

Evaluation of environmental rehabilitation practices in bauxite mining at the plateau of Poços de Caldas

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Abstract

Bauxite mining has been carried out around Poços de Caldas, Minas Gerais, since the 1940s. Companies operating in the region pioneered land rehabilitation in Brazil, conducted since the early 1980s. Different procedures of recontouring, runoff drainage, soil preparation and vegetation planting were employed. This research aims to evaluate current environmental rehabilitation practices employed in the region, in order to identify possible deficiencies, investigate probable causes of these deficiencies and prevent recurrence of failures, thus avoiding rework and additional costs to deliver outcomes satisfactory to land owners. Areas with different ages of rehabilitation were studied. The practices adopted in recently rehabilitated mines and in the final phase of operation were evaluated through a problem identification procedure, based on field observations, document analysis and interviews. Some unsatisfactory results were found related to ground terracing, drainage systems, block sliding, soil sampling, soil preparation, planting of vegetation and monitoring of the recovered area. Improvements are proposed, on the basis of good practices, that even if more complex and laborious, can result in future savings, as they enable, in addition to avoiding rework, the fulfillment of contractual obligations to landowners and regulatory bodies.

Keywords: mining, rehabilitation of degraded areas, evaluation, monitoring, topographic reconfiguration, revegetation.

1. Introduction

There is a considerable body of knowledge and extensive practical experience with rehabilitation of land degraded by bauxite mining (Burton *et al.*, 2012). Yet, actual outcomes are not always perceived as satisfactory by local communities (Rosa *et al.*, 2018). This research evaluates the environmental rehabilitation practices in bauxite mining at the Poços de Caldas plateau, in order to identify possible deficiencies and investigate their probable causes, thus contributing to improve outcomes and to prevent failure repetition. Evidence found in some rehabilitated mines in the region indicate a number of recurrent problems, such as soil erosion and stream sedimentation resulting from runoff, unequal crop growth and poor plant development. As a consequence, rework is necessary to deliver outcomes satisfactory to landowners, entailing ad-

ditional costs for mining companies.

Bauxite has been mined in the Poços de Caldas region, Minas Gerais, since the 1940s. Extraction is usually carried out in small pits with a mine life of between 2 and 8 years, footprints of up to 50 hectares, and ore outputs between 15,000 and 20,000 tons/month. Pre-mining land use is predominantly agricultural in a landscape featuring stands of native forests that are currently not mined.

Companies operating in the region pioneered land rehabilitation in Brazil, conducted since the early 1980s (Weissberg, 1995). As the pits are small and mine life is short, mining companies simultaneously operate a portfolio of areas and plan for developing new pits and rehabilitating mined out deposits. Therefore, rehabilitation of degraded areas occurs constantly

in this region.

The objective of land rehabilitation in these mines is the restoration of the previous land use (Bizuti, 2017). Landowners inform the companies their intended post-mining land use, what guides rehabilitation practices. Most owners want their land to be used either for producing marketable eucalyptus or for raising cattle. Nevertheless, actual rehabilitation outcomes are sometimes contested by landowners, who perceive limitations in the post-mining land use, such as inadequate growing of grass for cattle raising and irregular tree development.

Hence, this article explores the following research question: if land rehabilitation has been conducted in the region for so many years, and the purpose of rehabilitation is, in most cases, simply

to return mined land to agricultural use, why are there complaints from landowners and documented failures?

This research seeks to collect

2. Materials and methods

A combination of document review, field observations and interviews was used to collect evidence about land reclamation conducted in two mines. Daily bauxite is mined and land is rehabilitated by several companies operating in the Poços de Caldas region. The two case studies that make up the work were selected according to the schedule of the companies that agreed to participate in this research. The reviewed documents were rehabilitation plans and monitoring reports. The interviews were conducted with: (i) representatives of companies, (ii) officers of government agencies responsible for the inspection of the enterprises, and (iii) landowners where mining activities occur. Site visits aimed at observing ongoing rehabilitation works and inspect rehabilitated areas. Guidance for the field observation was obtained from literature review, in particular good practices for rehabilitation organized by Neri and Sánchez (2010, 2012). Evidence was collected aiming at identifying what is effectively implemented and possible deviations from the declared or prescribed practices.

