities. The role of public bodies in managing these areas is important and encouraging the correct disposal of waste.

Keywords: Reabilitated areas, soil management, FEAM

RESUMO
O objetivo deste trabalho é apresentar as ações de gerenciamento realizados pelos estados do Sudeste Brasileiro após a criação da Resolução CONAMA nº 420, e propor pontos de melhoria para o gerenciamento dessas regiões. Este trabalho foi elaborado a partir de uma revisão da literatura baseado nos relatórios e dados disponibilizados pela Fundação Estadual do Meio Ambiente (FEAM) de Minas Gerais, pela Companhia Ambiental do Estado de São Paulo (CETESB) e pelo Instituto Estadual do Ambiental do Estado do Rio de Janeiro de Janeiro (INEA). Em São Paulo e Minas Gerais, os estados que possuem cadastros mais antigos, os números de áreas reabilitadas têm passado por constante crescimento, diferente do Rio de Janeiro que possui um cadastro mais novo. A falta de padronização na disponibilização dos dados estaduais, dificultam o entender do processo a nível regional e nacional. Merece destaque as atividades de postos de combustíveis pelo elevado número de áreas contaminadas. A presença de aterros sanitários e lixões tem potencial de ser mais bem abordado nos estados do Sudeste Brasileiro. Esta região, além
de ser a mais populosa, possui inúmeros lixões clandestinos espalhados pelas cidades. Importante o papel dos órgãos públicos para gerenciamento dessas áreas e incentivo à correta destinação dos resíduos.

**Palavras-chave:** Áreas reabilitadas, manejo do solo, FEAM.

1 INTRODUCTION

Humans use the soil to produce approximately 95% of their food. This is in fact its best-known function; however, the soil has other important functions such as filtration and water reserve, carbon sequestration (FAO, 2015), climate regulation among many others.

Brazil has a great diversity of soils in its continental extension, due to the wide diversity of pedoenvironments and soil formation factors. The wide peculiarity observed in the pedoenvironments also represents an important condition for the evaluation of the potentials and limitations of each soil, conditioning its sustainability as a function of the uses and management practices applied (EMBRAPA, 2020).

In recent years, soil contamination has intensified globally, whether due to the impact of the increase in waste deposited in open dumps, oil spills and its derivatives, poorly handled chemical products in agriculture and others.

A contaminated area can be understood as the place that contains quantities/concentrations of any substances or residues in conditions that cause or may cause damage to human health and the environment that have been deposited, accumulated, stored, buried, or infiltrated in it, in a planned manner, accidental or even natural way (BRASIL, 2020).

Considering the need to establish criteria to define guiding values for the prevention of soil contamination and to define guidelines for the management of contaminated areas in Brazil, CONAMA Resolution number 420 was created (BRASIL, 2009).

The Brazilian Southeast is the most populous region in the country, and consequently, one of those with the highest levels of soil contamination. With the advent of this resolution, it was possible to observe an increase in the identification of contaminated areas, in addition to the interventions carried out and the inspection actions of state agencies.

Thus, the objective of this work is to present the management actions carried out by the states of Minas Gerais, São Paulo, and Rio de Janeiro after the creation of
CONAMA Resolution No. 420, and to propose points of improvement for the management of these regions, which could serve as a model for those states that do not yet have their own management system.

2 MATERIALS AND METHODS

CONAMA Resolution No. 420, in line with the principles dealt with in the National Environmental Policy (BRASIL, 1981) proposes the management of contaminated areas with the active participation of the States and the Federal District, which have the duty to establish the guiding quality values of the soil for the presence of chemical substances.

This work was prepared from a literature review based on reports and data provided by the State Environmental Foundation of Minas Gerais (FEAM), by the Environmental Company of the State of São Paulo (CETESB) and by the State Environmental Institute of the State of Rio de Janeiro de Janeiro (INEA).

Through FEAM, 12 annual reports are available containing the inventory and list of contaminated areas from 2009 to 2020. The list made available by CETESB runs from 2002 to 2019, totaling 18 reports. INEA makes its data available through the digital platform GeoINEA where it is possible to know the updated data in a geospatial way (GEOINEA, 2020), in addition to two cadastral reports.

