“BEFORE THE MINING COMPANIES ARRIVED, WE PRODUCED A LOT... NOT ANYMORE”: THE IMPACT OF COAL MINING ON AGRICULTURAL PRODUCTION IN COMMUNITIES SURROUNDING THE MINES IN MOATIZE

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The texts published in OBSERVADOR RURAL are in draft form. The authors are grateful for contributions to deepening and corrections to improve the document.
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THE IMPACT OF COAL MINING ON AGRICULTURAL PRODUCTION IN COMMUNITIES
SURROUNDING THE MINES IN MOATIZE

SUMMARY

"Before the mining companies arrived, we produced a lot.... Not anymore." "They don't care about us". "Nor is it worth complaining". This is the tone in which the communities express their dissatisfaction with the mining activity carried out in the Moatize district. These communities powerlessly and first-hand observe their land and production capacity being traded for a dream of development that is increasingly distant, as poverty grows within their families. But the question that remains unanswered is: "What to expect in a place where the group of excluded and dissatisfied people only grows?"

The objective of this Observador Rural was to analyse the impact of coal mining on agricultural productivity in Moatize, focusing essentially on the communities living in the vicinity of the mines. To this end, primary data collection was carried out in the district, through surveys and interviews, to understand the socio-economic situation of local communities (with a special focus on agriculture) in the period before and after the mining activity. Soil samples were also collected in order to analyse the impact of soil pollution on agricultural productivity in Moatize.

Among the main results, the reduction in the production of some agricultural crops in the year 2022 stands out, when compared to the period before 2011 (the year of inauguration of a mining complex for large-scale coal extraction). According to the information obtained in the surveys, the loss of land for mining, dust pollution and reduced water availability may have contributed to a decrease in agricultural productivity, production and incomes at the local level. Laboratory analyses of the samples collected revealed contamination of the soils of Moatize with substances such as copper, chromium, iron, manganese and zinc, with the possibility of these contaminants being of mining origin.

Key words: Coal mining, Agricultural productivity, Soil contamination, Moatize

1. INTRODUCTION

With the discovery of large resource reserves in Mozambique, the contribution of the mining sector to the national GDP changed from a constant 1% until 2010 to an average of 7% in the following years. However, this “development” has not been inclusive, as a large part of the Mozambican population still lives in extreme poverty. Authors, such as Azevedo (2020), argue that, although there are positive and negative impacts of mining activity at all scales, most of the negative impacts (such as water scarcity, environmental pollution and resulting socio-economic impacts) are observed in the communities where mining occurs. In fact, it is noted that a similar pattern of events and reports is observed in some studies conducted on coal mining in other parts of the globe. For example, in a

1 Data from the Instituto Nacional de Estatística (INE).
survey conducted in the Dinajpur district of Bangladesh, in a rural community where the Barapukuria coal mine was operating, problems such as reduced agricultural production were identified (Harun-Or-Rashid et al., 2014). A study carried out in the municipality of Itamarati, in the Brazilian state of Minas Gerais, concluded that the appearance of dust and reduced water availability were caused by mining, affecting the livelihoods of communities based on small-scale agriculture (Henriques & Porto, 2015). In the survey by Monteiro et al. (2020), on the impact of opencast coal mining in the localities of Benga and Moatize, in the Moatize district, reports from surveyed residents indicate that the land did not have good production, when potential sources of land degradation had already been addressed in the Environmental Impact Assessments (EIAs) of some companies operating in the district (Monteiro et al., 2020).

The objective of this study was to analyse the impact of coal mining on agricultural production in Moatize (based on respondents' perceptions), focusing essentially on communities living in the vicinity of the mines. The period of analysis in this study was considered to be from 2011 to 2022, since it was in 2011 that the mining company VALE (one of the large-scale coal mining companies in Moatize) inaugurated a new coal extraction complex at the Moatize mine (Cascais & Riffel, 2011; Valoi, 2022).

This study aims to answer the following research question: "How is the impact of coal mining on agricultural production of communities living in mining areas, based on respondents' perceptions, in Moatize district?" In order to answer the question, household surveys were conducted. Soil samples were also collected and analysed (in the laboratory) at locations close to potential sources of mining pollution in order to determine the possible impact of substances found in high concentrations on the agricultural productivity observed and reported by respondents.

2. DESCRIPTION OF THE PROBLEM

Coal mining in Moatize began in 1940, with annual production of around 10,000 tonnes of coal (MAE, 2014). By 1975, this production had grown exponentially to 575,000 tonnes (MAE, 2014). From 1982 to 1985, a total of 8 million tonnes of coal were produced, extracted from the Moatize basin (Passe, 2018). When the VALE project in Moatize was established in 2011, it was stated that 11.3 million tonnes of coal would be produced per year until 2046 (Valoi, 2022). However, after 10 years of exploration and criticism, not only from communities, but also from civil society organisations, academics, among others, VALE announced its withdrawal plan, selling the mine to Vulcan Minerals (of the Jindal group2 for 270 million dollars (DW, 2021).

In the context of the socio-economic and environmental impacts of mining, the expression "the resource curse" has been debated by the academic community to designate the paradox that countries that own, exploit and export mineral resources usually experience slower growth than other resource-poor countries, in addition to a greater likelihood of negative social effects such as authoritarianism, corruption and poor economic performance (Azevedo, 2020; Lima, 2011). This may

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2 At present, there are large-scale coal mining operations conducted by VULCAN (VALE’s replacement), ICVL and MINAS DE MOATIZE, according to information obtained in an interview with the District Services of Economic Activities (SDAE) of Moatize.
occur due to the absence of a consolidated democracy and the high economic dependence on mineral extraction activity (Azevedo, 2020; Lima, 2011). In this context, local communities bear all the impacts arising from the establishment, development and closure of mining activities (such as land loss, environmental pollution and resulting socio-economic impacts), benefiting little from the rents resulting from it (Azevedo, 2020).

According to MEF & MITADER (2015), the significant industrial mining activity observed in the district may involve direct disturbance to soils. The direct impact on the environment comes from dust, from the circulation paths\(^3\), from the extraction operations and from the processing and storage of coal (MEF & MITADER, 2015). According to Bomfim (2017), apart from particulate matter (dust), another significant form of environmental pollution from mining is explosions. Air pollution, however, is not limited to activities in the mine (Milanez, 2017). Particulate matter is dispersed by winds, reaching areas outside the mining areas, tens of kilometres from the emission sources (MEF & MITADER, 2015). This aspect was also observed in the study by Milanez (2017), in the city of Vitória (Brazil), where “black dust”, as the particulate material was locally called, from the loading operation of ore ships in a port facility, compromised the air quality of the city.

