Artisanal mining and preservation of the environment in Madagascar: development of a methodological approach to help identify the challenges and constraints for territorial development

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1 Introduction

1.1 General remarks

Known mainly for the richness of its biodiversity and the endemism of numerous animal and plant species, Madagascar is also famous for its considerable and varied mineral resources. Mining activities exploiting gemstones, decorative stones, ornamental stones and gold, and also industrial rocks and minerals, are scattered across the country.

In terms of artisanal mining, the exploitations generate considerable income (e.g.: sapphire) and account for a significant number of people in terms of employment. This strong societal basis has in itself non-negligible spin offs for the rural economy and, in this way, contributes to combating poverty. However, the expansion of artisanal mining, because it is based on an activity that is to a large extent informal, represents a certain risk for the conservation of biodiversity and, in particular, protected areas.

As regards industrial mining, the richness of the country's subsoil has led to the birth of several projects in various zones such as, for example, Fort Dauphin (ilmenite mining) or Ambatovy-Moramanga (nickel-cobalt mining) where, in terms of social impact, the number of people directly employed over the 30 year life of the project, will lie between 1,400 and 2,000 (La Gazette-Dgi, 2006). However, the implementation of this type of mining activity must also be subject to important socio-environmental constraints. More precisely, it means maintaining or even extending preliminary public information briefing sessions (which are required, moreover, by the legislation in force) on the fine details of the industrial mining project in question, under the aegis of environmental organisations such as the National Environment Office (ONE) of Madagascar.

Today, it is clear that the challenges associated with the mining sector and its impacts are identified with increasing clarity by the scientific community and multilateral funding institutions - principally the World Bank – the support of which to the various mining communities involves the formalisation, the training and the dissemination of best practices. Recent initiatives have kindled hope for a renewal of such efforts through the scientific modelling of human-nature interactions.

1.2 Objective of the article

In this context of promoting mining activities while taking environmental factors into consideration, the aim of this communication is to contribute to the development of a methodological approach to help identify the challenges and constraints linked to the sustainability of artisanal mining activities, while combining economic growth with conservation of biodiversity. The long term viability of territorial development prospects must for example be carefully weighted, depending on the bio-geographic, economic and social contexts and on the substances being exploited.

Our scientific approach is directed towards the coupling of socio-economic and socio-environmental approaches, designated SE² in this article. It consists, in a first stage, in carrying out an integrated analysis of the territory studied leading to the possibility, in a subsequent stage, of elaborating and simulating, through the use of computerised modelling tools, possible prospective evolution scenarios for these two levels over time.

In this respect, we used the case study on quartz mining, already carried out in the region of Rantabe (north eastern Madagascar), as a methodological reference before initiating other projects in this country. In perspective, the present work opens up the possibility of extending the approach to other Madagascan targets and, in particular, the areas of Tuléar (Atsimo-Andrefana region) or Ambatovy (Alaotra-Mangoro region) where major emerging industrial mining projects go hand in hand with artisanal exploitations, and in which the preservation of the environment also constitutes a major challenge.

However, although the aim is Madagascar, the approach that we propose herein has led us to implicitly and extensively take into account work carried out on other countries faced with the same types of problem. This other work is, to us, not only a source for enriching our approach, but also provides an additional argument for validating the proposed structure.

1.3 Why methodology?

The central idea consists in appropriating the means for resolving problems linked to the management of mineral resources in a given territory, while meeting its needs and requirements. Subsequently, even if the solution found is valid in this territory, the idea consists in finding an approach that can be extended to other application areas. In the final analysis, the result aims to provide decision makers (authorities, experts, operators, etc.) with a scientific basis for developing policies aiming to contribute both to combating poverty (through mining activities) and preserving the environment. The appropriation of such a method will allow them, in tackling a new pilot zone or when drawing up future policy strategies, to have recommendations/guidelines on which they can rely.

The remainder of this communication is enlarged on as follows: section 2 describes the methodology as it stands today, focusing particularly on the manner in which it has been elaborated. Section 3 presents and interprets the results of the application of this methodology to test zones. Section 4 concludes the article.

