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Contribution to artisanal gold ore processing methods in Africa and their impact on the environment

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Abstract

The current practice of artisanal gold ore processing in Africa has a significant impact on the region's biophysical and socio-economic environment. Crushing, grinding, gravity separation and amalgamation are the traditional methods of processing gold ore. These activities can lead to the release of toxic elements such as mercury and cyanide into the environment, which can have harmful effects on local ecosystems and human health.

The aim of this work is to monitor the impact of artisanal gold ore processing methods on the physical environment. In the course of this study, we assessed the impacts of these different treatment methods on the biophysical and socio-economic environment, as well as their interactions with other components of the environment.

Artisanal processing of gold ore can be an important source of income for local communities in socio-economic terms, but it is often associated with unsafe working conditions and unsustainable practices. In addition, competition for access to mineral resources can lead to social and political conflict in the region.

Keywords: Methods; Artisanal; Gold; Impact; Environment

1. Introduction

Artisanal gold mining or gold panning has been around for a very long time and is practised by millions of people around the world. It involves between 10 and 15 million people in more than 70 countries around the world. It is an activity that provides substantial income for gold miners and their families. Although gold panning is carried out using rudimentary methods with little or no mechanization, it is an activity that injects considerable quantities of yellow metal into the global gold circuit.

In fact, 15-20% of the gold produced in the world comes from artisanal mining. Artisanal and small-scale gold mining is on the increase in many low- and middle-income countries, mainly because of rising gold prices and widespread poverty. Gold from these informal mines could account for 20-30% of global production. It is estimated that around 15 million people work in this sector and perhaps 100 million people worldwide depend on it for their livelihoods**(1)**

Artisanal gold mining in Africa is characterised by a diversity of practices and techniques adapted to local contexts and available resources. According to the World Labour Organization, around 15 million people, including 4.5 million

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women and children, are involved in artisanal and small-scale gold mining in Africa **(1)**. These figures underline the socio-economic importance of this activity, while highlighting the environmental challenges it poses.

Artisanal gold ore processing methods in Africa are of crucial importance to many local communities who depend on this activity for their livelihoods. According to a recent study by the Food and Agriculture Organization of the United Nations, artisanal gold processing is a major source of income for millions of people in Africa, but it is often associated with health and environmental risks due to the use of toxic chemicals and rudimentary techniques**(2)**.

The artisanal processing of gold ore in Africa is an ancient practice that continues to play a crucial role in the economies of many African countries. This method relies on traditional, manual techniques to extract gold from ores, often with limited resources and in difficult conditions. Despite the challenges, the artisanal gold mining sector makes a significant contribution to gold production on the continent.

2. Material and methods

Artisanal gold mining is a labour-intensive process that often takes place in less regulated environments, mainly in developing countries. Although these techniques are generally conventional and simple, they can be effective in recovering small quantities of gold. Artisanal gold ore processing techniques vary according to the resources available, the size of the mining operation and the technical knowledge of the miners. In this section we have mentioned the artisanal processing tools and methods commonly used. There is a wide variety of methods used, but they generally aim to maximise gold recovery with limited resources and technology. These include:

2.1. Gravimetric concentration

In gold processing, gravimetric concentration is a technique commonly used to differentiate between particles of gold and other minerals. This technique is based on the difference in density between gold and the other minerals present in the ore. Using equipment such as shaking tables, spirals or centrifuges, the gold particles can be concentrated according to their specific weight. This technique is widely used in mineral processing to concentrate important or useful minerals by eliminating less dense gangue materials.

According to **(2),** the effectiveness of gravimetric concentration in gold processing, highlighting its advantages in terms of high recovery and relatively low costs compared with other separation methods. However, the size of the gold particles, the presence of other heavy minerals and the need for pre-concentration can limit the effectiveness of this method. Because of its reliability and cost-effectiveness, gravimetric concentration remains an essential technique for processing gold ores in the gold mining industry. In Eastern and Southern Africa, mercury contamination linked to small-scale gold mining and processing is a major problem for the environment and human health. In Tanzania and Zimbabwe, around 200,000 to 300,000 people work in small-scale gold mining. Mercury (Hg) is mainly used to treat supergene gold mineralisation and primary gold-bearing quartz veins.

According to gravimetric analyses of the flow of materials, 70 to 80% of the mercury is lost to the atmosphere during processing, while 20 to 30% is lost to tailings, soils, river sediments and water. 1.2 to 1.5 grams of mercury are produced for each gram of gold produced.

