ARTISANAL GOLD MINING: ECO-ENVIRONMENTAL DAMAGE, LOSS OF MINING WEALTH, LOCAL SURVIVAL AND DEVELOPMENT. WHAT STRATEGIES HAVE BEEN ADOPTED? CASE OF VAVATENINA DISTRICT

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ABSTRACT

Artisanal gold mining is the occupation where many households have opted to work in order to cope with the socio-economic difficulties that the country has gone through. This activity presents several threats to the environment, including: loss of cultivated surface area, soil destruction manifested by the loss of sediment transported by erosion, loss of soil biodiversity, water pollution and disruption of wildlife life. On the other hand, it is a profession that also offers socio-economic benefits, including the reduction of a high unemployment rate, the reduction of rural exodus, the survival of the local population and, by extension, local development.

In order to develop this artisanal gold industry while reducing the threats to the environment, strategies will have to be taken, among others: raising the awareness of all the actors in the industry, the rehabilitation or restoration of the exploitation areas. An environmental improvement plan will have to be proposed in order not only to support artisanal miners with environmental mitigation and restoration programs during mining and after the closure of the small mine, but also to promote best practices in environmental management.

Keyword: *artisanal gold mining, eco-environmental damage, valuable minerals, rare earths, strategies*

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1. INTRODUCTION

Due to national political crises and international economic crises, Madagascar has gone through great socio-economic difficulties because firstly, more than 90% of the population lives below the poverty line of 2$ per day and nearly 80% has less than 1.25$ per day, according to the World Bank in 2013; secondly, Madagascar's Human Development Index (HDI) is 0.510, which places it 156th out of 190 countries evaluated2 in 2014; thirdly, the GDP

per capita is $393 in 2015, making it one of the 10 poorest countries1 in the world. In addition, the country is subject every year to natural disasters and scourges: cyclones, floods, drought, and attacks by harmful organisms (locusts, rats, insects) and various related diseases: cholera, malaria, plague, etc.
All these realities have led the majority of the population to turn to a new source of income, artisanal gold mining, where several gold zones scattered across the country are targeted by miners. The district of Vavatenina is among the most chosen sites. This research work highlighted the socio-economic-environmental impacts recorded in the seven (7) study sites. The impacts are presented under various aspects and according to the method of gold extraction by panning practiced by gold panners. These impacts include forest and plant degradation, soil destruction, loss of soil biodiversity, wildlife disturbance and various impacts on water resources and the atmosphere. In addition, x-ray fluorescence spectrometric analysis of soil, sand and rock in primary and secondary deposits at the study sites in the Vavatenina district showed the existence of valuable minerals. These minerals include Sodium, Vanadium, Neodymium, Ytterbium and Yttrium, with different grades depending on the study site. The last three are rare earths, which are highly sought-after ores currently used for a variety of purposes.

2. METHODOLOGIES

2.1. Study area: Vavatenina district gold sites

The District of Vavatenina belongs administratively to the former Autonomous Province of Toamasina. It is located in the southern part of the Analanjirofo region and covers an area of 2,926km². It is the only district of the Analanjirofo region which does not have the seaside area. It is delimited in the North and in the East by the District of Fénérive-Est, in the South by the District of Toamasina II, in the West by the Districts of Amparafaravola and Ambatondrazaka. The chief town of the District of Vavatenina, is located 45 km south-east of Fénérive-Est. It is connected to the latter by the RN5 and then by the RN22.

Figure 1 : Presentation of the map of the former province of Toamasina
The study area is located in the District of Vavatenina, in particular in the Rural Communes of Vavatenina, Ambohibe and Miarinarivo. These bell-shaped municipalities opening to the south are separated from each other by a seasonal provincial road 25 km from the capital of the District: Vavatenina. The study area is located at latitude: 17 ° 36 ′43 ″ S and at longitude: 49 ° 9′23 ″ E.

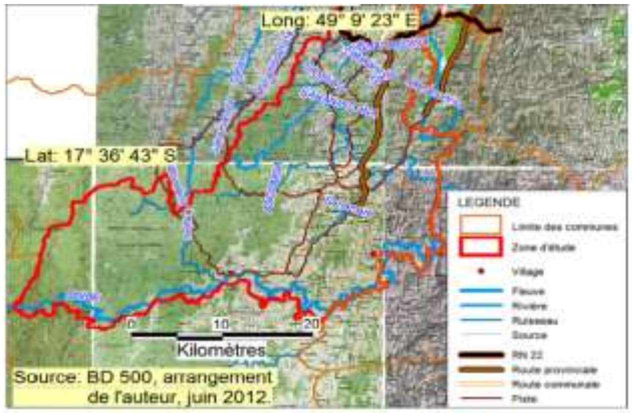


Figure 2: Presentation of the Vavatenina District Study Area Map

2.2 Environmental impact of artisanal gold mining

By definition, it is the effect, the influence of a strong action" but also as "the possible consequences of a development on the environment following a development. These changes may be positive or negative and may occur in the more or less long term.

Impacts, from a strictly ecological point of view, are deviations from natural evolutionary dynamics leading to changes in the theoretical state of the ecosystem. This change in state will therefore determine the type of assessment.

An environmental impact can be defined as the effect, during a given time and over a defined area, of a human activity on a component of the environment in the broad sense of the term (i.e. including biophysical and human aspects), compared with the likely situation in the event of the project not being carried out. By his actions, man thus consciously or unconsciously generates influences and impacts on ecosystems. These effects are referred to as impacts. To deal with impact, three dimensions are inseparable:

2.2.1. Size of the impact

both spatial and temporal. This magnitude can be either a measure or a prediction. It is a quantifiable measure.

2.2.2 Impact Significance

The significance of the impact is the expert's judgement of the significance of the anticipated changes, taking into account the context of the spatial and temporal insertion of the project.