After initial talks to managers of three companies operating in the region, two agreed to participate by facilitating access to the sites, documents and interviews. Two mines were intentionally selected, one from each company, being

evidence of perceived rehabilitation failures and to explore their possible causes, hypothesising that they could stem from: (i) inadequate technical guid-

ance; (ii) high costs of applying good practices; (iii) low technical capacity; or, (iv) practical problems in the execution of rehabilitation actions.

under rehabilitation during the research period (rehabilitation started in January 2018) and another recently rehabilitated (late 2015 and early 2016). Field observations were conducted in both sites, looking for evidence of topographical, edafic and ecological rehabilitation practices (Almeida and Sánchez, 2005; Neri and Sánchez, 2012). The following items were checked by walking the area: (i) presence of erosive features, of mass movements and final terrain recontouring; (ii) return of topsoil, soil preparation (decompaction, liming and fertilizing); (iii) planting of seedlings (trees) and seeds (grasses).

In reviewing documents, information was collected to characterize each mine (extraction method, amount of material removed, post-mining land topography, crop employed in rehabilitation, etc.), its surroundings, rehabilitation objectives and techniques adopted. The chemical analysis of the soil is intended to determine the nutrient content and physicochemical parameters that may interfere with its availability to the plants. The parameters determined by the soil chemical analysis were compared with the established reference values for the desired crop type, thus allowing for the classification of the soil fertility level and the indication of the amount of correctives

and fertilizers to be applied for maximum crop yield (Prezotti, 2013).

The interviews were semi-structured (Manzini, 2003), which basically consists of a previous analysis of factors such as language, form, sequence of questions in the scripts, among others. This interviewing mechanism is designed to optimize information transmission, especially avoiding inappropriate use of jargon, multipurpose questions and inappropriate sequence of questions in the script.

The mines studied for this research were operated by different companies. Mine 1, under rehabilitation, had a mineral reserve amounting to 220,000 metric tons, mined intermittently over 4 years. According to the landowner's choice, post-mining land use should be pastures for cattle raising. For that purpose, the company seeded the most preferred grass in the region, *Brachiaria*. Monitoring the development of the culture chosen by the owner is conducted on a monthly basis for two years, when the area is scheduled to be handed over to the owner's care. In mine 2, approximately 90,000 metric tons of bauxite were mined through periodic extractions over 3 years until 2015. Following the landowner's choice, post-mining land use is growing *Eucalyptus*, suitable for the pulp and paper industry.

3. Results

In this section, results are first presented for each mine, followed by a synthesis of the interviews.

3.1 Mine 1

Rehabilitation activities are started immediately after extraction ends. The first stage of this process is recontouring, which usually occurs by replacing topsoil removed previously and stocked in the minesite and, if necessary, materials from other regions are used to set the ground. A backhoe or loader is used to load a truck with the topsoil, the truck unloads heaps of material into the mine in a spaced way and a bulldozer spreads and levels the ground, recontouring according to the slope of the terrain, in order to protect the land from erosion and to prevent landslides or overloading of the drainage

systems and protecting the fertile soil layer. Grating occurs previously to soil preparation for planting. This operation consists in the use of a tractor with a grid composed of plow discs. The tractor moves on the ground with the grid attached to it and the plow discs have the function of cutting the soil, breaking the clods and leaving the soil in the smallest granulometry possible to receive the next phase.

Soil preparation is very important for the good formation of a pasture. The first stage is liming, the application of finely ground limestone with the purpose of increasing the calcium

and magnesium percentage, correcting soil pH and neutralizing the action of aluminum (toxic element for plants) (Embrapa, 2018). Liming at this mine was developed by four employees who manually applied dolomitic limestone. Afterwards, the area was manually fertilized, followed by application of humus, organic matter resulting from the decomposition of dead animals and plants, where bacteria, fungi and external agents (such as humidity and temperature) contribute to its formation. Humus releases several nutrients, is an organic fertilizer and contributes to

effective and long-lasting fertilization.

