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Assessments, changes, challenges, and solutions

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Impact of mining on the environment and water resources in northeastern Angola

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Abstract: Mining, and particularly diamond exploitation, is one of the most ancient human economic activities and even today plays a crucial role in the economy of many countries. Our study aimed to inventory and map mining activities in the northeastern provinces of Angola (Lunda Norte and Lunda Sul) to enable the subsequent assessment of their impact on the natural environment and on water resources. To achieve this aim, we carried out several field campaigns. Various effects on the environment have been observed, ranging from visual impact to deforestation, soil depletion, and changes in topography. Water resources are the most affected part of the ecosystem, resulting in pollution of lakes and rivers, changes in river courses, silting of streams, and the dry-up of some watercourses. As a whole, our observations show that the effects of mining activities on water pollution in rivers impact large parts of the northeastern provinces of Angola and reach the border areas of the inner Congo Basin.

Resumo: A mineração, especialmente a exploração de diamantes, é uma das actividades económicas antigas dos homens e, até hoje, desempenha um papel crucial na economia de muitos países. Este estudo teve como objectivo efectuar um inventário e o mapeamento das actividades mineiras nas províncias do Nordeste de Angola de Lunda Norte e Lunda Sul, para uma posterior avaliação do seu impacto no meio natural e nos recursos hídricos. Para atingir esse objectivo, foram realizadas várias campanhas de campo. Observaram-se vários tipos de impactos no ambiente, desde impactos visuais e desmatamento, depleção do solo e mudanças na topografia. Os recursos hídricos são a parte mais afectada do ecossistema, resultando em poluição de lagos e rios, mudanças nos cursos de rios, assoreamento de riachos e extinção de alguns cursos de água. De um modo geral, as observações mostram que os efeitos das actividades de mineração sobre a poluição das águas dos rios cobrem quase todas as partes das províncias do Nordeste de Angola, e atingem as áreas fronteiriças da bacia interna do Congo.

Introduction

Mining can take a variety of forms, such as quarrying, dredging, drilling of wells, and other forms of surface exploitation, but also includes subsurface activities carried out in underground mining galleries. According to Craig et al. (2007), extractive activities can lead to a number of environmental problems, among which those related to sterile (sediment) discharges during the clearing and extraction processes and to wastewater discharges resulting from extraction treatments should be particularly highlighted. There is, of course, a set of standardized measures and procedures for the proper conduct of mining activities. However, the mode of exploitation depends greatly on the characteristics of the minerals and

the interests and responsibility taken by the explorer.

The extraction of diamonds in the northeastern Angolan provinces of Lunda Norte and Lunda Sul dates back to the first decade of the 1900s, thanks to the discovery of large deposits of diamond, which are still being exploited there today. The deposition of Phanerozoic sedimentary sequences resting discontinuously on previously eroded surfaces (Pereira et al., 2003) and the subsequent breakup of Gondwana during the Jurassic to Cretaceous, between 190 and 60 Ma (e.g., Jelsma et al., 2004), caused the development of basins that are associated with deep fault systems in Angola. These fault systems facilitated the intrusion of alkaline, carbonatic, and kimberlite magmas (Pereira et al., 2003) and permitted the

mineralization of diamonds in the region, primarily in the eastern parts of Angola.

As one of the traditional economic activities in the Lunda provinces, diamond mining plays a crucial role in the region's economy and supports many livelihoods. Activity is dispersed over large areas of the northeastern region following along kimberlitic rocks and fluvial sediments. However, information is lacking on the degree of environmental transformation caused by the impacts of such anthropic mining activity. Therefore, the main focus of this study is to present an environmental diagnosis of the mining activities carried out in the northeastern provinces of Angola, including a brief summary of the mining procedures and their implications for the natural environment.