2.2.3 Significance of the impact

The significance of the impact is the variable value that each of the actors gives to the two preceding characteristics (reflection of appropriation of the living space, desired perception and evolution).

2.2.4 Direct and indirect impact

Environmental impacts can be direct or indirect. Direct impacts are defined as "impacts resulting from a cause and effect relationship between a project component and a component of the environment" and considers indirect impacts as "impacts resulting from a change in a directly impacted component of the environment". Thus, the effects caused by direct impacts generate indirect impacts.

With regard to artisanal, small-scale mining, gravel extraction for gold is done in two ways, depending on whether one is in the riverbed or outside. Thus, for deposits located in the bed of a watercourse, the direct impact lies in the process of diverting the watercourse by means of a dam and a gutter of variable length, depending on the size of the deposit and the workforce. The sediment layer covering the gravel is then cleared before it is extracted. For the deposit outside the riverbed, we can identify as direct impact: the destruction of the forest cover and the digging to discover the diamond gravel.

The extraction and washing of the gravel cause a disruption of the site which results in a change in the dynamics of the river, for example, its turbidity, which in turn impacts the nutrients needed by fish and other aquatic species (Indirect Impact). Forests and forest galleries are also systematically

destroyed, causing some biodiversity to be lost locally. In some localized cases, artisanal mining has diverted rivers and caused indirect impacts, damaging the local ecosystem.

2.3 Environmental remediation

Remediation can therefore be seen in the environmental context as a process of reparation, which is part of land use planning and the organization of economic activities that minimizes anthropogenic impacts on the environment. It therefore includes the notions of ecological restoration, rehabilitation, reallocation, ecological clean-up and ecological recovery.

There are two main approaches, each of which refers to a set of objectives and appropriate techniques for dealing with ecosystem degradation: Heritage management for the conservation option. According to this approach, priority is given to the exceptional aspect of the ecosystems (rare, threatened, endangered species), to a maximized conservation of species diversity, to specific strategies aimed at protecting existing ecosystems. The remediation approach, for its part, consists of giving priority to principles and techniques centered on the functioning of the ecosystem, including its composition, structure, landscape dimension and services rendered.

For this research work, an approach oriented towards the remediation of degraded ecosystems has been adopted following intensive exploitation of forests, soils and rivers by artisanal mining.

2.4. Ecological restoration

It is a process whose objective is to restore a degraded ecosystem to its original form. To use the term restoration is to adopt an objective of "rebuilding" a damaged ecosystem.

Ecological restoration is "a process of assisting in the restoration and management of ecological integrity. Ecological integrity includes an important set of variables relating to biodiversity, ecological processes and structures, regional and historical context, and sustainable cultural practices".

On a strictly technical level, restoration pursues a "rehabilitation" objective: "We will refer to ecological restoration in the strict sense of the term when the objective is to restore an ecosystem to its natural state equivalent to its original state, to which it corresponded before the deterioration suffered, generally due to human causes".

The processes mobilized may be the result of either natural regeneration, but it is often assisted, in order to promote the recovery or redial of the old ecosystem. Restoration is the enhancement of natural capital and ecological services through actions to repair damage at the community, ecosystem and landscape levels.

2.5. Rehabilitation

The concept of rehabilitation is frequently used to describe actions of different kinds. There is therefore some confusion surrounding the concept of rehabilitation, which is often used as a generic term, commonly used to refer to all actions whose purpose is to "repair", in part or in whole, ecosystems that have been damaged.

In Madagascar's mining code, it is the only term chosen for environmental protection. For example, the Madagascar Mining Code, Article 100, Chapter II, Title V, states that: "For beneficiaries of gold panning or extraction and collection authorizations, the execution of their work shall be carried out in compliance with specific environmental obligations defined by regulation" (Mining Code, Madagascar, 2005). Like the restoration process, rehabilitation takes as a reference the ecosystem as it was supposed to function before degradation. However, rehabilitation has more modest objectives than those envisaged in a restoration process: "rehabilitation focuses more on repairing processes and a number of services than on restoring ecological integrity or authenticity, which is the prerogative of restoration" (Mining Code, Madagascar, 2005).

Rehabilitation in degraded areas therefore involves the reintroduction of few or no significant ecological features or services. This action does not aim to return the ecosystem to its original state, but rather to create a viable alternative ecosystem, possibly different in structure, composition and function.

2.6. Reallocation

Reallocation refers to a series of actions leading to assigning to a degraded ecosystem a biodiversity, functioning and new use that is not ecologically related to the ecosystem prior to degradation. These new inputs and uses include transformation towards agriculture and/or reforestation. The reallocation process consists of creating an alternative ecosystem to replace the original one, which is too severely degraded to return to its original state: "Reallocation is a general term describing actions leading to assigning to a degraded forest a new biodiversity, functioning and use with no ecological relationship with the ecosystem before degradation".

Generally, reallocation is appropriate for highly degraded ecosystems (mining areas or soils in urban areas) that are intended to be reclaimed for exploitation that can benefit its users. The reallocation process can also allow for the reconversion of degraded soils, which are now unsuitable to support the activity that has generated a significant series of degradation, as is the case in the artisanal and industrial mining sector.

2.7. Ecological cleaning

This process is often mistakenly equated with the rehabilitation process. It consists of cleaning degraded areas of physical elements or components that are sources of pollution and degradation. It is in fact a preliminary phase that must be carried out before any restoration, rehabilitation or reallocation is undertaken: "This term has occasionally been used as a synonym for rehabilitation. However, we prefer to apply it to specific cases in which certain elements foreign to the natural system are eliminated, whether they are physical (garbage, contaminants) or involve exotic species. In a sense, it is a rehabilitation approach".