Figure 1 Gravimetric gold processing method

2.2. Amalgamation

Amalgamation in artisanal gold mining refers to the traditional method used to extract gold from ores. This method involves the use of mercury to form an amalgam with the gold, making it possible to differentiate gold from other materials. Despite its simplicity and effectiveness, this method is widely used in artisanal mining, but because of the toxicity of mercury, it presents significant risks to human health and the environment**(3)**.

2.3. Environmental and health issues

In the current context of industrial development, the environmental and health problems associated with the amalgamation process are major concerns. As the World Health Organisation (WHO) points out, exposure to hazardous chemicals is increasingly recognised as a major public health problem. According to the World Health Organisation, when toxic substances are released into the environment during the amalgamation process, this can have negative effects on the health of local populations and the ecosystem as a whole.

Mercury pollution from artisanal gold mining cause's serious environmental and health problems, particularly for workers and people living near processing facilities. Artisanal miners are the largest man-made source of mercury pollution, releasing more than 2,000 tonnes of mercury per year into the environment**(4)**.

Artisanal gold mining has serious negative effects on the environment and the health of local populations. This process involves the use of toxic chemicals such as mercury to extract gold from ores, which can contaminate water, soil and air. Deforestation, water pollution and loss of biodiversity are some of the environmental problems associated with this practice. In addition, mercury exposure can cause neurological problems, kidney problems and birth defects**(5)**.

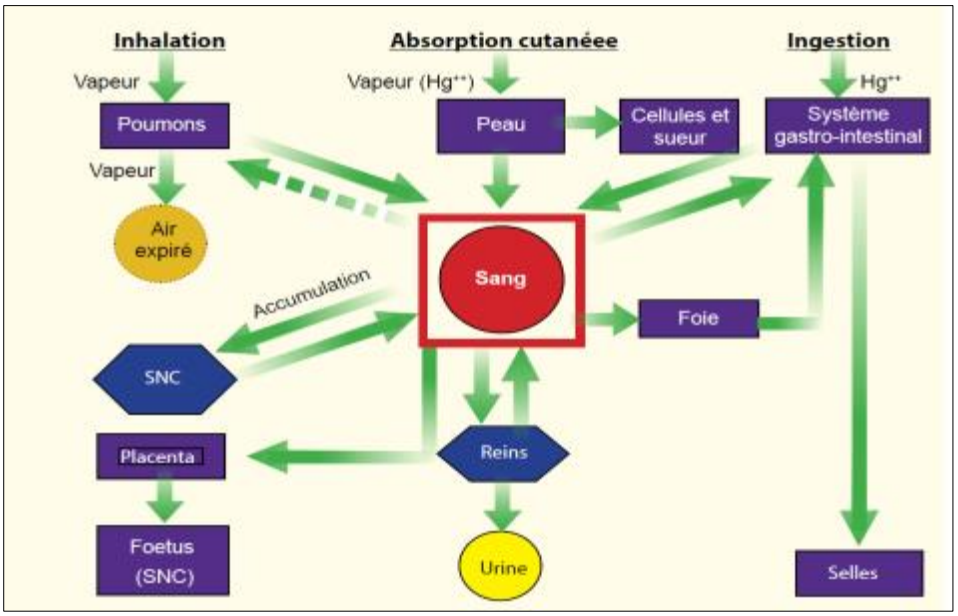

Figure 2 Toxicokinetics of methyl mercury. Source: Elinder et al 1988

2.4. Alternatives and Innovations

According to **(4),** alternatives to the amalgamation process are increasingly being explored by companies in an ever-changing economic and regulatory environment. They underline the need to actively seek innovative ways to realise synergies and create value without systematically resorting to traditional amalgamation operations.

Because of the use of mercury, amalgamation, a process traditionally used in metallurgy to extract precious metals such as gold and silver, has given rise to environmental and health concerns. These concerns have prompted the search for solutions and innovations to make this process safer and more sustainable. One notable alternative is the use of cyanide leaching, which, although it also presents environmental problems, is considered less harmful than the use of mercury. In addition, technological advances such as electrolysis and hydro-metallurgical processes offer promising alternatives to the extraction of precious metals. These techniques aim to reduce environmental impact while improving the efficiency of the extraction process**(6)**.

Using cyanide to treat gold is a common method, but it poses significant risks to the environment and human health. Here are some of the alternatives that are most respectful of the environment and human health.

2.4.1. Gravity

This method uses the difference in density between gold and other minerals to separate it. The ore is crushed and then subjected to gravimetric separation techniques such as the shaking table, spirals or centrifuges to recover the gold.

2.4.2. Floating

This process is mainly used to treat sulphide ores containing gold. The ore is pulverised and mixed with flotation reagents that render the gold particles hydrophobic. When air is blown into the suspension, the gold particles attach themselves to the air bubbles and rise to the surface, where they can be collected.