When present in the environment, the dispersion of pollutants depends on various factors, such as the accentuated relief of the region, the runoff and infiltration of rainwater, enabling the contamination of soil (and water bodies) and jeopardising their productivity (Ávila et al., 2015). Macie (2015), in a study on the environmental impacts of coal mining in the Moatize district, points changes in surface water quality as one of the main impacts. Another study conducted in Moatize identified high levels of contamination in surface soils, sediments and in the waters of the Murrongoze and Moatize rivers by heavy metals such as chromium (Cr), copper (Cu), manganese (Mn) and zinc (Zn), among others (Marove et al., 2022). When such waters are used for irrigation of the farms, crop abnormalities, reproductive structures, cell growth and production (Huerta et al., 2022), yellowing/whitening, necrosis and loss of leaves, root atrophy, among others can be observed (Cooperative Extension Service, 1998; Kayo).

According to the EIAs presented by Vale and Riversdale, the vicinity of their mines (Moatize and Benga) to the settlements of Moatize and the city of Tete, and to the Zambezi and Revubóé rivers, increases the risk of negative impacts on the economy, especially in the case of mitigation failures (Monteiro et al., 2020). There are communities that reside in the path followed by the winds that carry the air pollutants resulting from mining, becoming factors of land degradation, and not only (Monteiro et al., 2020). According to the EIA on the Moatize- Malawi railway, impacts on soil could arise from the generation of waste and effluents [from maintenance workshops and during spraying (herbicides) on the railway reserve strip] during the works phase, but these were considered to be minor (Aurecon, 2011). The emission of dust and particulate matter (PM10 and total suspended particles) during the construction phase, resulting from vehicle movements, excavations, wind erosion of exposed surfaces, earth movements, was considered as an impact of medium significance (Aurecon, 2011). In the operation phase, one of the main activities generating negative environmental impacts is the railway transport of coal (combustion engines’ gas emissions, and emission of particulate matter from coal being transported due to wind). However, the EIA considers that the impacts of these

\(^3\) The district’s main access routes (roads N7 and N9, and the Sena railway line) are potential pollution hotspots, with a focus on coal transport by rail (MEF & MITADER, 2015).
activities in the operation phase will not be very significant since, according to the EIA, the implementation of the measures proposed in the Environmental Management Plan (EMP) allows a possible reduction of about 50% of the impacts derived from wind (Aurecon, 2011). However, during their research on the impact of opencast coal mining in the localities of Benga and Moatize in the Moatize district, Monteiro et al. (2020) obtained reports from surveyed residents that the land no longer had good production, reports that are similar to those obtained in the present study. On the other hand, Monteiro et al. (2020) report that over 90% of respondents have observed an improvement in water availability in the last 5 years. Part of the respondents in the present study also mentioned having observed improvements in water availability, however, another part complained about its scarcity. In relation to this aspect, the literature argues that mineral extraction can cause the lowering of the water table, resulting in a decrease in the flow of water from rivers, among other impacts (Milanez, 2017). Two impacts can result from these factors: (1) When aquifer levels are reduced, conditions for salinization are created (Pierson, 2019). When using salinized water for irrigation, soils become salinized, which in itself negatively impacts crop growth and yields (Joint Research Centre, 2019; Ye et al., 2022); (2) When cleaning coal with high ash content, such as the coal from Moatize, around 5 to 10 tonnes of water may be used per each tonne of coal (Arsentyev et al., 2016). Another aspect related with mining that can also result in the reduction of water volume is siltation (accumulation of sediments in watercourses) (Henriques & Porto, 2015). In fact, it was reported, during the interviews in this study, that one of the rivers dried up as a result of the activity (more details on this issue are discussed in section 4 "Presentation of Results" of this report).

3. METHODOLOGY

3.1. Description of the Study Area

Three areas were selected for this study in two localities of Moatize, namely: Moatize-sede locality (having worked (1) in the town of Moatize, in three of its neighbourhoods (Liberdade, 25 de Setembro and Bagamoyo); and (2) in the community of Ntchenga) and Benga locality [(3) Chitambo community]. These places were selected based on the research of Monteiro et al. (2020) on the impact of opencast coal mining (in Benga and Moatize localities) and on the field experience of Justiça Ambiental related to the impact of coal mining in Moatize district.

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4 Construction Phase: (i) Restrict deforestation and earthmoving to what is strictly necessary; (ii) Humidification of traffic lanes, in critical roads, by water trucks; (iii) Determine a maximum speed of 30 km/h for the circulation of vehicles in critical roads; (iv) Adequate maintenance of the vehicle fleet, avoiding excessive emissions of gases and particles (black smoke) from the internal combustion engines of vehicles and mobile machinery; and (v) Recovery of the vegetation cover of exposed areas, stabilizing the surface and avoiding the generation of dust immediately at the end of the construction phase (Aurecon, 2011). ∥ Operation phase. (i) Application of suppressive agents to the coal in wagons, with possible reapplication along the track if necessary; and (ii) Preventive and corrective maintenance of the equipment that makes up the suppressive agent application systems (Aurecon, 2011).

5 In a process called beneficiation, whose function is to modify and purify the raw coal (Run-of-Mine - ROM) in order to obtain a suitable material for industrial use (Passe, 2018).

6 According to Passe (2018)
3.1.1. Geographical location, soil and coal morphology of Moatize

The Moatize District is located in the province of Tete (in central Mozambique), bordered to the north by the districts of Chiúta and Tsangano, to the east by the Republic of Malawi, to the south by the districts of Tambara, Guro, Changara and the municipality of Tete, and to the west by the district of Chiúta (Map 1) (MAE, 2014).

![Map 1](source)

The district of Moatize is located in a region made up of basic rocks, such as gabbro, anorthosites, norites, leucogabbro and others, highlighting the clusters of greyish-brown, shallow reddish-brown soils on limestone rocks and those derived from basaltic rocks (these can be reddish, reddish-brown or black, of variable depth and characterised by good nutrient and water retention capacities) (Passe, 2018). Alluvial soils also occur in small proportions, particularly on the terraces of the Revubué and Zambezi rivers (DNAL, 2014 apud. Passe, 2018).

Moatize is home to the largest coal basin in Mozambique, and one of the largest in the world, with estimated reserves of over 2.5 billion tonnes (Passe, 2018). The Moatize coal seams are composed of greyish-white arkosic sandstone, fine argillaceous or micaceous sandstone with plant fossils and intercalations of black argillite with coal seams (GTK CONSORTIUM, 2006 apud. Passe, 2018). The
quality of the coal from the Moatize coalfield is of high grade\textsuperscript{7}, bituminous type, with volatile content ranging from high to low (DNG, 2006 apud. Passe, 2018). They are rich in vitrinite, poor in liptinite, with varying sulphur content, and have a high level of ash (Passe, 2018).

3.1.2. Demography of Moatize

The population of the district is 260.8 thousand inhabitants in 2017\textsuperscript{8}. The age group structure is 9 people of working age for every 10 children or elders (MAE, 2014). Households in the district consist of 4.5 members on average (MAE, 2014). The main sociological type of families in the district is nuclear with children (i.e. with one or more relatives in addition to children) (MAE, 2014).