2 Structure of the methodology

2.1 Constructive approach

Our thinking up to now has allowed us to construct a central theme based on two fundamental concepts:

- Upstream, a socio-economic and socio-environmental analysis (SE²) of the mining activity.
- Downstream, prospective modelling and simulation in order to identify the possible evolution of these very challenges in coming years.

This successivity in passing from one phase to the next means that any system subject to modelling could be said to have already implicitly gone through the analysis phase. However, the opposite is not always true. In short, in this article, when we speak of analysis it implicitly refers to "pure" analysis, in other words without the modelling aspects. On the other hand, modelling is always linked to preliminary analysis work.

This "analysis and modelling" theme is progressively constructed through the cross-over between an *iterative* approach and an *incremental* approach to validate the proposal, by applications generated principally from various mining projects carried out successively or in parallel within the BRGM in different territories. "Iterative" signifies that the same processes acquired are theoretically repeated from one application to another (or on several terrains of a same application) while "incremental" signifies that the methodology is however enriched as applications progress, further to the new requirements induced by these applications. This approach is interesting to find out up to what point a methodology may be extendable or not on switching from one application to another.

In more detail, this iterative-constructive approach consists in:

- Taking the objectives and the requirements of an application into account.
- Constructing a methodology to meet these requirements in an appropriate manner and then re-employing existing methodologies (if this is the case) or even methodologies under development in parallel projects (if they exist).
- And, vice versa, transferring the knowledge acquired from the application in question to feed other parallel projects (if feasible).
- Enriching the overall knowledge acquired (in other words the guide), for future applications. This latter phase does not take place on a precise date but instead over time, as each project underway evolves.

2.2 The SE² "Analysis" aspect

SE² analysis, as we have conceived it at present, is based on five classes of parameters:

- The activity studied: artisanal mining or industrial mining, which follow two different development logics.
- The scale of the geographic study: global or local.
- The choice of the application terrain, since two applications may be located in a same or a different country.
- The field of the impact study: political or technical.
- The categories of raw materials studied: gems or gold.

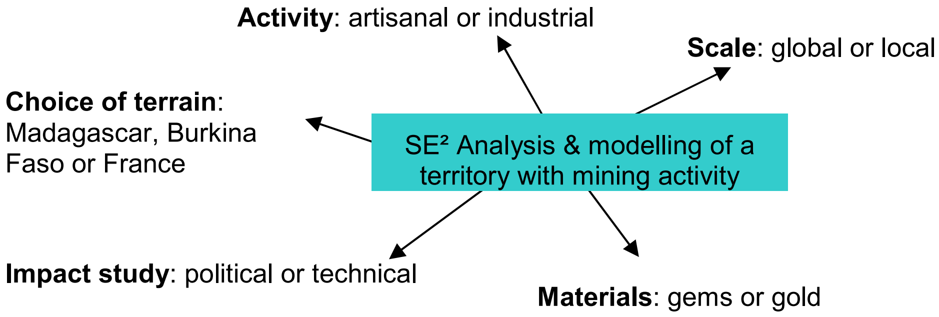

Figure 1: The class of parameters, the basis of an SE² analysis

More specifically, we have taken the following approach:

- Analysis of the overall policies adopted in terms of mines (seeking good governance) and their impacts:

- Legislation, the policy of the country.
- Identification of the informal part (mines).
- Evaluation of the place of the environment in mining studies.

- Multisectoral analysis:

- Account taken of other activities and, in particular, farming activities (since mining can be a subsidiary activity in certain zones).

- Technical and economic analysis:

- Characterisation of activities, identification of relevant parameters, conflicts of use and intra-community organisation.
- Evaluation of the cost of different tasks (e.g.: exploration, extraction, crushing, etc.).

- Study of the impacts of activities on the population:

- On the income of families.
- On induced employment.

- Study of the impacts of activities on the physical environment:

- On the forest, due to the use of wood for shoring up working mines.
- On the level of space occupied by tailings.
- On the fields that in fact become bush or, quite simply, become infertile.

- Study of the impacts on air space:

- On the air, particularly pollution (due for example to the use of mercury for gold washing).
- On the general health of the population: children and pregnant women, adults, etc.