2.8. Ecological recovery or natural regeneration

Reference is made to the concept of ecological recovery or natural regeneration when an ecosystem, once freed from the stressors that contributed to its alteration, begins a progressive succession of natural regeneration phases. The ecosystem then begins a spontaneous process of redial that is often limited by the degradation suffered. For example, in cases of natural regeneration in forests, regeneration appears as a discontinuous process. "According to Alexandre

D.Y., only the disappearance of part of the canopy allows the appearance of new species or the start of those that remained inhibited".

Natural regeneration is a component frequently mobilized in restoration projects, since the forms of natural regeneration can make it possible to recover certain elements and dynamics of the original ecosystem when degradation has been minimal. Ecological recovery can also be "directed" or "assisted". This is referred to as regeneration or assisted recovery.

3. RESULTS

Artisanal gold mining has created several eco-environmental damages, losses of mining resources, but it is also a survival job for small-scale gold miners, the local population and a channel for rural exodus mitigation and local development.

3.1. Eco-environmental damage

Eco-environmental damage has several aspects:

-Firstly, the degradation of forests and plants through deforestation and the weakening of the plant cover and the gradual disappearance of protected species;

-secondly, the threat to protected areas and food security through the loss of cultivated area and the loss of soil biodiversity and the destruction of soil through erosion,

-tertiary, the impacts on water resources due to dams and diversions that can lead not only to a risk of acid mine drainage but also to water pollution and a lack of drinking water or even silting up of rice fields,

-Finally, the disruption of wildlife life and even human and domestic animal health.

3.1.1. Forest and plant degradation

Forest degradation, although temporal, has several consequences for forests. It can lead to the opening of the canopy, loss of biodiversity, changes in vertical structure or change to other attributes. It also reduces the quality and quantity of forest area and alters the spatial structure of landscapes through the process of fragmentation leading to the weakening of the vegetation cover and the progressive disappearance of protected species.

The development of mining sites and the influx of populations are putting strong pressure on wood resources. The digging of shafts and trenches can contribute to deforestation and the destruction of the vegetation cover, as has been observed at each site. For the production of wood needed for the extractive activity (supporting galleries, making ladders, diverting rivers), and to meet the current needs of the sites (timber for habitat construction, coal production, firewood), miners carry out uncontrolled felling of trees of all species. All these actions lead to the weakening of the vegetation cover and the gradual disappearance of protected species. We are thus in the presence of a real forest degradation. This situation is illustrated by the following figures

(a)

(b)

Figure 1: Degradation of vegetation cover; (Picture a) and (Picture b) Betsakotsako artisanal gold mining site in the Miarinarivo RC in the North where a degradation of the forest cover resulting from the anarchic cutting of trees and shrubs can be observed.

3.1.2. The threat to protected areas

A protected area is defined as: a clearly defined geographical space that is recognized, dedicated and managed, by any effective legal or other means, to ensure the long-term conservation of nature and the associated ecosystem services and cultural values (Dudley, 2008)".

The Vavatenina Gold District contains a great diversity of landscapes consisting of savannahs, forests, mangroves and floodplains. The highly diverse ecosystems found throughout the region support a wide variety of flora and fauna. Thus, the tropical forests of Zahamena constitute a very rich area with endemic species (Conservation International, 2010). This rainforest represents one of the last remnants of the forests in this country and contains a significant number of rare and threatened species locally and globally.

Protected area ecosystems are of paramount importance in the:

- Socio-economic as they provide a source of employment and income for communities living on the periphery (collection of non-timber forest products (NTFPs) or honey production;

- Socio-cultural, as some plant species are used during rites addressed to ancestors in villages, or during traditional ceremonies (weddings, deaths, etc.) or through traditional medicine (treatment of diseases with plants or phytotherapy).

In addition, they also provide other services such as rainfall regulation, protection against strong winds, provision of raw materials such as timber and firewood, fruits, seeds and fodder.

At the same time, the Gold District is trying to limit and control artisanal gold mining, but these activities are still often carried out illegally within no-go zones, particularly in protected areas.

Figure 2: Satellite image of the Angomoa (Betsakotsako) CR Miarinarivo gold mining site in the peripheral zone, North-East of the Zahamena National Park

This biodiversity, which is of major ecological and socio-economic importance to the local population, is unfortunately under significant pressure from artisanal mining.

In addition to the growing need for firewood and construction wood due to strong demographic pressure, the accelerated conquest of species devoted to gold panning is detrimental to the sustainability of primary and secondary forests and savannahs. Slash-and-burn agriculture and the establishment of gold panners' exploitation sites push people to clear several hectares in their path. In addition, artisanal winches, obstacles that serve as dams, the construction of camps for semi-nomads and the cooking of food lead to the clearing of forests. As a result, the fauna and flora are depleted in species. The primary forest diminishes in surface area. It is only found in ragged forest, except around the Angomoa River, which covers an area of 200 ha. This situation is illustrated by the following figure

a

b

Figure 3. Slash-and-burn cultivation practice on the periphery of Zahamena Park and on the periphery of the Angomoa River CR Miarinarivo for the establishment of logging sites

3.1.3. Gold panning linked to food safety

Currently, it is estimated that 70% of the total area of Vavatenina is still untouchable for gold panning. These areas are occupied by rice fields and cultivated fields. By digging the alluvium, the gold panners manage to reach the cultivation area. But during the rainy season, the surface cover of the soil is eroded. This can wash away a large part of the plantations. On the other hand, agricultural products are the main sources of income and food supply for the local population.