3.1.3. Socioeconomy of Moatize

Coal mines, railways and tobacco cultivation are essential in the district’s economy and are also important sources of income that absorb a large share of the local labour force (MAE, 2014). Agriculture is the dominant activity and involves almost all households (MAE, 2014). Along the Zambeze River, irrigated agriculture is carried out using mechanical means of propulsion (MAE, 2014). Further into the district some small irrigation systems are used in agricultural production (MAE, 2014). Agriculture is mostly practised manually on small family farms under intercropping arrangements based on local varieties (MAE, 2014). The main food crops grown are maize, sorghum, millet, sweet potato, nhemba and butter and peanuts, in addition to some vegetables such as cabbage, onions, tomatoes, okra, garlic and pumpkin (MEF & MITADER, 2015). "Given the importance of coal mining, Vale Mozambique and other entities, such as NGOs, have carried out some projects to promote agriculture" (MEF & MITADER, 2015). On the other hand, the occupation of soils with agricultural aptitude by mining projects has been a barrier to agricultural production, giving rise to land use conflicts (MEF & MITADER, 2015). Other important constraints to agricultural production in the district are climate issues, pests, drought and lack or insufficiency of improved seeds (MEF & MITADER, 2015).

Moatize is connected to the national electricity grid system that covers the district headquarters and some localities and settlements (MAE, 2014). This electricity grid supplies public services, households, the commercial sector, businesses, commercial establishments, among others (MAE, 2014). The main source of energy used by households is oil (49%) (MAE, 2014). The majority (94%) of dwellings in the district are owned, with shack being the dominant type (74 %) (MAE, 2014). About 31% of households have access to drinking water sources and about 10% of households use improved sanitation systems (MAE, 2014). Moatize has a water supply system set up in the district headquarters, which supplies

\textsuperscript{7} Coal’s chemical and physical composition varies widely depending on its type (Takanohashi, 2011). The widely used ASTM (American Society for Testing and Materials) classification system defines four levels of coals (presented here in ascending order of quality), namely: lignite, sub-bituminous coal, bituminous coal and anthracite (according to their carbon content, calorific value and percentages of volatile materials) (Takanohashi, 2011). The carbon content in coal ranges from 65% to 95% and increases with the concomitant decrease in the percentages of oxygen and hydrogen, which usually range from 2%-30% and 2%-7%, respectively (the nitrogen and sulphur content is only 1 to 4%, regardless of the coal rank) (Takanohashi, 2011). "According to Suárez-Ruiz and Crelling (2008), a high-quality coal is a coal with low mineral matter content and high organic matter content" (Pass, 2018).

\textsuperscript{8} Data from INE (2017).
the residents of Moatize village through fountains (MAE, 2014). The district also has two small water supply systems in the resettlement neighbourhoods of Cateme and Muaradzi (MAE, 2014). In other parts of the district, supply is via boreholes and wells (MAE, 2014). However: "...the level of service, in terms of water supply and sanitation, is far from desirable, leaving many families dependent on unsafe water sources... with serious consequences for their livelihoods and public health" (MEF & MITADER, 2015).

3.2. Methodology of the study

Both quantitative and qualitative methodologies were used in this study, consisting of applying and processing surveys, applying interviews, collecting soil samples and processing laboratory results, and conducting semi-structured interviews.

The fieldwork was carried out in two periods, the first from 5 to 12 May and the second from 18 to 24 July 2022\(^9\). In the first fieldwork the interviews and collection of soil samples were carried out, and in the second the questionnaires were conducted.

3.2.1. Interviews and questionnaires

The interviews were conducted with the chiefs/heads of neighbourhood, farmers and officials of the District Services of Economic Activities (SDAE) of Moatize\(^{10}\). The interviews conducted served to gain a better understanding of the study area, which assisted in the preparation of the Household (HH) questionnaire and this report.

The questionnaires were applied to HH living in the mining areas. The surveys were intended to collect information on the income obtained by households before and after the inauguration of the mine (2011 and 2022, respectively), the evolution of agricultural and livestock production in the same period and its factors, the perception of respondents regarding the impact of mining on the community, the contribution of mining companies to community development and the socio-economic situation of communities, among other aspects.

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\(^9\) During the fieldwork, support was provided by Justiça Ambiental (JA!).

\(^{10}\) Interviews were requested with some mining companies operating in the district, without success.
The questionnaires were carried out by local surveyors, selected on the basis of their experience in conducting surveys and fluency in local languages. They underwent a one-day training given by the author of this study before the questionnaires was undertaken in the field.

The local guides (chiefs and heads of neighbourhoods/units) were appointed by the SDAE and the Moatize Municipal Council. These guides served as liaison between the task team and the surveyed HHs. During the questionnaires, it was decided to work with non-resettled HHs who had been residing in Moatize since 2011 or earlier. The selection of respondents was randomised.

The data obtained from the surveys were processed using the pivot tables and charts.

Sample Size Determination

The number of questionnaires conducted was calculated using the following formula (considering the finite population, i.e. 58,368 households in Moatize district):¹¹

\[
n = \frac{N \cdot \hat{p} \cdot \hat{q} \cdot (Z_{a/2})^2}{(N - 1) \cdot E^2 + (Z_{a/2})^2 \cdot \hat{p} \cdot \hat{q}}
\]

¹¹ Data from INE, 2017
Where:

- \( n \) Number of individuals in the sample
- \( Z_{\alpha/2} \) Critical value corresponding to the desired confidence level
- \( \hat{p} \) Proportion of the population belonging to the study target category
- \( \hat{q} \) Proportion of individuals not belonging to the study target category
- \( E \) Margin of error
- \( N \) Population size

In this case, the critical value used is 1.645 (corresponding to the 90% confidence level) and the margin of error was 10%. Once not estimated, the value of \( p \) and \( q \) will be 0.5 (to obtain the maximum sample size). Thus, the number of questionnaires to be carried out per district is

\[
n = \frac{58.368 \times 0.5 \times 0.5 \times 1.645^2}{(58.368 - 1) \times 0.1^2 + 1.645^2 \times 0.5 \times 0.5} = 67.57 \approx 68 \text{ Questionnaires}^{12}
\]

### 3.2.2. Soil data collection

The purpose of the collection and laboratory analysis of the soil samples\(^{13}\) was to determine the possible impact of the substances found in high concentrations in the soils on the agricultural productivity observed by the respondents.

From each of the three mining sources identified in the study area [Benga Coal Mine, Moatize Coal Mine and Section 6 (Mine)], a trajectory was followed to collect five soil samples, at a depth of 20 cm\(^{14}\), totalling 15 samples in the study area (Map 2). These sampling sites were georeferenced with GPS-Locus Map Android version. After collection, the samples were labelled and sent to the Chemistry Laboratory of the Faculty of Sciences, Eduardo Mondlane University, for their analysis (using X-Ray Fluorescence - XRF\(^{15}\)).