The culture chosen for the revegetation of this mine is *Brachiaria*. Planting was conducted manually by four employees who dispersed seeds and scratched the area with the use of hand rakes. The intention of this step is to homogenize the seed to the other components applied

3.2 Mine 2

This mine was rehabilitated at the beginning of 2016 to produce marketable eucalyptus. At the time of field work, it was observed that the spacing used is the same as recommended by literature (Embrapa, 2018), 3x3 meters. The occurrence of erosive processes in the main access road to the property was detected.

The ore extraction at the site finished in June 2015, and the topographic reformation occurred in the months of July and August of 2015. Through the images available, the existence of a large number of rock blocks in the soil was detected, where most of the larger blocks were displaced to the lower part of the mine, in order to avoid future landslides.

3.3 Interviews

As previously mentioned, the purpose of the interviews is to acquire information from the point of view of each party involved, including company employees, environmental agency employees responsible for supervising the developments and owners of rural properties in which mining activities occur. A questionnaire was developed and handed to each interviewee with the declared commitment of not disclosing the name of the company and of the interviewee, whereby

4. Discussion

In Mine 1, it was observed that in many points, the level contours cause the water runoff to flow longitudinally through the mine, but as final systems to capture this water were not implemented, the water flows through the access roads of the mine, causing erosion and preventing vehicle traffic.

Some considerations can be made about soil preparation and planting. Initially, good practices related to the rehabilitation of degraded areas recommend that a soil chemical analysis be done previous to the application of any product, in order to determine soil nutrient contents and indicate the type

to the soil, in order that the germination and the development process happen more quickly and efficiently.

Although standard procedures were followed, failures were detected in the terracing practices, which resulted in erosion problems. Regarding soil preparation and planting, deficiencies were also observed,

The planting of eucalyptus occurred in January 2016, during the rainy season for the best possible outcome.

The type of fertilizer used to prepare the soil was not remembered by the employee of the company that collaborated with the information and was not included in the photographic collection. After planting, herbicide, insecticide and mineral oil were applied with spray pumps. Succinctly, mineral oil is applied to potentialize plant capacity to absorb nutrients; the herbicide is indicated for the control of weeds; and the insecticide is a product intended to protect cultures against insects, especially ants (Embrapa, 2018).

The Rehabilitation Plan is part of

the single purpose of the interview was to gather information on the opinion of the interviewee. Three people were interviewed, one from each group.

Succinctly, the owner of the rural property where mine 1 is located considered that there are some aspects that can be improved in the recovery developed, such as: reduction of the time between the end of the extraction and the beginning of the recovery, slope of the inserted roads and standardization of the planting. The

and amount of fertilizer to be applied for the best development of the cultures. In this mine, this analysis was not done by the company. The chemical analysis is fundamental to verify soil fertility conditions and the results found are directly used as a basis for fertilization. Thus, it may be that the fertilizer used is not the most indicated, or that the amount applied is lower or higher than adequate. This can lead to high costs in the preparation of the soil or entire loss of the process because some seedlings may not develop as a consequence of the lack of nutrients, whereby all the products used and the procedures devel-

resulting in poor formation of the crop chosen for planting.

Monthly visual inspections are performed by the company after planting. The aim is to monitor the development of the vegetation, detect possible deficiencies and document vegetation growth through photographs.

the regulatory RCA/PCA (Environmental Control Report and Environmental Control Plan), a document prepared by an outsourced consultancy that prescribes rehabilitation practices in a way that is easy to understand for anyone who is responsible for coordinating the team that carries out these activities. According to the company, monitoring is limited to photographic register and no other information is required by the environmental regulatory agency.