Thus, about 97% of the population lives from agriculture (CSA Vavatenina, 2012). However, this practice is subdivided into six categories of agricultural activities: rice cultivation in flooded rice fields, slash-and-burn agriculture, cultivated on hillsides with direct sowing, food crops (Artocarpus altilis) and (Manioc), cash crops with cloves (Syzigium aromaticum) and coffee (Caffea arabica); industrial agriculture, represented by sugar cane, an abundant raw material for artisanal production: The industrial crop, represented by sugar cane, an abundant raw material, intended for the artisanal manufacture of: local hygienic fermented drink or "Betsabetsa" and alcoholic drink, distilled or "toaka Gasy"; fruit crops: bananas, lychees and other fruits; market gardening with different kinds of vegetables or breeds and finally the specialized or associated cosmopolitan crop including (coffee, clove, coconut, banana, avocado, breadfruit, etc.); the industrial crop, represented by sugar cane, an abundant raw material, intended for the artisanal manufacture of: local hygienic drink, fermented or "Betsabetsa" and alcoholic drink, distilled or "toaka Gasy"; fruit crops: bananas, lychees and other fruits; market gardening with different kinds of vegetables or breeds and finally the specialized or associated cosmopolitan crop including (coffee, clove, coconut, banana, avocado, breadfruit, etc.)..).

Each extraction site has its own specific culture (species). For the ten study sites, it was possible to determine the species affected by gold mining. The Principal Component Analysis (PCA) applied to the matrix of the ten mining sites on ten species cultivated by the villagers made it possible to determine the species most affected by mining,

The figure below shows the determination of the species cultivated according to the farm sites. On the abscissa axis, TBV (Tanambiavy), ABV (Ambodiovitra), ABL, (Ambolofotsy), ABF (Ambalafary), BGR (Bongarano), ABH (Ambalahady), ABD (Ambalahady), MHN (Mahanoro) is positively correlated on the abscissa axis. On the ordinate axis, ABG: Ambodimanga and BTS: Betsakotsako are correlated on the positive ordinate.

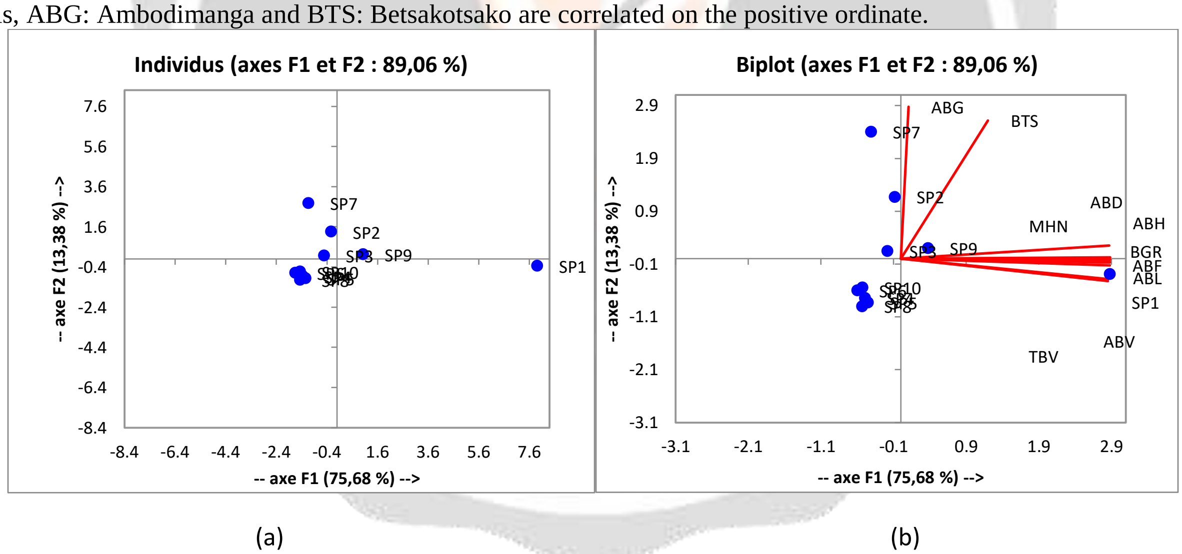


Figure 4. Determination of crop species (graph a) according to farm sites (graph b)

Site rating: ABV: Ambodiovitra; MHN: Mahanoro, ABF: Ambalafary; BGR: Bongarano; ABL: Ambolofotsy; ABH: Ambalahady; ABG: Ambodimanga; ABD: Ambalahady; BTS: Betsakotsako; TBV: Tanambiavy. SP1: Orizza sativa; SP2 : Syzigium aromaticum ; SP3 : Caffea arabica ; SP4 : Litchi chinensis ; SP5 : Musa accuminita colla ; SP6 : Artocarpus altilis ; SP7 : Manihot esculenta ; SP8 : Saccharum officinarum, SP9 : SP2, SP3, SP4, FP5, SP6 and SP 10 : Brède (Brassica rapa , Solanum americanum, Amaranthus spinosus, Acmella oleracea, Brassica)

The following sites: MNH, ABD, ABH, BGR, ABF, ABL, ABV and TBV are grouped with SP1 so that all the sites have been affected by rice cultivation at the rice field level. ABG and BTS sites are grouped with SP7. In general, cultivation techniques remain rudimentary. There are not enough agricultural inputs: no fertilizer, insecticide or pesticide. Indeed, the annual yield is 0average. Consequently, the occupation of cultivated areas is aggravated by the total production deficit. There are six plant species affected by farm work.