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\(^{12}\) A total of 69 questionnaires were conducted, i.e. 23 questionnaires in each study area [in Moatize town, Ntchenga community (Moatize-sede) and Chitambo community (Benga locality)].

\(^{13}\) The possibility of storing different substances in soil makes it possible to analyse historically the activities in the study area and their impact, which is an advantage not observed in the case of air and water. For example, what was airborne and deposited in soil some years ago may no longer be identifiable in the air (if the emitting source has been eliminated), but may still be found in soils. This is also the reason why only one soil sampling was carried out in this study (a spacing of at least two years between different samplings is recommended - this period depends on what you want to analyse).

\(^{14}\) The top 20 cm of the soil belongs to the root zone of most of the crops grown by farmers.

\(^{15}\) This method was selected because it does not require prior dissolution of the samples (which would involve the use of more reagents, which would reduce the preservation of soil characteristics in the sample).
### Map 2
*Soil sampling points in the study area*

![Map Image]

### Table 1
*Information on soil sampling*

<table>
<thead>
<tr>
<th>No.</th>
<th>Sample</th>
<th>Description</th>
<th>Geographical coordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bagamoyo1</td>
<td>In Bagamoyo neighbourhood, Moatize town</td>
<td>S16°07.624' E033°43.765'</td>
</tr>
<tr>
<td>2</td>
<td>Bagamoyo2</td>
<td></td>
<td>S16°07.622' E033°43.800'</td>
</tr>
<tr>
<td>3</td>
<td>Liberdade1</td>
<td>In Liberdade neighbourhood, Moatize town</td>
<td>S16°06.725' E033°44.628'</td>
</tr>
<tr>
<td>4</td>
<td>Liberdade2</td>
<td></td>
<td>S16°06.747' E033°44.623'</td>
</tr>
<tr>
<td>5</td>
<td>25_Setembro1</td>
<td>In the 25 de Setembro neighbourhood, Moatize town</td>
<td>S16°06.113' E033°43.649'</td>
</tr>
<tr>
<td>6</td>
<td>25_Setembro2</td>
<td></td>
<td>S16°06.067' E033°43.687'</td>
</tr>
<tr>
<td>7</td>
<td>25Set-Benga1</td>
<td>In the section between Liberdade neighbourhood and Benga locality</td>
<td>S16°06.471' E033°39.623'</td>
</tr>
<tr>
<td>8</td>
<td>25Set-Benga2</td>
<td></td>
<td>S16°06.469' E033°39.678'</td>
</tr>
<tr>
<td>9</td>
<td>25Set-Benga3</td>
<td></td>
<td>S16°06.677' E033°39.655'</td>
</tr>
<tr>
<td>10</td>
<td>Benga1</td>
<td>In the locality of Benga</td>
<td>S16°08.800' E033°38.847'</td>
</tr>
<tr>
<td>11</td>
<td>Benga2</td>
<td></td>
<td>S16°08.564' E033°39.103'</td>
</tr>
<tr>
<td>12</td>
<td>Benga3</td>
<td></td>
<td>S16°08.480' E033°39.403'</td>
</tr>
<tr>
<td>13</td>
<td>Ntchenga1</td>
<td>In the community of Ntchenga, Moatize-sede</td>
<td>S16°13.274' E033°49.200'</td>
</tr>
<tr>
<td>14</td>
<td>Ntchenga2</td>
<td></td>
<td>S16°13.193' E033°49.245'</td>
</tr>
<tr>
<td>15</td>
<td>Ntchenga3</td>
<td></td>
<td>S16°13.347' E033°49.254'</td>
</tr>
</tbody>
</table>
After the laboratory analysis, the concentrations of the elements analysed were evaluated based on the international environmental quality control criteria of the Food and Agriculture Organization (FAO)\(^\text{16}\) and the concentrations of metals in soils without apparent mining influence\(^\text{17}\) based on Passe (2018)\(^\text{18}\). From the set of metals analysed (see Annex)\(^\text{19}\), the results of five of them are presented in this study: copper (Cu), chromium (Cr), iron (Fe), manganese (Mn) and zinc (Zn). These metals have also been analysed in other studies conducted in Moatize district, such as that of Marove et al. (2022), and are discussed here as their concentrations exceeded the FAO standard.

The local averages of the soil samples (calculated from the concentrations of the substances in the samples collected at each sampling point - see Table 2 in section 4 "Presentation of Results") were entered into SPSS for analysis of variance (ANOVA), which consists of identifying statistical differences between the averages of the concentrations of the metals in the different communities surveyed. With

\(^{16}\) For the analyses intended in this study, there are no criteria at national level for comparison purposes. Therefore, the FAO criterion was used because of its universal acceptance. Criteria obtained from: Khan, H. R., Seddique, A. A., Rahman, A., & Shimizu, Y. (18 July 2017). Heavy Metals Contamination Assessment of Water and Soils in and Around Barapukuria Coal Mine Area, Bangladesh. American Journal of Environmental Protection, pp. 80-86.

\(^{17}\) Obtained from samples collected at the Moatize Administrative Post. This information was used to verify whether the concentrations of the substances found in the soil samples are of their nature or not. If they are not, there is a possibility that they have been added as a result of mining. More details are discussed in section 4 ("Presentation of Results").

\(^{18}\) For budget reasons, it was not possible to analyse soil samples without apparent mining influence in this study. Therefore, the study by Passe (2018) was used.

\(^{19}\) Although Cadmium (Cd), one of the parameters considered important in this study, was part of the list of parameters analysed in the laboratory, it is not presented in this report because it was detected in the samples in quantities below the XRF detection limit.
this method, it was intended to observe some pattern in the concentrations of the substances in the
different sampling sites, which could support a common factor between them (sites): the existence of
potential sources of pollution from coal mining.

3.3.3. Data on heavy metals contaminating the study area

The contaminating substances in the study area, according to the laboratory analyses of the collected
soil samples, are: copper, chromium, iron, manganese and zinc. However, some of these substances
are beneficial to plants at given concentrations. To mention, copper\textsuperscript{20} and zinc\textsuperscript{21} are necessary for
plant growth and development (Britannica - The Editors of Encyclopaedia, 2022a; Passe, 2018) and
manganese\textsuperscript{22} is essential not only for growth but also for nitrate assimilation in plants and algae
(Britannica - The Editors of Encyclopaedia, 2023a; Passe, 2018).