- Study of the impacts on water:

- In quantitative terms, following pumping and drainage.
- In qualitative terms, due to insufficient or even non-existent recycling.

All of the analyses result in an initial set of tools, such as documents, graphs, maps, etc.

2.3 *The "Modelling & simulation" aspect*

In our approach, prospective modelling and simulation consists in reality:

1. In representing the mining system of the present terrain in a computer tool, on the basis of the results of the analysis, but only keeping those aspects that are relevant to the study (abstraction principle).
2. In simulating possible evolution scenarios of this same system over time and by analysing the interactions between the components and the evolution of relevant parameters. The result of these scenarios may be an important element for the decision makers who make use of such tools.

The modelling approach that we have adopted is the Multi-agent system (Ferber 1999, Wooldridge 2002), an approach generally used in systems where, among other things, complex socioeconomic systems are represented (Rateb et al., 2004).

All modelling also results in a series of tools that enriches former modelling: prospective simulation results, predictivity maps, etc. Apart from these supports in the form of documents, the simulation tool is, in itself, also a tool that can be made available to technical experts.

3 Applications and present results

At present, three countries are or have been studied through our application:

- Madagascar: exploitation of ultra-pure quartz in Rantabe: artisanal mining sector (Barthélémy & Bouchut, 2002; Andriamasinoro & Angel, 2007)
- Burkina Faso: gold washing on the Alga site; artisanal mining sector (Angel, 2002; Jaques & Zida, 2004; Andriamasinoro et al., 2006)
- France: exploitation of aggregate in the Seine-Normandie basin; industrial mining sector.

3.1 *Results table*

3.1.1 Summary

The follow table summarises the *partial* results obtained (analysis and modelling aspects) following the application of the methodology.

Country of application	**Approach**	**Impact study**	**Sector**	**Activity**	**Scale**	**Elements identified within the application (partial list)**
Madagascar	Analyse pure	Political	Mine	Artisanal /Industrial	Global	- Identification of the MAP[1], the PGRM[2] and the laws on major mining investments. - Impact of the production of gold and sapphires on the population.
			Environment		Local	- Rather than conservation policy, preservation policy, participative policy: GELOSE[3]. - Seeking the right path between combating poverty and protecting species.

[1] MAP: Madagascar Action Plan: framework document for all projects (mining, environmental, tourist, economic, etc.) in Madagascar for the period 2007-2012.

[2] PGRM: Mineral Resources Governance Project: Madagascan Government aid project on the implementation of the strategy to foster sustainable development and reduce poverty in Madagascar through the reinforcement of transparency and governance in the management of mineral resources, with the special support of small mining and artisanal exploitations.

[3] GELOSE: GEstion LOcale de SEcurité: Management of renewable resources consisting in entrusting sustainable development and the economic development of certain resources included within the limits of their territory to basic local communities.

Country of application	Approach	Impact study	Sector	Activity	Scale	Elements identified within the application (partial list)
			Mining + Environment	Industrial	Global	- In-depth environmental study with organisations and the population before any industrial mining exploitation. - Joint commitment by the Ministries of Mines and Forests to resolve the problems of superimposing quarries and protected areas.
	Modelling	Technical, political	Ultra-pure quartz	Artisanal	Local	- Understanding the possible impact of an increase in the price of quartz on the exploiting families.
Burkina	Pure analysis	Political	Mining	Artisanal	Global	- Impact of opening up the artisanal activity to private sectors.
	Modelling	Political	Mining	Artisanal	Local	- Possible reduction in the clandestine distribution channel by acting on the price of gold.
			Environment	Artisanal	Local	- Possible impact of deforestation on forests, fields, etc. and on the population
		Technical	Mining	Artisanal	Local	- Possible improvement to exploiting families' revenue by acting on the price of gold. - Impact of the materials used on the health of the population
France	Pure analysis	Political	Mining + environment	Industrial	Global	- Authorisation granted depending on social acceptability and environmental impact.