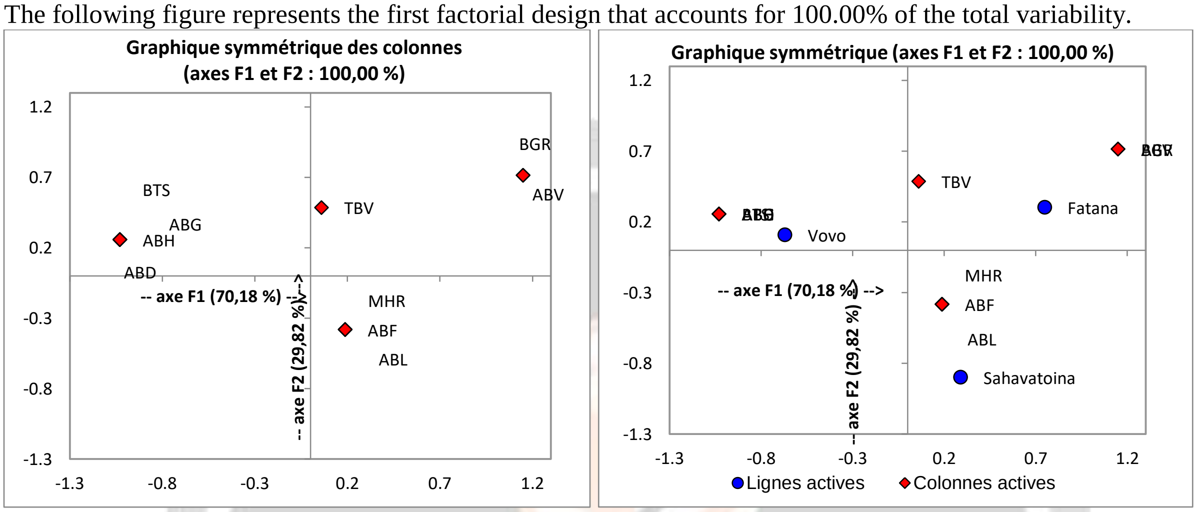
3.1.4. Loss of cultivated area

3.1.4.1. Change in method by operating site

The loss in cultivated area depends on the extraction method used at each study site. Artisanal gold mining activity is occupying more and more space. This activity is carried out in the lowlands, either in the rice fields or along the river banks. On the other hand, it is also practiced in the plateaus and hills. The estimation of the exploited spaces depends on the type of method used, whether it is the Fatana method, the Vovo method or the Vakirano method.

Each exploitation site has its own method of exploitation practiced: either all three methods are practiced at the same time, or both of them, or sometimes even just one method. The application of the Correspondence Factor Analysis (CFA) on the method used at each mining site distributed in the alluvial, eluvial and primary repository made it possible to determine the method variation in relation to the mining site.

The following figure represents the first factorial design that accounts for 100.00% of the total variability.



(a) (b)

Figure 5: Factor maps of cultivated areas, (a) 10 farming sites and (b) the three useful farming methods

Site rating: ABV: Ambodiovitra; MHN: Mahanoro, ABF: Ambalafary; BGR: Bongarano; ABL: Ambolofotsy; ABH: Ambalahady; ABG: Ambodimanga; ABD: Ambalahady; BTS: Betsakotsako; TBV: Tanambiavy.

Each study site has their relative preference for known extraction methods: axis 1, shows the BGR and ABV sites (in positive abscissa) using the Fatana method. The other BTS, ABG, ABH and ABD sites (in negative abscissa) use the Vovo method. This distribution leads to interpret this axis as representing the method used in the operating site. The BGR and ABV sites use the Fatana method and the respective sites: BTS, ABG, ABH and ABD only use the Vovo method. Along axis 2 is associated in positive ordinates the TBV site using both the Fatana and Vovo method. All the following sites: MHR, ABF and ABL, in the negative ordinate use the Fatana, Vovo and Vakirano method

3.1.4.2. Comparison of the surface area of the spaces operated in relation to the site of operation (in 2016)

Of the three methods used, the Fatana and Vovo methods occupy the most cultivated area compared to the Vakirano method, which does not occupy space but is practised only in the rice field or in the stream. The area of land cultivated each year (in 2016) for each farm site was known using the non-parametric test of independent samples. The test applied is the non-parametric "k" sample test (Kruskal-Wallis test) corresponding to the Fataña and Vôvo methods.

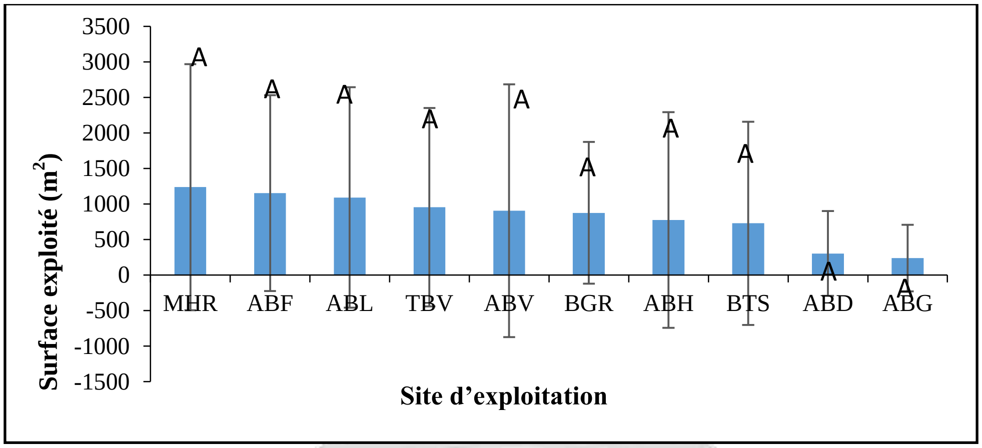


Figure 6. Comparison of the annual amount of space operated at 10 operating sites in 2016

Averages followed by the same letter constitute a statistically homogeneous group at the 5% threshold, according to the Newman-keuls test.

According to the figure above, at significance level alpha=0.050 the null hypothesis of no difference between the 10 groups (operating site) cannot be rejected. In other words, the difference between the groups is not significant. There is no significant difference in the area of cultivated land between the 10 gold mining sites (p = 0.945).