However, high levels of copper, iron\textsuperscript{23} and zinc impact the production of crops such as maize, creating
abnormalities in reproductive structures, plant growth and cell production (Huerta \textit{et al.}, 2022; Passe,
2018). Although maize can tolerate high concentrations of heavy metals without interrupting its life

\textsuperscript{20} It is a metallic chemical element that can be found in a free state in nature (Britannica - The Editors of
Encyclopaedia, 2022a). Because it is very ductile and a good conductor of electricity and heat, copper is widely
used in the electricity industry (Britannica - The Editors of Encyclopaedia, 2022a). It is also associated with metals,
such as zinc, tin, and nickel, to form metal alloys, such as brass, bronze, and others (Britannica - The Editors of
Encyclopaedia, 2022a). In compounds, copper usually has valence 1 (cuprous) or 2 (cupric) (Britannica - The
Editors of Encyclopaedia, 2022a). Cuprous compounds constitute pigments, fungicides, catalysts for certain
organic reactions, etc. (Britannica - The Editors of Encyclopaedia, 2022a). Cupric compounds include wood
preservatives, disinfectants, food additives, pesticides, and others (Britannica - The Editors of Encyclopaedia,
2022a).

\textsuperscript{21} It is a metallic chemical element, ductile when pure (Britannica - The Editors of Encyclopaedia, 2023b). It forms
brass (with copper) and many other metal alloys (Britannica - The Editors of Encyclopaedia, 2023b). Its principal
use is in galvanising iron, steel, and other metals (Britannica - The Editors of Encyclopaedia, 2023b). Zinc oxide is
used as a pigment, dietary supplement, cosmetics, plastics, pharmaceuticals, and so on (Britannica - The Editors
of Encyclopaedia, 2023b). Many other zinc compounds (of valence +2 or, rarely, +1) are used as pesticides and
wood preservatives (Britannica - The Editors of Encyclopaedia, 2023b).

\textsuperscript{22} It is a hard, brittle, silvery-white metallic chemical element widely distributed in the Earth’s crust in combination
with other elements (Britannica - The Editors of Encyclopaedia, 2023a). Manganese compounds are used in
fertilisers, textile printing, and as reagents (Britannica - The Editors of Encyclopaedia, 2023a).

\textsuperscript{23} It is one of the most widely used metals on the planet, making up 5% of the earth’s crust, making it the most
abundant metal after aluminium (Britannica - The Editors of Encyclopaedia, 2022b). Iron is also the fourth most
abundant element on earth, after oxygen, silicon and aluminium (Britannica - The Editors of Encyclopaedia,
2022b), and is an important element in the composition of mineral coal (Speight, 2013 apud. Passe, 2018). In the
human body, 65% of existing iron is in the form of haemoglobin (responsible for transporting oxygen in the
blood) (Britannica - The Editors of Encyclopaedia, 2022b). Iron sulphate, heptahydrate, serves as a raw material
for the manufacture of various other iron compounds and as a reducing agent (Britannica - The Editors of
Encyclopaedia, 2022b). It is used in the manufacture of paints, fertilisers, pesticides, and for electroplating iron
(Britannica - The Editors of Encyclopaedia, 2022b). Ferric sulphate is used as a coagulant in water purification and
sewage treatment, and as a fixative in textile dyeing and printing (Britannica - The Editors of Encyclopaedia,
2022b).
cycle and reproductive process, the development of various organs of plants grown near mines is affected, due to the inhibition of cell production and growth (Huerta et al., 2022). Chromium\textsuperscript{24} is toxic to plants even at low concentrations (Asati et al., 2016, Minari et al., 2020 \textit{apud} Kayode et al., 2022), causing yellowing/whitening of leaves, stunting of roots and inhibition in growth (Kayode et al., 2022). Studies on the impact of chromium on maize crops point to significant reduction in root growth and cell damage (Maiti et al., 2012). Excess manganese in plants is toxic, with toxicity symptoms varying according to plant species and plant tissue organs affected (Britannica - The Editors of Encyclopaedia, 2023a; Cooperative Extension Service, 1998). On older leaves, symptoms usually appear as small yellowish to dark brown spots, necrotic lesions, and chlorosis of leaf edges and tips (Cooperative Extension Service, 1998). Eventually, the leaves dry and fall off (Cooperative Extension Service, 1998). These symptoms are believed to be caused by manganese oxides (Cooperative Extension Service, 1998). In young leaves, symptoms commonly include leaf “puckering”, resembling calcium deficiency (Cooperative Extension Service, 1998). There is evidence that “leaf puckering” is a consequence of manganese-induced calcium deficiency (Cooperative Extension Service, 1998).

4. PRESENTATION OF RESULTS

4.1. Brief Description of the Questionnaires Sample

The sample consisted of 69 households (HHs). The average number of members per household in the study population is 5.5 persons. Of the 69 households surveyed, 52 are headed by men (75%) and the remaining 17 by women (25%). The average age of male household heads (HHHs) is 43 years and of female HHHs is 48 years old. The majority of HHHs (male and female headed) have completed primary level of education. Regarding marital status, 71% of the HHHs were in a marital union, 13% were widowed, 10% were single, 4% were married and 2% were divorced.

In 2022, most of the HHs are engaged in activities such as manufacturing/selling of forest products and wage labour (carried out by 32% of the surveyed HHs in both cases). Farming is the third most practised activity among HHs (30%), followed by resale of food products at stalls (23%), construction or sale of building materials (9%), animal breeding (7%), various odd jobs (4%), sale of clothes (3%), plumbing, traditional medicine and fishing (1% each).

\textsuperscript{24} It is an abundant metallic element in the earth’s crust whose free metal is never found in nature (Gregersen, 2023). It is mostly found in the form of the mineral chromite (FeCr2O4) (Gregersen, 2023). It can also be found in association with manganese, aluminium and silica (Gregersen, 2023). One of the main uses of chromium is in metal alloys (stainless steel, etc.) to increase strength and corrosion resistance (Gregersen, 2023). Several coloured gemstones (such as ruby, emerald and serpentine) derive their colour from chromium. Chromium trioxide is used in chrome plating and as a colorant in ceramics (Gregersen, 2023). Chromium oxide, lead chromate and various other chromium compounds are used as pigments (Gregersen, 2023). It usually has the valence +2, +3 or +6, but some other compounds may have the valence chromium +5, +4 and +1 (Gregersen, 2023).
Between 2011 and 2022, 43% of the surveyed HHs observed an increase in their annual income, 33% observed a decrease and 23% observed no change. In the group of HHs who observed an increase in annual income, the majority mentioned having a job\textsuperscript{25} (57%), with 30% of the latter reporting being employed by a mining company or a mining company subcontractor. It should be noted that mining company/subcontractor jobs represent 50% of the jobs of HHs who observed an increase in their annual income\textsuperscript{26}.

On the other hand, 30% of HHs who observed a reduction in income mentioned practising agriculture. Indeed, while annual incomes from wage labour increased by 28% over the period 2011 to 2022, incomes from crop production decreased by 21% over the same period (survey data).

4.2. General Impacts of Mining Companies on the Community

Regarding the impacts of mining companies on their community, the following positive impacts, the provision of clean water (mentioned by 25% of the total respondents), employment to locals (16% of respondents), construction/rehabilitation of schools/hospitals (14%) and provision of groceries or "txopelas" (10%), and among the negative impacts, the emergence of health problems due to environmental pollution (88%), water pollution (67%), loss of land (51%) and air pollution (26%)\textsuperscript{27}.