Failures were observed in the terracing practices, which resulted in erosion problems, alongside water runoff channels in the tree plantation area, rock block landslides and slope landslides at the main mine access road.

company employee acknowledged some points that should be improved, however, says that the company develops the best possible service according to the working conditions and budget offered to the sector. The representative of the environmental agency responsible for inspection said that the mechanisms used are lagging, and that the number of employees is incompatible with the number of areas to be supervised, which prevents periodic inspections in each area.

oped in them are lost. The application of all the products (limestone, fertilizer, humus and seed) was done manually, which caused an unequal release along the extensive terrain, resulting in an asymmetric development of the culture, as expected in the future accompaniments. Differently from all the comings and goings that the employees underwent to apply these products, the correct thing would have been to carry out all the applications with a tractor, and to use a device coupled to it to spread the limestone homogeneously on the ground. Fertilizer, humus and seed could be homogenized and applied

in the same action by the tractor (since planting occurs on the same day that the mix is prepared) either with the same device (used for the limestone) for this process or some other equipment developed for this function. This would have optimized pasture development, making the process faster (Embrapa, 2016). Regarding liming, Embrapa (2016) recommends that the limestone be applied in the area before plowing and after the grating (in this case only the second stage was developed). The liming should be done between 60 and 90 days before planting, unlike the less-than-one-week interval used. Regarding the soil raking after planting, the process would be optimized if the tractor was used with the leveling grid closed, in a regulated way, so the discs would be parallel to the direction of the advance of the equipment, so that the seeds are covered by the soil and especially so that they do not bury them at depths greater than 4 centimeters.

In general, the accompaniments found results already expected over the months. Figure 1 (a) presents a superficial way for the development of vegetation after 6 months of planting. In several places vegetation development occurred unequally (Figure 1 (b)). This fact is a consequence of the failures previously mentioned in the preparation and planting of the soil. Finally, Figure 1 (c) portrays erosion grooves resulting from erroneous procedures in the topographic reformation stage, in addition to a poor formation of the vegetation. This phenomenon was unleashed by improper ground terracing in this locality in the mine, so that the level curves were not able to control the longitudinal flow of the water, resulting in these erosive processes. This fact can lead to problems between the miner and the landowner because as the formation

of pasture is for cattle, these erosions can bring risks to the physical integrity of the animals.

In the Mine 2, several erosive problems were detected since the planting phase. During January, there were irregular water flows in the plantation (Figure 2 (a)), accumulation of water in several points of the area and on the access roads, sliding of rock blocks (figure 2 (b)) and slides in the cut slope implemented for the delineation of access roads to the plantation. These problems are the result of an erroneous reformation of the terrain. The mine is characterized by an accentuated declivity, therefore ground terracing should have occurred based on safety measures to avoid rough outflow and water accumulation on the ground. This uneven flow of water along the terrain may have withdrawn the nutrients from the reformed soil, reducing soil fertility for seedling development. Another inadequate factor was in relation to the rocky blocks. Even though it was affirmed by the company representative that the tractor removed the larger blocks from the tops of the area, it was proven in practice that not all were removed, leading to landslides that may have killed several seedlings and could even have led to worse problems.

The only record of monitoring the development of vegetation occurred in December 2016 (Figure 2 (c)), eleven months after planting Eucalyptus. According to a company employee, the monitoring of the site was monthly, however no other photographic records occurred. After planting, the company had a contractual obligation to take care of the development of the culture for two years, whenever necessary carrying out interventions in the area, such as brushing, applying herbicide and insecticide. The owner of the rural

property has a contractual obligation to neither develop any type of activity in the area in the same period nor release any kind of animal in the area. Since January 2018, the care with the Eucalyptus plantation became the sole responsibility of the owner of the farm.

Chemical analyses of soil were not performed previously to planting. The company claimed by that "a number of neighboring properties had been mined and reclaimed in the past, so it was already possible to have a notion of the chemical characteristics of the soil in the mine". This attitude was erroneous because soil studies show that samples from near places could have different chemical properties (Prezotti, 2013).

All the contents that make up the RCA/PCA are approached in a broad and comprehensible way throughout the text, which facilitates the understanding of the employees who put into practice what was established. However, companies do not always exactly follow what is established in the documents, often because of: (i) inadequate technical guidance, (ii) high costs for applying good practices, (iii) low technical capacity of company professionals or, (iv) problems in the execution of rehabilitation actions. Based on the results obtained in the accompaniments and the relationship achieved with the various employees of the company, the qualification, orientation and commitment of the professionals are not questionable, however, the company's involvement in relation to environmental rehabilitation and the supervision of the regulatory bodies can be. As the organ rarely inspects remote locations, companies develop rehabilitation with focus on costs, and secondly the quality of actions, which should be the contrary, often resulting in poorly elaborated procedures and poorly developed cultures.