3.1.5. Soil Destruction

3.1.5.1. Soil erosion

In artisanal mining areas, during the rainy seasons with high runoff, a natural process of erosion can occur by detachment and transport of soil particles and leaching of soil, which loses its nutritive properties for vegetation and consequently for wildlife. The runoff factors have been analyzed in detail by Lafforgue and Naah (Lafforgue, et al., 1976) and according to these authors, on bare soil, the energy of the rains is capable of destroying the soil structure and totally modifying the hydrodynamic properties. Under the force of runoff, particles are detached and carried away, and settle further. The destruction of the vegetation cover caused the nakedness of the soil and subsequently increased the risk of erosion. The more unstable the soil, the greater the risk of erosion (Maradan, et al., 2011).

(a) (b)

Figure 7. Soil destruction, (Photo a) 5 m landslide near the Village of Ampisikinana, (Photo b)

landslide along the Sahavatoina River 500 m from the Village of Miandravato, Commune Vavatenina

Soil particles settle in quieter areas, less exposed to the forces of water. Thus, streams receive the particles carried by runoff into the watershed, accelerating their hyper-sedimentation, which will be discharged into the seawater causing disturbance to the marine ecosystem and even coral reef life. The accumulation of sediment can alter the bed of the watercourse, which can lead to flooding and bank erosion.

3.1.5.1.1. Comparative study of the quantities of eroded soil

To verify the amount of sediment at each study site, non-parametric testing of independent samples is used. The test applied is the non-parametric "k" sample test (Kruskal-Wallis Test) corresponding to the Ambodiovitra, Mahanoro, Ambalafary, Bongarano, Ambolofotsy, Ambodimanga, Ambalahady, Betsakotsako and Tanambiavy mining sites.
of Ambalahady, Ambodimanga, Ambalahady, Betsakotsako and Tanambiavy.

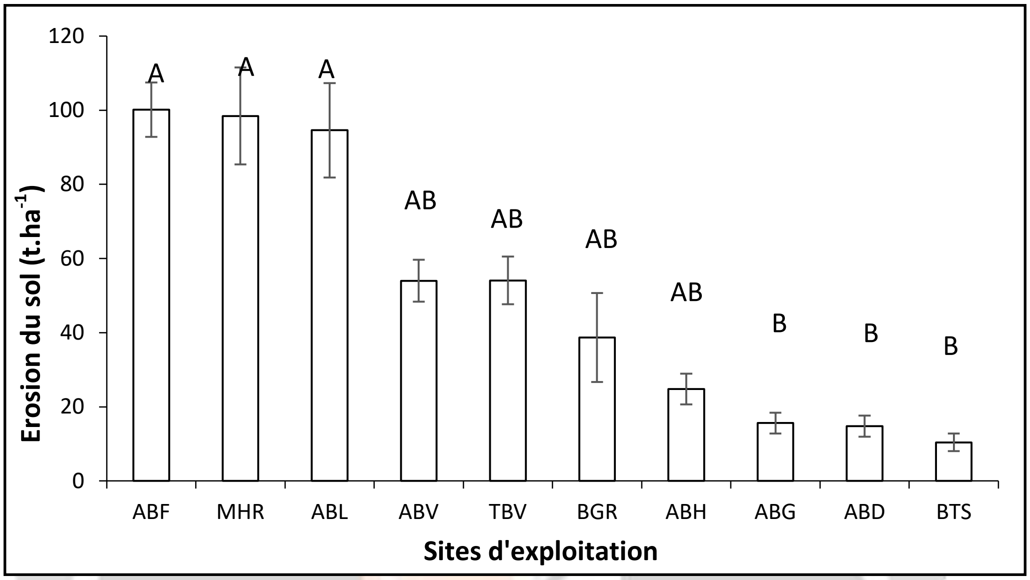


Figure 8 : Tonnage de sol érodé à l'hectare dans 10 localités du District de Vavatenina

Averages followed by the same letter constitute a statistically homogeneous group at the 5% threshold, according to the Newman-keuls test.
In the figure above, the amount of eroded soil in t.h-1 accumulated in a highly significant way (p=0.000). A larger amount for: ABF, MHR and ABL (100.17; 98.47; 94.60 t. ha-1) compared to the respective sites of: ABV, TBV, BGR and ABH (54.02; 54.10; 38.73; 24.80 t. ha-1) and ABG, ABD BTS (15.62; 14.77; 10.40 t. ha-1).
In short, for ABF, MHR and ABL sites, the amount of eroded soil is very significant. On the other hand, for GBS, DBA and TBS sites, the amount of eroded soil is small. These variations in the amount of eroded soil depend on the mining method used and the artisanal gold deposit. The practice of gold mining in the lowlands is more dangerous in terms of soil destruction compared to the eluvial and primary deposit.

3.1.5.1.2. Comparative study of quantities of sediment transported by erosion

Washing and wiping water from the operating process is often laden with suspended solids (André, 1999). The phenomenon of erosion is thus accompanied by river transport of sediment, with a quantity of suspended matter ranging from 50 to 140 g/l. Aubertin et al. in 2013. This confirms the importance of sediment input via hydraulic transport after excavation of the hills and plains, which are the object of mining operations.
Artisanal gold mining operations cause massive destruction of the environment including sediment accumulation, soil erosion and silting of crop fields. The consequence of this type of activity (artisanal gold mining) is the destruction of crops, leading to a considerable reduction in agricultural production and disruption of the peasants' food chain.
The following figure shows the amount of sediment transported by erosion for the different sampling locations (Angomoa, Sahavatoina, Ambodiovitra and Manambitanona Rivers) by applying the non-parametric test of independent samples. The method used is the non-parametric Kruskal-Wallis test of "k" unmatched sample from a non-Gaussian population.