Methods

Between 2014 and 2016, we conducted several field campaigns covering Angola's Lunda Norte and Lunda Sul provinces in order to carry out an inventory of mining-related land use activities and their respective characterisations. During each campaign, we visited some of the large enterprises that constitute the main actors of mining in the region. The campaigns took place in both the dry and rainy seasons. We applied qualitative methods such as observation, photographic documentation, and comparison of main features to describe the location, type, and characteristics of the activities carried out and to observe the extant sterile and waste treatments, e.g. the mineral extraction areas, tailings, sterile deposits, stockpiles, camps and warehouses, and treatment areas. To estimate the loss of vegetation, surrounding natural land was compared with exploited areas, which allows assessment of mining's effects at the landscape level.

The conditions for the treatment and disposal of mine wastewater into rivers or retention basins, river deviations, sediment inputs, and silting of streams were recorded. We also assessed the state of affected river sections and of undisturbed river sections under natural conditions, with emphasis on the modification of river margins, turbidity of the water, silting, and sediment loads.

In the next step, we analyzed the acquired data, conducted photograph and aerial image interpretation, and integrated the results in thematic maps. Change detection was done by visual image interpretation. In some cases, this involved comparing different places with different land uses; in other cases, we analysed time series of mining hotspots in order to detect changes within the systems.

To quantify impacts at landscape scale, we studied the land use evolution in the Cuango municipality by comparing the area occupied by mining, urban settlements, and undisturbed land between 2005 to 2015. Our methodology involved a land-use classification of Landsat images, based on a mixed-scale approach using descriptive statistics and GIS tools, which allowed us to calculate the land cover maps and the occupied area for

each of the analysed land use types and their respective percentage of change.

In order to broaden the spectrum of information available for study, interviews were conducted with members of the local population, exploration company technicians, artisanal miners, local authorities at different levels, and stakeholders from related national authorities (e.g., water, geology, mining). These populations were asked about the benefits of the mining operations for the communities, their aspirations, and about the inconveniences caused by mining. For mining technicians, managers, and prospectors, the focus of the interview was on work procedures and environmental responsibility. For government authorities, the most frequently addressed issues were compliance with mining regulations; management of possible conflicts between stakeholders, especially between local populations and mining companies; and concerns regarding local water supplies and the implications caused by the use of untreated water from rivers affected by mining operations.

Results

Mineralisation and forms of mineral exploitation

The diamond reserves in the Lunda provinces can be found as kimberlitic rocks and as alluvial deposits. Kimberlites are primary mineralisation which occur in

the depths and reach the surface; alluvial deposits are secondary mineralisation, occurring as a result of weathering and erosion of the superficial part of the kimberlite—their material accumulates in the most superficial layers. Depending upon the type of mineralisation, the ore can be explored using different techniques. In both cases, it is necessary to remove huge quantities of sterile materials (e.g., thick layers of gangue) before reaching the ore layer (gravel). This implies occupying large areas of land for the deposition of waste rock, as well as other spaces required for the treatment of the ore and the tailings for the washing water produced during the operational processes.

Mining activity in the Lunda provinces is carried out at three scales: an industrial scale, which operates large-scale mining projects; a semi-industrial scale in which newly created mining cooperatives operate; and finally, an artisanal scale, the so-called 'garimpo'.

Industrial mining exploitation

Industrial diamond mining is carried out by large enterprises employing heavy and varied machinery; these efforts occupy large tracts of land. For both types of deposits, industrial-scale extraction is done using open pit mines. In the case of kimberlites, the pits can reach depths of more than 90 m, whereas with alluvial deposits, the diamond can be found in more superficial gravel layers. Industrial