In southeastern Brazil, only the State of Espírito Santo does not have a register/report that gathers information on contaminated or remedied areas. According to the Coordination of Air Quality, Contaminated Areas and Environmental Information (CQAI) of the State Institute for the Environment and Water Resources (IEMA), such information, if any, is within the scope of the activities' environmental licensing processes (VIEIRA, 2020).

For modeling the number of contaminated areas as a function of time, the nonlinear logarithm regression model was used and a coefficient of determination above 70% was considered for validation.

3 RESULTS AND DISCUSSIONS

Reports of contaminated areas in the State of Minas Gerais from 2009 to 2020 were analyzed. There is a growing increase in the areas managed by FEAM (Figure 1). From 2007 to 2020, a variation of 56 to 479 areas, respectively, was observed (FEAM, 2020), which represents an increase of more than 8 times.
As it has been observed in the last ten years, it is estimated that for the next decade the number of areas managed by FEAM will increase from 479 areas to approximately 587 areas.

Figure 1: Number of managed areas (contaminated and rehabilitated) registered in the State Foundation for the Environment and in the Municipal Environmental Secretariat of Belo Horizonte between 2007 and 2020.

Despite the growing number of areas managed by FEAM, the number of areas managed by the Municipal Secretariat for the Environment of Belo Horizonte has remained constant over the last ten years, with an average of 197 areas per year.

Table 1 shows the percentage of areas managed by economic activity in the period 2009 and 2020 (FEAM, 2019; SISEMA, 2009). Gas stations lead the most managed activities in the state of Minas Gerais, representing more than 70% of the total.

Table 1: Managed areas separated by economic activity in the period 2009 and 2020 in the State of Minas Gerais.

<table>
<thead>
<tr>
<th>Economic Activity</th>
<th>2009</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orphan Area</td>
<td>0.45%</td>
<td>-</td>
</tr>
<tr>
<td>Bases of Petroleum and Alcohol Derivatives</td>
<td>2.27%</td>
<td>2%</td>
</tr>
<tr>
<td>Chemical Products and Pipelines</td>
<td>0.45%</td>
<td>-</td>
</tr>
<tr>
<td>Oil Refining</td>
<td>-</td>
<td>3%</td>
</tr>
<tr>
<td>Metallurgical and Steel Industry</td>
<td>9.55%</td>
<td>7%</td>
</tr>
<tr>
<td>Chemical Industry</td>
<td>0.91%</td>
<td>1%</td>
</tr>
<tr>
<td>Transport Infrastructure</td>
<td>2.27%</td>
<td>-</td>
</tr>
<tr>
<td>Mining</td>
<td>4.09%</td>
<td>2%</td>
</tr>
<tr>
<td>Gas Station</td>
<td>79.55%</td>
<td>75%</td>
</tr>
</tbody>
</table>

Managed Area = 162.98 ln (year) + 72.13

$R^2 = 0.98$

Source: (FEAM, 2020).
The accidental release of significant amounts of fuel on the ground has been increasingly common due to the amount of fuel stored and dispersed throughout the state (OLIVEIRA; LOUREIRO, 1998). At the national level, Minas Gerais has the second highest concentration of oil product sales stations, a total of 10.9% (ANP, 2019).

The metallurgical and steel industry deserves to be highlighted in the percentage of managed areas representing 9% of the total. The State of Minas Gerais has the highest concentration of steel companies in Brazil, mainly due to the proximity of raw materials (INDI, 2020).

Due to the participation of large multinational industries in this sector, the identification of contaminated areas is favored by constant inspection by public bodies, in addition to internal inspections carried out by the companies themselves.

Regarding the management stages in Minas Gerais, in 2009 around 53% were classified as contaminated area under intervention (ACI) while in 2020 the percentage decreased to 29% (Table 2).

<table>
<thead>
<tr>
<th>Management Steps</th>
<th>2009</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contaminated area under intervention</td>
<td>53%</td>
<td>29%</td>
</tr>
<tr>
<td>Contaminated area under investigation</td>
<td>20%</td>
<td>12%</td>
</tr>
<tr>
<td>Area under monitoring for rehabilitation</td>
<td>25%</td>
<td>26%</td>
</tr>
<tr>
<td>Rehabilitated area</td>
<td>2%</td>
<td>33%</td>
</tr>
</tbody>
</table>

Source: (SISEMA, 2009; FEAM, 2020).