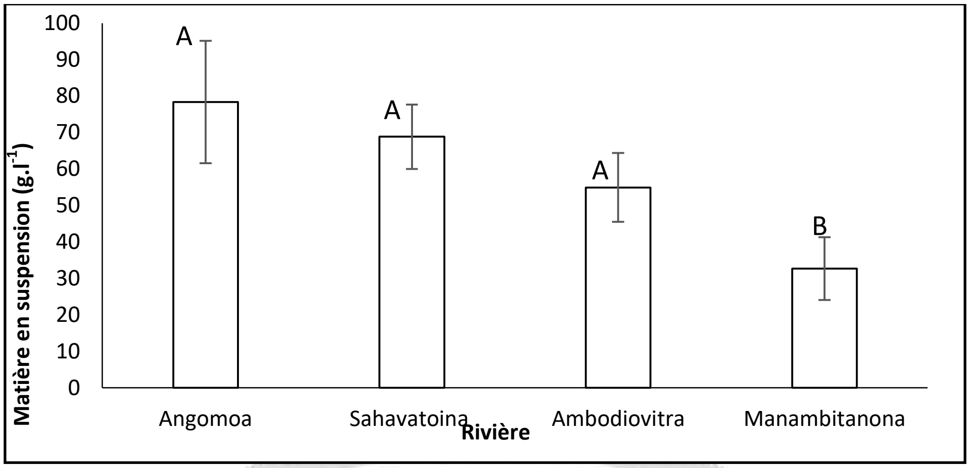


Figure 9. Amount of sediment displaced by erosion or suspended matter

Averages followed by the same letter constitute a statistically homogeneous group at the 5% threshold, according to the Newman-keuls test.

According to the figure above, a significant difference ($p = 0.030$) was found between the Angomoa, Sahavatoina, Ambodiovitra and Manambitanona Rivers. The highest amount was recorded for the Angomoa River (91.4±68.5) and the lowest amount is attributed to the Manambitanona River with 40.5±25.3 g.l-1

The residues from the mining process are highly loaded with suspended solids up to 91.4 g. l-1. These are solid particles responsible not only for the quality of the river but also for the pollution of rivers and groundwater, which become non-potable for the population. Tons of sediment are displaced by soil erosion (Figure 9). Thousands of tons of soil are displaced by erosion after logging activities and dumped into rivers and pollute them making the water undrinkable.

3.1.6. Loss of soil biodiversity

The soil may appear as an inert mass. Yet soil is in fact an incredibly dynamic and heterogeneous system, full of pores filled with water and air, but also with many organisms of many shapes and sizes, inducing many habitats. It is important to consider that any physical alteration of the soil or soil degradation resulting from artisanal gold mining can lead to a loss of biodiversity.

The current levels of soil biodiversity in the Vavatenina gold area have been little studied and although their quantification is difficult, it is essential to enable the assessment of impacts. However, it can be pointed out that artisanal gold mining leads to profound changes in the edaphic environment, particularly in terms of soil architecture (soil structure, porosity, bulk density, water retention capacity, etc.).

3.2. Survival of small-scale gold miners

3.2.1. Productivity by method of operation

The three most common methods of gold mining in the Vavatenina district are the Farana or framing method, the Vovo or hole method and the Vakirano method. Each method uses ramming to extract the gold. At each mining site, several groups of operators have been registered, each of which has its own area occupied by framing (fatana method) and its own staff (men and women) to carry out the various tasks. The duration of the work depends on the number of personnel in each group and the volume of earth excavated to bring out the minerals sought. The following tables summarise the results of the data collected from each group of operators at six sites where the practice of the three mining methods was found.

3.2.1.1. Fatana method or framing

The following table summarizes the production yield for the small-scale gold mining operation using the Fatana panning method.

Table 1: Summary of the activities of operators using the fatana method at the six gold sites in Vavatenina

Number of operator groups	Operating sites	Occupied area per frame (m2)	Volume of soil extracted per frame (m3)	Product obtained per frame (g)	Number of working days	Number of persons/group			Working hours (h/d)
						M	W	T	
13	Ambolofotsy	77	679	408,9	106	59	65	124	106
20	Mahanoro	96	796	709,6	165	87	82	169	146
17	Bongarano	73,8	1121	541,9	124	79	78	157	146
13	Ambalahady	65	40,46	116,6	125	330	406	736	122
11	Ambodiovitra	56	504	128,9	85	47	82	99	90
6	Ambodimanga	908	58,1	47	28	26	54	80	49

This table shows respectively the number of gold mining groups per study site, using the fatana method, the surface area occupied by framing, the volume of land extracted per framing, the product obtained, the number of working days per group, the number of staff (male, female) and the total working time.
From this table, the results can be interpreted as follows:
-the 13 operator groups of Ambolofotsy with 77 m2 of occupied surface area produce 408.9 g of gold for 106 working days. They are made up of 124 people, 59 of whom are men and 65 women. In short, for about 3 months and 16 days, they have been able to obtain 408.9 g of gold, that is to say 3.29 g/people if the share of each one is identical and without taking into account the other charges.it is thus a survival job for the farmers.

3.2.1.2. Vovo or Hole method

The following table summarizes the production yield for the small-scale gold mining operation using the Vovo per pan method.

Table 2: Summary of the activities of Vovo operators at the five Vavatenina gold sites

Number of operator groups	Operating sites	Occupied area per frame (m2)	Volume of soil extracted per frame (m3)	Product obtained per frame (g)	Number of working days	Number of persons/groups			Working hours (h/d)
						M	W	T	
3	Ambolofotsy		203,472	94,3	39	9	11	20	27
2	Mahanoro		523,37	87,4	33	15	21	36	45
Néant	Bongarano	Néant							
2	Ambalahady		106,44	37,4	16	6	7	55	16
4	Ambodiovitra		196,68	73,2	40	12	13	25	36
11	Ambodimanga		1008,0028	262	123	33	44	77	93
"31	Betsakotsako		3768,67	3361,7	534	179	159	338	301

This table shows respectively the number of gold mining groups per study site using the Vovo method, the surface area occupied per frame, the volume of land extracted per frame, the product obtained, the number of working days per group, the number of staff (male, female) and the total working time.
It should be noted that the Bongarano farmers do not use the Vovo method of operation.