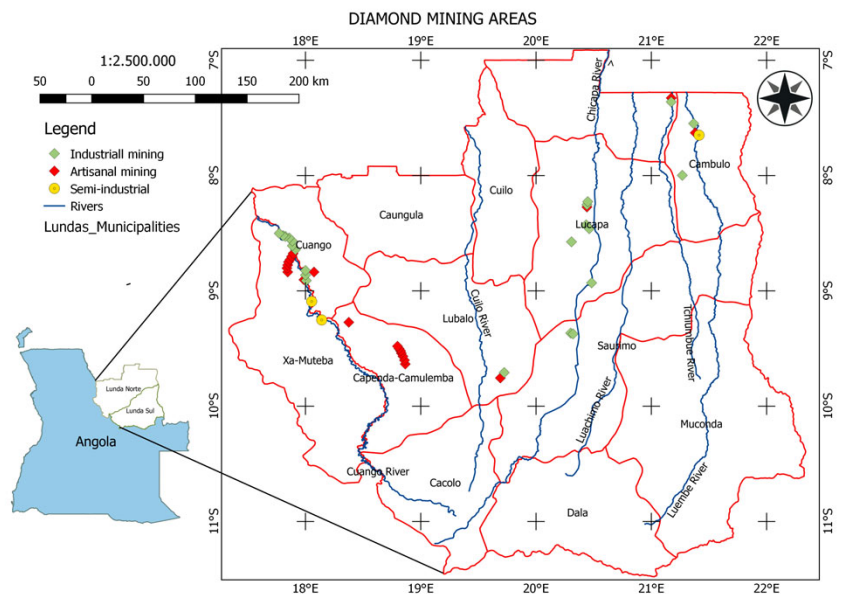


Figure 1: Distribution of mining activities in the Lunda provinces.

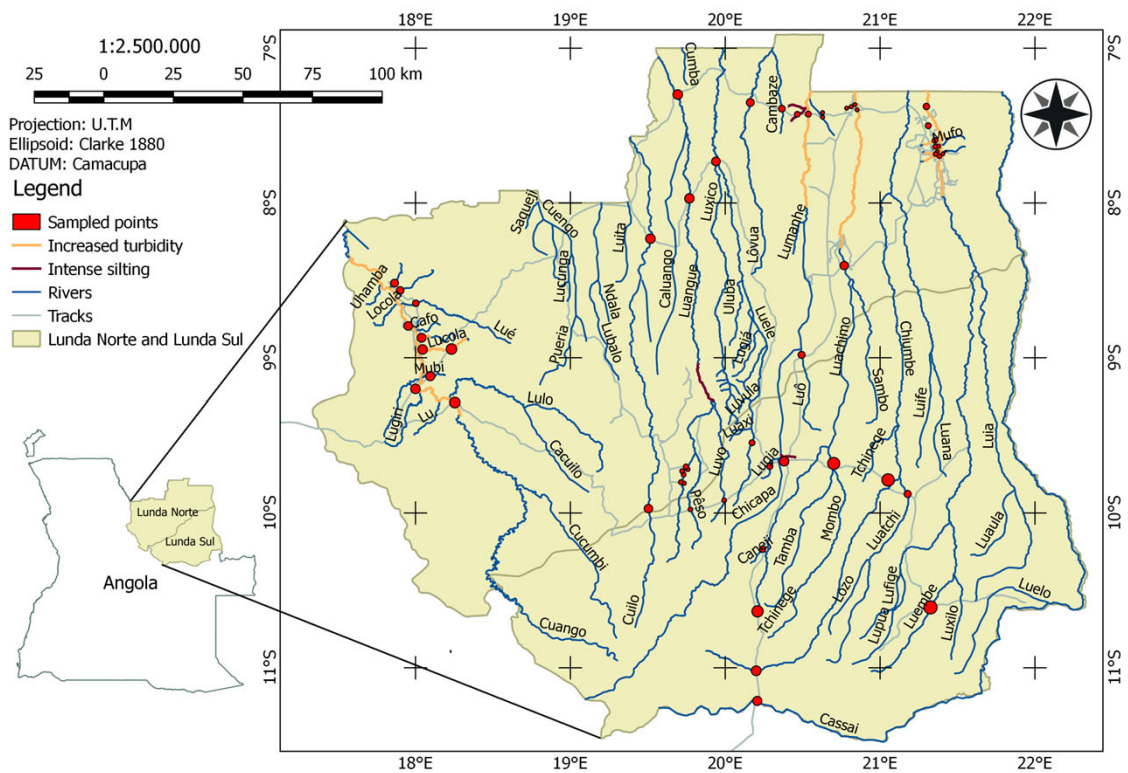


Figure 2: Hydro-graphic network showing affected rivers (turbidity and silting) (modified from Esri, HERE, Delorme, Intermap).