During the interviews in the Ntchenga community, it was mentioned that Vale supplied water by tanker truck as a way to make up for the water shortage resulting from the drying up of the Nhacamuanzi River (due to mining activity). Different authors argue that the use of water for coal cleaning can result in a significant reduction in river flow, even causing salinization (Arsentyev et al., 2016; Milanez, 2017; Pierson, 2019). As a result, in addition to water shortages for people, impacts on agriculture can be observed when using salinized water, such as reduced crop growth and reduced harvests (Joint Research Centre, 2019; Ye et al., 2022).

When asked about their satisfaction with the water supply, respondents mentioned that it has been irregular, which may intensify with the departure of this mining company. It is thus possible to note some unsustainability in the solution found to replace the river on which the community depended on for consumption and irrigation of their fields.

Of the total number of respondents, only 27% mentioned that they would be resettled\textsuperscript{28}. However, when respondents without resettlement plans were asked if they would like to be resettled, a large proportion responded positively, due to factors such as dust pollution (mentioned by 52% of HHs

\textsuperscript{25} The HHH him/herself or some other member of the HH
\textsuperscript{26} 88% of mining/subcontractor jobs lasted at least 1 year, and 69% were permanent. It was not the aim of this study to qualitatively analyse mining jobs.
\textsuperscript{27} Each respondent mentioned more than one impact, so the sum of the percentages is not 100%.
\textsuperscript{28} Respondents awaiting resettlement had promises made at different times over a period between 2010 and 2021. None of the households surveyed in this study had been resettled by the time of the surveys.
who would like to be resettled), explosions and resulting impacts (41% of the same HHs) and water contaminated by pollution (17%).

### 4.2.1. Impacts on Agriculture

Analysing the data obtained from the surveys regarding the agricultural practice of HHs, it can be seen that 90% practised agriculture before 2011 and only 64% practised in 2022. Of the HHs whose total annual income has reduced, 22% mentioned having stopped producing at least one of the agricultural crops they produced before 2011 and 26% mentioned having lost their agricultural land to mining.

Based on the analysis of the surveys, it was found that of the total number of households’ surveyed practising agriculture in 2022, about 47% observed a reduction in the quality and volume of their agricultural production. On the other hand, about 18% observed an improvement in the production and quality of agricultural products (with the use of agricultural inputs mentioned as the main reason for this improvement) and 35% observed no change.

Among the households that reported a reduction in the volume and quality of agricultural production, a large proportion identified drought/lack of water (33%) and dust (29%) as possible causes of the reduction in the quantity produced; and dust (45%), loss of soil quality (15%) and lack and/or poor quality of agricultural inputs, particularly seeds (15%), described as possible causes of the reduction in the quality of agricultural products, perceived by HHs due to the size and aspect of these products. This reduction affected most of these households (HHs). According to the survey results, about 63% of HHs who obtain income from agricultural production report a reduction in income obtained in 2022 compared to that obtained before 2011.

According to the results of this study, there has been a reduction in the number of HHs producing certain crops, as shown in Chart 1. However, for the case of some crops, such as watermelon, sweet potato, lettuce, beetroot, onion, mango, pepper, chilli and cabbage, there was no reduction in the number of HHs practising these crops in the period analysed.

Chart 1 shows the reduction in the proportion of respondent households by crop produced, before 2011 and in 2022. Among the respondents practicing agriculture, it was noted that a large part produces maize, having the number of producers of this crop reduced by about 23% (87.1% before 2011 to 64.5% in 2022). Other crops that recorded relatively smaller reduction in the number of

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29 Cracks in walls and collapsing houses, increased dust and dust sedimentation on clothes and outdoor dried food (e.g. flour), etc.
30 During the farmer interviews conducted in this study, it was mentioned that VALE provided seeds for the 2021/2022 campaign.
31 Some respondents who noted a reduction in the quality and volume of their agricultural production said they did not know what the possible reasons might be. On the other hand, some respondents mentioned more than one possible reason. For these reasons, the sum of the percentages is not 100%.
producers are nhemba beans and sorghum (13% each), tomatoes, cucumbers and vegetables \(^{32}\) (10% each), okra and peanuts (8% each) and pigeon pea (2%).

**Chart 1**

*Evolution of the number of producers by crop before 2011 and in 2022*

It can be seen from Chart 1 that the proportion of pigeon pea producers in the total number of HHs surveyed is low. However, when analysing the universe of producers of this crop, it appears that 50% of the respondents who produced it before 2011 no longer produce it in 2022, which is therefore the largest reduction between crops. Next, a reduction of about 46% is observed in tomato producers, followed by nhemba beans (31%) and sorghum, maize and okra (between 29% and 21%). The crops that registered the lowest percentages of reduction in the number of producers were peanuts, cucumbers and vegetables (below 20%).

Regarding the causes for the reduction in production of these crops, a large part of the surveyed HHs mentioned the following factors:

- **Loss of agricultural land to mining**: mentioned by more than 80% of the HHs who stopped producing peanuts, okra, vegetables, nhemba beans, tomatoes and pigeon peas, and about 60% of maize, cucumber and sorghum producers. Among the HHs producing these crops and who lost land, only 30% received cash compensation and another 20% have been waiting for compensation for about 10 years\(^{33}\).

- **Contamination of river water by charcoal**: mentioned by about 56% of HHs who obtain income from agricultural production, of which 38% used this water for irrigation. This coincides with what was observed by Macie (2015) in a study on the environmental impacts of coal mining in Moatize district, where he pointed out changes in surface water quality as one of the main impacts.

- **Reduction in water availability**: Between 20% and 40% of respondents who stopped producing okra, vegetables, maize, sorghum and cucumber mentioned having observed some reduction in water availability for the community. When asked about the practice of irrigation in their fields,

\(^{32}\) Lettuce, cabbage, spinach, and others are included in the group of vegetables.

\(^{33}\) The remaining 50% mentioned that they no longer expect to be compensated.
44% of respondents who stopped producing any crop irrigated before 2011 and only 17% still irrigated in 2022. Considering the drying up of the Nhacamuanzi River, it may be that a double impact on production was observed, i.e. the reduction and consequent salinization of water for irrigation (as reported during interviews in Benga and Moatize town, the water became salty with the coming of mining).

Among the respondents who stopped producing at least one crop, 56% observed an increase in their annual income generated from non-agricultural economic activities between 2011 and 2022, with resale of food products at commercial stalls, sale of forest products and wage labour being the activities most indicated as having increased income in 2022 compared to 2011. Of the total number of respondents who stopped producing any crop, 6% were employed by a mining company. Thus, the influence of income from mining/subcontracting jobs on the reduction of agricultural practice is negligible.