The increase in rehabilitated areas from 2 to 33% from 2009 to 2020, respectively, stands out. According to FEAM, 2020, these data reflect an expected continuity following the management steps, as the reductions in areas under monitoring for rehabilitation are being accompanied by an increase in the number of areas rehabilitated in recent years.

In the State of São Paulo, the Environmental Company of the State of São Paulo (CETESB) has been annually publishing reports containing information pertinent to the state's contaminated areas, such as FEAM in Minas Gerais (CETESB, 2009; CETESB, 2010; CETESB, 2011; CETESB, 2012; CETESB, 2013; CETESB, 2020).
There is an oscillation in the number of contaminated areas under investigation from 2009 to 2019 with the peak in 2010 reaching 2088 areas (Figure 2). In June 2013, Decree No. 59,263 was created, which provides guidelines and procedures for the protection of soil quality and management of contaminated areas (SÃO PAULO, 2013).

While CONAMA Resolution No. 420, defines only four classes of contaminated areas, that is, Suspected contamination area – AS, Contaminated area under investigation – AI, Contaminated area under intervention-ACI and Area in the monitoring process for rehabilitation-AMR, the Decree No. 59,263 defines eight classes of contaminated areas namely: Contaminated area under investigation (ACI), Contaminated area under remediation process (ACRe), Contaminated area under reuse process (ACRu), Contaminated area with confirmed risk (ACRi), Area with potential for contamination (AP), Area in process of monitoring for closure (AME), Area rehabilitated for declared use (AR) and Area with suspected contamination (AS).

Due to this new definition in 2013, a gap is observed in the graph of contaminated areas in the State of São Paulo in the same period.

Figure 2: Number of contaminated areas in the State of São Paulo between 2009 and 2019.

The rehabilitated areas did not undergo changes with the advent of the new state legislation, and it is possible to evaluate it from 2009 to 2020. As observed in Minas Gerais, the growth trend has been constant (Figure 3). Through a nonlinear polynomial model, whose observed coefficient of determination was 99%, it is possible to estimate an increase to more than 6,700 rehabilitated areas in the next ten years.

Assessing the contaminated areas in the process of monitoring for completion, which represents areas in which no risk was found, or the remediation goals were achieved after implementing the remediation measures (SÃO PAULO, 2013), an increase from 2013 to 2020, from 987 to 1369, respectively.

The increase in rehabilitated areas and areas in the process of being monitored for completion, both in Minas Gerais and in São Paulo, show the positive effect desired by CONAMA Resolution No. 420. In addition to observing the increase in the management of contaminated areas, measures were adopted to minimize potential risks.

Figure 3: Contaminated and estimated areas from 2009 to 2020 in the State of São Paulo.

Regarding the percentage of enterprises with contaminated sites registered in the State of São Paulo, gas stations stand out, which from 2012 to 2020 represent more than 70% (Table 3), values very similar to those observed in Minas Gerais.
Table 3: Areas managed by economic activity in the period 2012, 2015 and 2020 in the State of São Paulo.

<table>
<thead>
<tr>
<th>Economic Activity</th>
<th>2012</th>
<th>2015</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry</td>
<td>14.9%</td>
<td>17.1%</td>
<td>20%</td>
</tr>
<tr>
<td>Business</td>
<td>4.7%</td>
<td>5.2%</td>
<td>6%</td>
</tr>
<tr>
<td>Gas Station</td>
<td>76.8%</td>
<td>74.0%</td>
<td>70%</td>
</tr>
<tr>
<td>Residue</td>
<td>2.8%</td>
<td>2.9%</td>
<td>3%</td>
</tr>
<tr>
<td>Agriculture</td>
<td>0.0%</td>
<td>0.1%</td>
<td></td>
</tr>
<tr>
<td>Unknown</td>
<td>0.3%</td>
<td>0.3%</td>
<td>1%</td>
</tr>
<tr>
<td>Accidents</td>
<td>0.5%</td>
<td>0.5%</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100%</strong></td>
<td><strong>100%</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>


The State of São Paulo, in addition to having the highest consumption of oil products, has the highest concentration of retail stations, accounting for 21.8% of the country (ANP, 2019).