mining uses trucks with up to a 20 t payload to move huge quantities of excavated material and consumes high volumes of water for pretreatment and gravel washing operations. The used washing and mining waters are a cause of a great concern, as they have to pass through retention basins and must be treated before their final disposal in rivers. Most of the mining projects we visited, however, did not have appropriate tailings, so the waste water was poured directly into the rivers. One diamond mining project of medium size, exploring a kimberlite in Lunda Norte, moves about 123 000 m³ of waste rock and 75 000 m³ of kimberlite per month and consumes about 375 m³ of water per hour.

When large mining concerns exploit alluvial deposits on active riverbeds, they frequently build dikes and force the rivers to deviate. At the start of exploitation, most of mining projects deviate the river courses over a large distance; however, in some cases, they remove gravel from the riverbed by dredging with powerful electric pumps.

Semi-industrial exploitation

Associations of small mining entrepreneurs, using medium and small equipment, work at the scale of semi-industrial

exploitation. This type of exploitation is usually conducted in alluviums using mechanized equipment. Installations at this level are smaller than in industrial mining, with lower volumes of earth moved and less water used for the washing process. The latter is normally done by hand directly in the streams, employing a local work force without specialisation.

Artisanal mining: Garimpo

Artisanal mining, the so called ‘garimpo’, is widely scattered across almost the entire territory of both Lunda provinces, mainly in the municipalities of Cuango, Cambulo, and Lucapa, as well as in the vicinity of the large industrial explorations. Generally, it is carried out by the local population, individually or in small groups. In the artisanal type of exploitation, the miners make their explorations in alluvial sediments and in the riverbeds. Dismantling and extraction are done using simple tools such as hoes, shovels, and picks. The transport of the gravel is done manually, in baskets, bags, or handcarts and its treatment (washing) is carried out with sieves and batts, again manually. This manual washing process is preferably done on the banks and beds of the rivers and lakes.

In all three types of mining exploitation, we detected procedures which affected the environment and particularly the available water resources, although in different dimensions:

- Dismantling and extraction of the alluvial deposits encourages deforestation of large swaths of land, leading to the decrease or total destruction of land cover; after abandonment, the exploited areas are not properly restored.
- Washing gravel in riverbeds and expelling wastewater into rivers leads to siltation, enhances turbidity, and increases the suspended material content of the water. Figure 2 shows the hydrographic network of the region and the river sections most affected by anthropic mining activities.

Other notable impacts concern the deviation and cutting-off of watercourses; in some cases, the affected streams are completely silted, to the point that they lose their normal flow rates. Field observations confirmed the extinction of some small rivers due to silting, excavations in their beds, and frequent deviation of their courses by mining activities.



Figure 3: (a) industrial mining; (b) artisanal mining; (c) river deviation and artisanal mining along a riverbed; (d) silted river; (e) increased turbidity in river water; (f) consumption of turbid and untreated water.

Table 1 shows the land use evolution of a part of the Cuango municipality from 2005 to 2015, with respect to the areas occupied by vegetation, urbanisation, and mining activities. Notably, the increase in areas affected by mining is still larger in other municipalities (e.g. Cambulo), which implies a larger loss of natural vegetation cover there.

Discussion

Industrial mining of diamonds is a long-standing practice, and in the northeastern provinces of Angola, the exploitation phase of the major mining projects is estimated to last more than 50 years; the old-

est mining projects in the Lunda provinces are still active. Due to the procedures used by these industries and because of their persistence, dimensions, and long duration, the implications of industrial mining activities for the environment and particularly for water resources are much more significant than those of artisanal short-term exploitations.