Figure 1 – Superficial development of vegetation (a), poor vegetation formation (b) and erosion grooves at the main mine access (c).



Figure 2 – Irregular water runoff in the plantation (a), rock block landslides (b) and the only record of monitoring the development of vegetation (c).

In general, the failures in both companies start from the same principles: erroneous practices of recontouring, causing erosion, falling blocks and landslides, as well as soil preparation and planting. The companies chose not to carry out chemical analysis of the areas to be rehabilitated. Through the interviews, it was verified that because they have developed this type of activity for many years in the region, they do

not see the need to analyze each specific area, which could be a reason for the perceived failures in the development of cultures. Apart from visual inspection and photographic documentation, the companies do not monitor the area, mainly due to lack of regulatory obligations and oversight of government agencies. In interviews, the representative of environmental agency claimed that they do what they can with what

is available to them, due to the low contingent and lack of investments by the government in hiring employees, buying vehicles, releasing funds for inspections and basic infrastructure of the agency, among others. The interviewee declared that they require well-prepared documents to obtain the environmental licenses, and inspect the maximum of possible areas through field visits and satellite images.

5. Conclusions

Based on the results analysis, it can be concluded in relation to the mines studied that:

I) Some different procedures could have been carried out in recontouring. In Mine 1, ground terracing was coherent, the level contours are at safe distances from each other, but as the flow of water occurred longitudinally through the mine, it would require gutters so that water would not flow over the roads, as well as sinks able of supporting the volume of water accumulated at the end of these gutters, which would avoid the erosive processes found in the access roads of the mine. Mine 2 was located in a very steep region. Since ground terracing into level contours was implemented far apart, there occurred irregular water flow along the ground, which may have withdrawn the nutrients from the reconfigured soil, and thus decreased the fertility of the soil for the development of seedlings. Another inadequate practice was in relation to the rock blocks, which should have been removed and allocated to the lower part of the terrain, but were not. Therefore, there were these blocks slid in several points of the mine, which may have caused the mortality of several seedlings;

II) Regarding soil preparation and planting, before taking any action, chemical analysis of the soil of the mines should

have been carried out. The grating operation was performed only once, although it is recommended that it be done at least twice, with a liming between them and another liming afterwards. The planting should be done between 60 and 90 days after this action. All products were applied manually and not with the use of a tractor with an equipment coupled for spreading, which provoked unequal releases along the extensive terrain, resulting in asymmetric culture developments. Also, in pursuit of a more homogeneous action, raking could have been replaced by a tractor with a leveling grid or a coupled subsoiler.

III) The accompaniments of Mine 1 led to what was already expected: unequal development of the *Brachiaria* pasture. Mine 2 has only a photographic record of monitoring the vegetation. It is recommended that monitoring reports on the rehabilitated areas be prepared, with regular monitoring and photographic collection of all dates.

IV) The Rehabilitation Plan of Mine 2 contains sufficient guidelines for carrying out rehabilitation works, which facilitates the understanding of the employees to put into practice what which was established. Yet, failures were observed.

V) Through the interviews, it was possible to recognize the fundamental role

that mining has in the region of Poços de Caldas, and that even with some deficiencies in the programs of rehabilitation, it is possible to notice the evolution over the years and increased attention to the subject by all parties involved in the proceedings.

It is noteworthy that for the present research, only one mine was studied from each company that agreed to participate in the research, chosen by the companies themselves according to their activity schedules. Therefore, it is clear that the procedures adopted can be improved. Based on the possible hypotheses of failure occurrence, it can be concluded that companies should give autonomy and provide resources to their employees so that they can develop their services in the best possible way. It has been found that more rigorous application of good practices, even if more complex and laborious, can result in future savings because they do not need to conduct rework, a situation also observed in other small scale mines (Jesus and Sánchez, 2013), in addition to complying with obligation to landowners and the regulatory bodies. In addition to government agencies, landowners can also exercise an important role to improve outcomes, filing complaints to the mining company and regulators, if rehabilitation is unsuccessful.

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