From 2013 to 2020 there is an increase in the proportion of managed areas in the road activity in the State of Rio de Janeiro, rising from 2 to 6% (Table 5). Gas stations lead with 55%.

Rio de Janeiro was the only state in the Southeast of Brazil that has waste landfill in its economic activity classification. In the Southeast alone, 10704 tons/day of urban solid waste were sent to landfills in 2018 (ABRELPE, 2019). The high volume of waste and the non-selectivity of compounds make these areas one of the main contaminated areas in Brazil, deserving greater attention from the states, not to mention the high number of clandestine deposits spread across cities.

Table 4: Areas managed by economic activity in the period 2009 and 2020 in the State of Rio de Janeiro.

<table>
<thead>
<tr>
<th>Economic Activity</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel station</td>
<td>56%</td>
<td>51%</td>
<td>59%</td>
<td>55%</td>
</tr>
<tr>
<td>Industry</td>
<td>40%</td>
<td>40%</td>
<td>34%</td>
<td>36%</td>
</tr>
<tr>
<td>Waste landfill</td>
<td>3%</td>
<td>4%</td>
<td>3%</td>
<td>3%</td>
</tr>
<tr>
<td>Transport</td>
<td>2%</td>
<td>5%</td>
<td>5%</td>
<td>6%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100%</strong></td>
<td><strong>100%</strong></td>
<td><strong>100%</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

Source: (GEOINEA, 2020).

Unlike the State of Minas Gerais, the states of São Paulo and Rio de Janeiro have a simpler breakdown of economic activities, not discriminating the classes of industries, making comparisons between the states difficult.
The standardization of activities, in addition to favoring technical analysis, would help in joint management measures between neighboring states, as provided for in article 21 of CONAMA Resolution No. 420 (BRASIL, 2009).

Table 5 shows the percentage of managed areas separated by management stages from 2013 to 2015. Through the GeoINEA digital platform, it is not possible to identify the management stages of the state of Rio de Janeiro in 2020, which is a point of improvement.

While Minas Gerais and São Paulo had an increase in the number of rehabilitated areas, the State of Rio de Janeiro was the only one that remained constant in this triennium analyzed.

Table 5: Areas managed by 2013 and 2015 management stages in the State of Rio de Janeiro.

<table>
<thead>
<tr>
<th>Management Steps</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contaminated area under investigation</td>
<td>42%</td>
<td>48%</td>
<td>41%</td>
</tr>
<tr>
<td>Contaminated area under intervention</td>
<td>40%</td>
<td>37%</td>
<td>46%</td>
</tr>
<tr>
<td>Area under monitoring for rehabilitation</td>
<td>14%</td>
<td>12%</td>
<td>8%</td>
</tr>
<tr>
<td>Rehabilitated area</td>
<td>4%</td>
<td>3%</td>
<td>4%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Source: (Adapted from AREAS et al., 2017)

Some authors suggest that the non-growth of rehabilitated areas was due to the recent creation of registries for these areas in 2013, not having enough time for the evolution of their monitoring and management (AREAS et al., 2017).

5 CONCLUSIONS

- In São Paulo and Minas Gerais, the states that have older records, the numbers of rehabilitated areas have gone through constant growth, unlike Rio de Janeiro, which has a younger record. This highlights the importance of this system not only for management but for the correction and rehabilitation of contaminated soils, being a reference point for other Brazilian states that have not started their registration process.
- The lack of standardization in the provision of state data makes it difficult to understand the process at regional and national level.
• It is worth noting the activities of gas stations due to the high number of contaminated areas. The constant management by public agencies is important to minimize the contamination of soil and aquifers.

• The presence of landfills and dumps has the potential to be better addressed in the states of Southeastern Brazil. This region, in addition to being the most populous, has numerous illegal dumps scattered throughout the cities. The role of public bodies in managing these areas is important and encouraging the correct disposal of waste.
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