Most of the mining activities identified in our study area have a preferential exploitation space along banks and riverbeds; at the least, they cross some watercourses. This is the case both in alluvial and kimberlite exploitation schemes.

So far, all industrial mining projects in the Lunda provinces (in both kimberlites and alluvial deposits) have been carried

out in open pit mines, which significantly transform the surface structure of the landscape and have a lasting impact on soils, vegetation, and watercourses. This increases the vulnerability of these components of the ecosystem, both during the exploitation phase as well as after the end of mining activities. The effects of these activities are visible in all areas of exploitation throughout the Lundas.

The decrease in vegetation cover, the destruction of ecosystems, and the abandonment of exploited areas without proper restoration are some of the most relevant observed effects of mining in northeastern Angola. Because banks and beds of watercourses, streams, and lakes are the preferred sites for diamond extraction as well as for the gravel washing, mining leads to increased turbidity and increased loads of suspended materials in the water, making it dangerous for human consumption. Unfortunately, most of the industrial mining exploitation projects we visited do not have tailings; they expel the mining water and derivative effluents from their operations directly into the rivers without applying wastewater treatments or taking other appropriate precautions. Figures 1 and 2 clearly show that the river sections most affected by turbidity and silting coincide with the distribution of the main mining areas. Industrial mining affects watercourses to a much higher degree and reaches farther downriver into greater streams than artisanal mining, the effects of which are somewhat restrained to smaller rivers and to shorter river sections. Meanwhile, in non-mining and sparsely populated areas, the rivers still exhibit good water quality.

Our landscape analysis revealed that the areas of mining exploitation, including those that have been abandoned, demonstrate a notable long-term reduction in vegetation cover. The area currently occupied by mining and urbanisation is increasing while natural areas continue to decline. In the region, the area used for mining has more than quadrupled within the last 10 years (see Tab. 1), demonstrating how mining activity is increasing dramatically. If this development continues unabated, the effects on water pollution will increase seriously over the next

Table 1: Land cover change in the Cuango municipality from 2005 to 2015.

| Description | Area (km ²) | Area (km ²) | Δ | % | % | Δ |
|--------------------|-------------------------|-------------------------|--------------------|------|------|------|
| Year | 2005 | 2015 | (km ²) | 2005 | 2015 | % |
| Total area | 1 108.2 | 1 108.2 | 0 | 100% | 100% | 0 |
| Natural vegetation | 1 095.0 | 1 078.8 | -16.1 | 98.8 | 97.4 | -1.5 |
| Urban settlements | 9.9 | 15.1 | 5.2 | 0.9 | 1.4 | 0.5 |
| Mining area | 3.4 | 14.3 | 10.9 | 0.3 | 1.3 | 0.9 |

several years and the extent of the rivers affected by turbidity and silting could increase proportionately dramatically (see Fig. 2 and 3).

Conclusion

In general, environmental degradation from mining in northeastern Angola consists of reduction of vegetation cover, environmental degradation due to the abandonment of exploited areas, a lack of restoration after the end of exploitation in an area, the dismantling of large areas by mining activities, a decrease in the water quality of rivers and lakes, and the silting and extinction of streams. Mining activities in the Lundas currently significantly impact water resources; more precautions are necessary to reduce adverse effects on the environment. The effects of river water pollution affect large parts of northeastern Angola and reach the transboundary areas of the Congo Basin. These effects are more pronounced in areas of intense mining activities, as illustrated in our maps of the region (see Fig. 1 and 2). The local population is affected by these activities due to the reduction of sources of clean (potable) water for consumption, particularly because some parts of important rivers such as the Luangue, Luembe, Luachimo, Cuango, Chicapa, Luxilo, Nzagi, and Mucunene are affected, exhibiting a high turbidity. However, due to the lack of alternative sources of potable water, the population has no other options than to consume contaminated water that has not undergone previous treatment. For this reason, we recommend that the ministry of mineral resources and petroleum enforce the use of good practices in the mining sector to prevent the dumping of mine waters in conditions little suitable and consequent pollution of the environment

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