It is clear that this table has only been partially completed because, as has been stated above, it is progressively added to as applications evolve. The first observation that it is possible to make is that, for a given application, each series of class of parameters:

- Either possesses values, but which are only valid for this application (e.g.: PGRM, GELOSE, which does not exist in Burkina).
- Or possesses a value that is valid for other applications (e.g.: obligatory environmental analysis before granting any industrial operating permits).
- Or does not possess any values at all.

However, the results are promising. Indeed, it is observable that the principles that can be extended from one application to another well and truly exist and are not negligible: the exploitation steps (extraction, crushing, etc.), the means used (mercury, wood, etc.), the idea of reinforcing the application of mining codes, the granting of operating permits uniquely after environmental analysis, etc.

As regards the cross-over of the mining/environment sectors for the Madagascar application, our methodology still only attains the pure analysis context and no impact study on the social aspects has yet been carried out. However, for the forthcoming mining projects in which we hope soon to be involved in Madagascar, the other applications currently in progress could act as a source of inspiration to us, whether in the artisanal sector (inspired in that case by Burkina) or the industrial sector (inspired in that case by France), in other words, reusing the renewable aspects. Drawing on inspiration in this way must however act as a means of acquiring complementary information. Indeed, any methodology must firstly comply with the criterion of coming closer to the local population and understanding its real requirements. It is only later that the renewable aspects should be integrated.

3.1.2 Results of simulations

The following examples explain in detail the lines of the table, corresponding to the simulations.

Example 1

Figure 2 shows the result of simulations on the Madagascar application (line 3 of the table), concerned in particular with the possible impacts of the variation in the price of quartz on the breakdown of the socioeconomic class (rich, middle, poor) of exploiting families after 25 years. This figure does not yet integrate the study of the environmental aspects but enables an idea to be obtained of the interest of our approach by prospective simulation, particularly as an aid to decision making (the figures are given by way of indication).

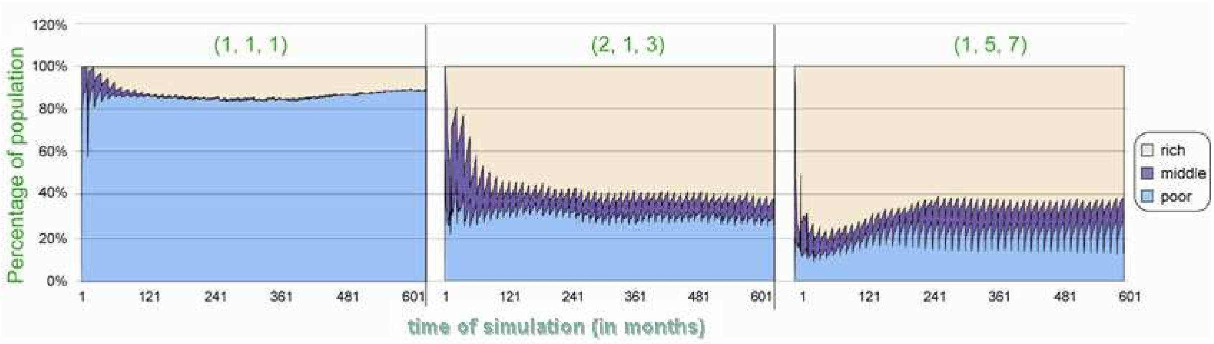

Figure 2: Possible impact of an increase in the price of quartz on the breakdown of the socioeconomic class of exploiting families

If we trust in this result, it is possible to note a trend in the system to move towards a relatively stable middle class if the price of quart is increased, but there is not necessarily an increase in richness or a reduction in poverty. This limit is due to the fact that the population does not use quartz to become richer but uniquely to assure its survival. A possible decision to take would therefore be that if the authorities want the activity to survive, the price of quartz should not be increased by too much. This decision has however been arrived at by completely disregarding any environmental impact of the activity.