3.2.1.3. Vakirano method

Table 3: Summary of the activities of the operators using the Vakirano method at the five Vavatenina gold sites

Number of operator groups	Operating sites	Occupied area per frame (m2)	Volume of soil extracted per frame (m3)	Product obtained per frame (g)	Number of working days	Number of persons/groups			Working hours (h/d)
						M	W	T	
7	Ambolofotsy	Néant	Néant	2,4	7	7	7	14	21
7	Mahanoro			5,7	7	7	10	17	49
7	Bongarano			2,4	7	7	7	7	48
7	Ambalahady			4,8	7	1	13	14	46
7	Ambodiovitra			3,2	7	2	12	14	47
9	Ambodimanga			4,9	9	4	13	17	63
31	Betsakotsako			88,4	30	18	51	69	240

This table shows respectively the number of gold mining groups per study site using the Vakirano method, the surface area occupied per frame, the volume of land extracted per frame, the product obtained, the number of working days per group, the number of staff (male, female) and the total working time.

3.3. Losses of valuable minerals

The district of Vavatenina is an area rich in ore but gold is the most sought after given its market value and its place in Malagasy culture. The use of panning as a tool for gold extraction allows valuable minerals other than gold to be lost.

Vavatenina's gold sites come from primary deposits and secondary alluvial and eluvial deposits. The alluvial deposits are located either on the riverbed, the river bank or in the bottom of rice fields. Eluvial deposits are found in lateritic clayey soil. Primary deposits are found in mountainous rocks.

-For the secondary alluvial deposit, analysis of Vavatenina gold sand samples by X-Ray Fluorescence Spectrometry was able to detect 48 ores (with atomic numbers ranging from Z= 11 to Z= 92) of which 33 of the 48 found are significant. Among these ores detected and which are lost during the panning operation, Sodium, Vanadium, Neodymium, Ytterbium and Yttrium could be found, with different grades depending on the study site.

-For the eluvial secondary deposit, the analysis of samples of Vavatenina lateritic clayey soil by X-Ray Fluorescence Spectrometry was able to detect 52 ores (with atomic numbers ranging from Z= 11 to Z= 92) of which 35 ores out of the 52 found are significant. Manganese is the mineral always present in almost all samples analyzed, followed by Zirconium, Yttrium, Cerium and Chlorine.

-For the primary deposit, the analysis of Vavatenina magmatic rock samples by X-Ray Fluorescence Spectrometry was able to detect 44 ores (with atomic number ranging from Z= 11 to Z= 92) of which 30 ores out of the 44 detected are significant. Manganese is the mineral with the highest concentration, followed by Sulphide, Calcium and Vanadium with the lowest concentrations. The following elements were also found: Gallium, Germanium, Selenium, Yttrium, Zirconium, Niobium, Praseodymium, Neodymium, Ytterbium, Hafnium, Thorium and Uranium.

4. DISCUSSIONS AND CONCLUSION

Artisanal gold mining has two different and contradictory aspects, because on the one hand, it is a profession that creates negative impacts on the environment and on the other hand, it is an activity that fights unemployment and rural exodus. Moreover, it promotes the development of farming areas. Several questions arise, among others:

-Firstly, does the development of artisanal gold mining rhyme with the eco-environmental damage it generates?

-Second, what strategies can be adopted to develop the artisanal gold industry while reducing environmental impacts?

To clarify these questions, we will answer these two questions separately.

(a) Does the development of artisanal gold mining rhyme with the eco-environmental damage it generates?

Because of the national political crises on the one hand and the international crises that the country has been going through on the other hand, households have gone through a difficult period that has impacted on their socio-economic living conditions. The solution found by the majority of them is artisanal gold panning. It is therefore the profession capable of absorbing a high rate of unemployment, even if this activity has a negative impact on the environment because, as the Malagasy saying goes, "it is better to die tomorrow than today". Logically, a mining operation must be in conformity with the environment according to the MECIE decree "Making investment compatible with the environment". However, artisanal gold mining is, in the majority of cases, an illegal activity, which is why everyone can intervene. To deal with environmental damage, measures and strategies must be taken by the State to deal with it.

b) what strategies can be adopted to develop the artisanal gold industry while reducing environmental impacts?

Artisanal gold mining is an activity practiced by many households as a source of income or as an income-generating activity (IGA). This activity presents not only socio-economic benefits but also threats, especially environmental threats, related to artisanal gold mining methods practiced in the traditional manner by gold miners. These threats include: loss of cultivated land, soil destruction through the loss of sediment transported by erosion, loss of soil biodiversity, water pollution and disruption of wildlife life.

In order to address the above-mentioned threats to the sustainable management of local mining resources, as gold panning is a main activity in the Vavatenina district where several operators of the sector live, measures need to be taken between the various actors of the sector: gold panners, landowners, the state, the mining administration and local decision-makers. Each entity must take its share of responsibility for better management and sustainability of the resource. Furthermore, in order to develop this artisanal gold industry while reducing the threats to the environment, strategies will have to be taken, among others, to raise awareness among all the actors in the industry and to rehabilitate or restore the mining areas. An environmental improvement plan will have to be proposed in order not only to support artisanal miners with environmental mitigation and restoration programs during mining and after the closure of the small mine, but also to promote best practices in environmental management.

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