On the other hand, 30% of respondents who observed a reduction in income from the sale of their agricultural production reported an increase in annual income from other economic activities (animal breeding being the activity most frequently mentioned as having increased their income in 2022); however, 50% of respondents with reduced agricultural income observed no change in income from other economic activities and 20% noted a reduction.

4.2.1.1. Results of soil analyses

Charts 2 to 6 show that the average concentrations of copper, chromium, iron, manganese and zinc exceed the respective FAO recommended levels (red line) in almost all sampling locations [except for zinc in Bagamoyo neighbourhood (Moatize town) and Benga locality]. The average values are also higher than the concentration of the metal in soils without apparent mining influence (yellow dashed line) (Passe, 2018), which suggests that the concentration of the substances found in the soil samples is not of their nature, but has been added. In another study conducted in Moatize, these substances were also contaminants found in surface soils, sediments and the waters of the Murrongoze and Moatize rivers (Marove et al., 2022).

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34 Among respondents who have stopped producing some crops and previously practised irrigation, in 2022, 25% still irrigate and 75% no longer practise agriculture.
**Chart 2**

Average Copper concentration levels at the different sampling sites, the FAO standard and metal levels in areas with little mining influence.\(^{35}\)

**Chart 3**

Average levels of Chromium concentration at the different sampling sites, the FAO standard and the levels of the metal in areas with little mining influence.\(^{36}\)

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\(^{35}\) The metal concentration in soils with no obvious mining influence (yellow line) was obtained from the study by Passe (2018).

\(^{36}\) Idem
Chart 4
Average levels of Iron concentration at the different sampling sites and the FAO standard

Chart 5
Average levels of Manganese concentration at the different sampling sites, the FAO standard and the levels of the metal in areas with little mining influence

Idem
As a result of pollution by these substances, impacts on the production of different agricultural crops can be observed. Indeed, a reduction in the quality (size) of harvested products of some crops was observed among respondents, such as maize. Studies on the impact of these metals have concluded that their bioaccumulation can have impacts on maize development (plant growth, among other impacts) (Huerta et al., 2022; Maiti et al., 2012).

4.2.2. Possible origin of the identified pollutants

The average concentrations of copper, chromium, iron, manganese and zinc in the different soil sampling areas exceeded the levels recommended by the FAO in almost all locations. Different studies (mentioned above) have proven the impact of these pollutants on the productivity of different crops, including maize (which is the crop most produced by the respondents, and which has seen a considerable reduction).

Analysing the origin of the pollutants identified in the soil samples, a possible connection is found between soil contamination and the mining activity in Moatize. In the study area, the N7 and N9 roads and the Sena railway are potential hotspots of environmental pollution, with emphasis on the railway transport of coal (MEF & MITADER, 2015). Once available in the environment, runoff and infiltration of rainwater contribute to the dispersion of these substances and consequent contamination of the soil, thus jeopardising its productivity (Ávila et al., 2015). When the watercourses receiving these pollutants as used for the irrigation of fields, they constitute vehicles for soil contamination.

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38 Idem
39 As identified by Marove et al. (2022) in a study carried out in Moatize.
The average concentration values of each soil sample site were entered into SPSS for analysis of variance (ANOVA), which consists of identifying statistical differences between the average concentrations of metals in the different surveyed communities (p-value <0.05)\(^{40}\) (Table 2).

### Table 2
Comparison of local averages of metal concentrations in soil samples

<table>
<thead>
<tr>
<th>Location</th>
<th>Copper (Cu)</th>
<th>Chromium (Cr)</th>
<th>Iron (Fe)</th>
<th>Manganese (Mn)</th>
<th>Zinc (Zn)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bagamoyo</td>
<td>403.9</td>
<td>210.6</td>
<td>143.962.3</td>
<td>2.687.0</td>
<td>255.1</td>
</tr>
<tr>
<td>Liberdade</td>
<td>431.4</td>
<td>353.6</td>
<td>171.132.1</td>
<td>2.579.3</td>
<td>463.8</td>
</tr>
<tr>
<td>25Setembro</td>
<td>489.7</td>
<td>241.7</td>
<td>185.668.2</td>
<td>3.133.0</td>
<td>310.9</td>
</tr>
<tr>
<td>25Set-Benga</td>
<td>444.5</td>
<td>207.1</td>
<td>200.178.1</td>
<td>3.727.7</td>
<td>416.0</td>
</tr>
<tr>
<td>Benga</td>
<td>439.6</td>
<td>249.4</td>
<td>148.667.6</td>
<td>2.865.9</td>
<td>283.0</td>
</tr>
<tr>
<td>Ntchenga</td>
<td>482.0</td>
<td>254.8</td>
<td>191.533.0</td>
<td>3.409.4</td>
<td>353.8</td>
</tr>
<tr>
<td><strong>P-value (0.05)</strong> (^{41})</td>
<td><strong>0.650</strong></td>
<td><strong>0.491</strong></td>
<td><strong>0.128</strong></td>
<td><strong>0.596</strong></td>
<td><strong>0.207</strong></td>
</tr>
</tbody>
</table>

Based on the results, the concentrations of the parameters analysed in the six communities of Moatize did not show statistical differences when compared to each other (i.e., all values were greater than 0.05, which did not allow the rejection of the null hypothesis\(^{42}\)). This may indicate that the averages of the metal concentrations at the different sites, obtained from samples from areas close to potential sources of mining pollution, tend to be practically similar. Therefore, the proximity of the averages of the soil samples collected in the different sites of the study area (where the common factor is mining/potential sources of mining pollution) may be an indicator of the mining source of the pollutants. It is possible to see here a possible connection between soil contamination and mining activity in Moatize.

5. CONCLUSIONS AND RECOMMENDATIONS

Of the total number of HHs surveyed, about one third observed a reduction in the production and quality of agricultural products when compared to the period prior to 2011. According to the perception of the surveyed HHs, the loss of land to mining, dust pollution and reduced water availability (due to drying up of the Nhacamuanzi River) are mining impacts that may have contributed to low agricultural production and consequently reduced income from agriculture. Air pollution from dust was mentioned by almost all HHs surveyed who stopped producing any agricultural crop. Although it was mentioned that the mining companies have developed activities to reduce dust, a large part of the HHs said they have not observed an improvement in the dust situation.

On the other hand, there is a perception that the average annual income from some economic activities, such as wage labour, has increased. Mining/subcontracting jobs account for about half of the jobs of HHs who observed an increase in their annual income. However, no significant influence

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\(^{40}\) Normal distribution of concentrations was observed.

\(^{41}\) The values are all greater than 0.05, meaning that there is a lack of statistical evidence of differences between the average concentrations at the 5% significance level.

\(^{42}\) H(0): “There are no significant differences between the averages of the samples from the different sites”.
of obtaining jobs in mining/subcontracting companies on the reduction of the production of the surveyed crops was observed according to the survey data.