Example 2

Figure 3 illustrates environmental factors being taken into account in a simulation (Burkina Faso application, lines 6 to 8). According to these results, decision makers could observe that acting on the official price of gold (within the context of artisanal mining) could possibly have a positive effect on exploiting families' income (for whom the increase, noted ß in the left hand figure, goes here from 0 to 1.5%) as well as controlling clandestine channels (the proportion of which, noted α_{cland} in the left hand figure, goes here from 84 to 60%). However, this same scenario shows, at the same time, a considerable erosion of wood (forests), which is however necessary for supporting mine shafts (right hand figure). In addition, this type of exploitation also leads to health problems for the exploiting families, especially due to the use of mercury (result not shown in the figures). Women and children are those most affected by this.

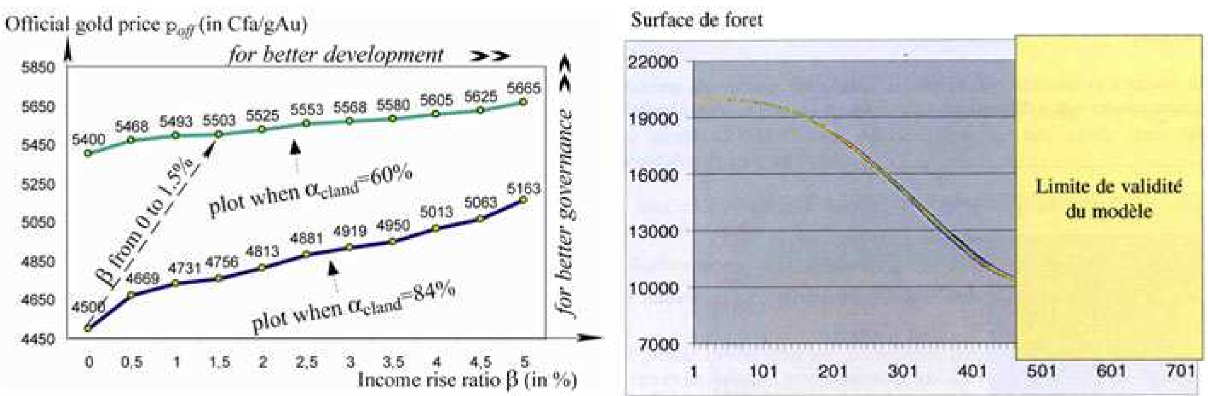

Figure 3: Impact of gold washing activities, both (positively) on the income of exploiting families and (negatively) on forest surface area

4 Conclusions

Madagascar finds itself at the crossroads between the need of a poor population to survive, which therefore does not hesitate to exploit the mineral resources and to destroy the forest, and an increasing need to promote the mining sector (given the wealth that it offers and the jobs that it creates) and to preserve its environment.

Our approach to help apprehend this problem consists in constructing a methodology to provide a scientific basis for appropriately managing these mineral resources by considering at one and the same time the environmental aspects, particularly protected areas and the air, as well as the harmful effects of their incorrect management on the health, income, etc. of the population. More precisely, the idea consists in proposing analysis and simulation results tools (documents, software, etc.) to decision makers, namely authorities, experts, operators, etc. Appropriating such a method will allow them, in initiating new pilot zones or by improving those already studied, or even when drawing up future political strategies, to have at their disposal recommendations/guidelines on which they can rely.

This article describes the present results of our methodological work: its construction and the evaluation and the validation of the proposed approach. In view of the illustrations presented with regard to the applications, the results obtained up to now are, in our opinion, very promising.

As for the future outlook, forthcoming projects that we would like to undertake in the near future in Madagascar, in the areas of Tuléar (Atsimo-Andrefana region) or Ambatovy (Alaotra-Mangoro region), will now have a sound working basis, which will need however to be fine tuned and enriched as a function of the context and through a very close collaboration with the stakeholders involved in these projects. From the modelling point of view, we hope to enrich the Multi-agent approach by combining it with another approach based on the Hotelling model (e.g. D'Aspremont et al., 1979) in order to gain a better understanding of the biodiversity aspects of our system (Rajaonson, 2005).

It should be noted that even though we are focusing on Madagascar, the construction of such a methodology implicitly and extensively involves the study of other countries faced with similar problems. This principle enables the initial methodology to be enriched by renewable concepts stemming from other applications, and this is what we have adopted until now by focusing on artisanal mining in Burkina Faso and the mining industry in France.

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