Therefore, it is concluded that even if there is some contribution of mining companies in increasing yields, as observed by some respondents with jobs in mining companies or subcontractors, there is also a negative impact on the means of agricultural production, which extends to the medium and long term. Thus, in the analysed communities, there is a minority who enjoy jobs that will last until the mines close, while the vast majority already see their rivers dry up and their farmland turned into mines, with adverse effects on their productivity. Thus, and as also argued by Henriques & Porto (2015), there is no financial compensation to repair what has been lost.

We need to start looking at the healthy environment as a human right. The Constitution of the Republic mentions this aspect, and the Environment Law consents, also mentioning that there is a “fundamental duty to defend and conserve the environment”. Indeed, environmental impacts of this nature can result in major problems and social tensions. What is observed in the study area, as well as in other parts of the country, is that both this right and this duty are neglected. The ability to produce one’s own food and income, to obtain water, and other aspects related to general well-being and stability, is exchanged for development that is little perceived by a large proportion of the people, who, in this transaction, find themselves further impoverished, and, feeling betrayed by the idea of development that has not taken hold, become prone to creating and/or joining movements rooted in their discontent. And in the end, mining and this idea of development are transferred elsewhere, while more and more communities remain without production, without water and left to their fate.

It is possible, however, to make better use of mining. In order to turn the impact of extractive activity into a positive one, it is suggested to:

- Improved environmental quality control (e.g. through sustainable and effective dust abatement measures) in order to reduce its impacts (such as contamination and consequent sterilisation of soils, etc.).
- Increased commitment by government bodies to monitoring environmental quality and following up community concerns.
- The creation of other economic activities and the empowerment of communities in these same activities in order to diversify sources of income, in a continuous effort aimed at economic sustainability. It should be noted that some mining companies, such as Vale, have had social responsibility initiatives, such as support for agricultural campaigns, which is very positive, but not sustainable. It is also (and mainly) necessary to invest in longer-term initiatives (as is the case of the health unit built by Vale in the 25 de Setembro neighbourhood in the town of Moatize). The new sustainable economic activities generated could benefit those who have lost agricultural land and beyond. This will require joint work between mining companies, government entities and civil

43 Another important impact is on public health, but this was not the objective of this study. Due to its relevance, it could be addressed in future studies.
society organisations in aspects such as financing, priority setting, training, etc. (entities from each sector may have different levels of contribution in different aspects).

- Monitoring the use of water for mining purposes to avoid overuse (to the detriment of communities) and improving the water supply process to eliminate irregularities in supply and ensure that water scarcity in communities is removed.
- The search for alternatives to the use of water resources for coal processing in order to reduce pressure on existing resources.
6. BIBLIOGRAPHICAL REFERENCES


https://www.semanticscholar.org/paper/Coal-Structure-and-Properties-Takanohashi/cf9b12f0376ba67581c9a19b2b25911c1e212715


7. **ANNEX - Substances Analysed in the Laboratory and Standards Consulted**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Aluminium (Al)</th>
<th>Calcium (Ca2+)</th>
<th>Lead (Pb)</th>
<th>Copper (Cu)</th>
<th>Chromium (Cr)</th>
<th>Iron (Fe)</th>
<th>Manganese (Mg2+)</th>
<th>Manganese (Mn)</th>
<th>pH</th>
<th>Potassium (K+)</th>
<th>Silica (Si)</th>
<th>Zinc (Zn)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1A1</td>
<td>239.532,9</td>
<td>46,0</td>
<td>60,6</td>
<td>447,0</td>
<td>208,6</td>
<td>144.175,9</td>
<td>1,2</td>
<td>2.913,7</td>
<td>7,7</td>
<td>0,4</td>
<td>460.397,1</td>
<td>568,3</td>
</tr>
<tr>
<td>P1A2</td>
<td>240.614,1</td>
<td>32,0</td>
<td>58,7</td>
<td>415,8</td>
<td>212,6</td>
<td>143.748,7</td>
<td>2,4</td>
<td>2.460,4</td>
<td>7,1</td>
<td>0,4</td>
<td>492.524,0</td>
<td>359,2</td>
</tr>
<tr>
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<td>199.668,6</td>
<td>14,0</td>
<td>60,6</td>
<td>392,0</td>
<td>156.268,3</td>
<td>1,6</td>
<td>2.196,3</td>
<td>8,1</td>
<td>0,1</td>
<td>497.222,3</td>
<td>206,2</td>
<td></td>
</tr>
<tr>
<td>P2A2</td>
<td>179.404,5</td>
<td>38,0</td>
<td>58,7</td>
<td>415,8</td>
<td>353,6</td>
<td>185.995,9</td>
<td>2,4</td>
<td>2.962,2</td>
<td>8,0</td>
<td>0,3</td>
<td>384.018,6</td>
<td>304,0</td>
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<td>248,0</td>
<td>176.079,4</td>
<td>1,6</td>
<td>2.950,5</td>
<td>8,1</td>
<td>0,2</td>
<td>432.534,9</td>
<td>325,7</td>
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<td>192.305,7</td>
<td>38,0</td>
<td>60,6</td>
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<td>235,4</td>
<td>195.257,0</td>
<td>2,0</td>
<td>3.315,6</td>
<td>7,5</td>
<td>0,2</td>
<td>450.059,1</td>
<td>291,6</td>
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<tr>
<td>P4A1</td>
<td>203.144,3</td>
<td>19,2</td>
<td>27,5</td>
<td>403,4</td>
<td>155,7</td>
<td>198.194,5</td>
<td>2,0</td>
<td>4.455,2</td>
<td>6,4</td>
<td>0,3</td>
<td>490.754,9</td>
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<td>23,6</td>
<td>45,3</td>
<td>485,6</td>
<td>258,5</td>
<td>212.589,9</td>
<td>1,6</td>
<td>4.494,5</td>
<td>7,0</td>
<td>0,4</td>
<td>471.422,6</td>
<td>454,2</td>
</tr>
<tr>
<td>P4A3</td>
<td>185.859,8</td>
<td>22,8</td>
<td>23,9</td>
<td>454,6</td>
<td>208,1</td>
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| Standards |
|------------|-------------|-------------|------------|-------------|------------|-------------|----------------|------------|-------------|-------------|-------------|
| FAO & EA   | 100,0       | 100,0       | 100,0      | 50,000,0    | 2,000,0    | 300,0       | 5,0-8,0^45   | 70         |
| Moatize Soils | 15         | 75          | 60         | 819         | 70         |
| NSW        | 5,0-8,0^45   | 70          |            |             |            |             |                 |            |

Note 1: Some parameters showed values below the levels detectable in laboratory XRF analysis. This is why some spaces in the table are empty.

Note 2: Concentrations above the FAO criteria are marked in yellow.

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44 Concentration of the substances in question in soils without apparent mining influence (Passe, 2018).
45 Although this is the optimum limit for different crops, it is possible to observe growth of certain plants outside it, in the range of 4.2 - 8.8 (Lake, 2000).
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