2.4.3. Alluvial deposits

This method is used to extract gold from alluvial deposits, such as rivers and stream beds. It involves the use of washing, dredging or manual digging techniques to recover gold particles from the sediment.

2.4.4. Putting into solution

This method is used to extract gold from low-grade ores using a leaching solution, such as cyanide or thiosulphate. The ore is treated with the solution, which dissolves the gold, and the gold is then recovered from the solution.

2.4.5. Low-intensity cyanidation

This method uses reduced concentrations of cyanide, which reduces the risks associated with this substance. However, it is crucial to carefully monitor and properly manage the use of cyanide.

2.4.6. Heap leaching

Rather than treating the rock in tanks, heap leaching involves creating a heap of crushed ore onto which a leaching solution is sprayed. This method is less labour-intensive and reduces the risk of groundwater contamination.

2.4.7. Alternative leaching methods

Other leaching methods, such as alkaline or acid leaching, can be used as alternatives to cyanidation. However, it is essential to ensure that these methods are implemented safely and responsibly.

2.4.8. Mercury-free technologies

Mercury-free technologies, such as dry amalgamation and gravimetric concentrators, can also be considered as alternatives for extracting gold without using harmful chemicals.

The adoption of these alternatives often depends on the specific nature of the gold deposit, local conditions, economic costs and regulations in force. It is important to implement responsible mining practices and to engage in methods that minimise environmental and social impacts while preserving the health of workers and local communities. It should be noted that each method has advantages and disadvantages in terms of cost, efficiency and environmental impact. The selection of the appropriate method will depend on the characteristics of the gold ore, the availability of resources and environmental considerations.

2.5. Cyanidation

Cyanidation is a method widely used around the world to extract gold from ores. It is the process by which cyanide is used to dissolve the gold present in ores. This creates a soluble complex which can then be extracted. Because of its simplicity and effectiveness, this method is often preferred. However, because of the toxicity of cyanide, it also raises problems for the environment.

Artisanal gold mining by cyanidation is often carried out in rudimentary conditions and can pose risks to the health of workers and the environment. Artisanal gold processing by cyanidation is a method commonly used in the small-scale mining industry. It involves the use of a cyanide solution to extract gold from ores. Some general steps in the cyanidation process:

2.5.1. Crushing and grinding

Gold-bearing ores are crushed and ground into a fine powder.

2.5.2. Preparing the cyanide solution

A cyanide solution is prepared by mixing sodium cyanide with water. This solution is then added to the crushed ore.

2.5.3. Leaching

The cyanide solution is poured onto the ore in special tanks called leaching tanks. The cyanide reacts with the gold to form a soluble complex called gold cyanide complex.

2.5.4. Adsorption

The gold cyanide complex is recovered by passing the solution through columns filled with activated carbon. The activated carbon adsorbs the gold dissolved in the solution, forming a gold-loaded charge.

2.5.5. Desorption and recovery of gold

The gold-laden activated carbon is then washed with a dilute cyanide solution to desorb the gold from the adsorption sites. The gold-containing solution is collected and the gold is then recovered using various methods such as electrolysis or chemical precipitation. It is therefore essential to follow strict waste management and safety protocols when using cyanide. It is highly toxic, but breaks down rapidly in solution and is not a cumulative toxin. If carried out carefully, the method is effective, but it requires considerable investment and skills.

Figure 3 Cyanidation gold processing technique

Figure 4 Cyanidation zones

3. Results and discussion

The main results obtained during this study focused on assessing the various impacts studied and examining the series of participatory and mitigating approaches. These impacts were established as follows:

3.1. Impact on the biophysical environment

The long-term environmental consequences of artisanal gold mining are often overlooked despite the immediate economic benefits. According to **(6),** exposure to mercury not only degrades water quality but also affects the health of local communities, highlighting a dilemma between economic development and environmental preservation. As well as distorting the landscape, gold miners create micro-reliefs when digging and bringing ore to the surface, resulting in the formation of claws, gullies, incisions and gullies, which encourage the movement of treatment chemicals and elements from deep underground, contributing to soil erosion.

In addition, all the research is unanimous that for each gram of gold obtained by amalgamation, approximately two (02) grams of mercury escape into the surrounding environment**(7).**

Artisanal gold mining can have a number of negative impacts on the biophysical environment. Here are some of the most common impacts:

3.1.1. Soil degradation

Mining activities can lead to deforestation and the displacement of land, resulting in the destruction of natural habitat and soil degradation. This can lead to a reduction in soil fertility and a loss of biodiversity.

3.1.2. Water pollution

The use of chemicals such as mercury and cyanide in the gold mining process can contaminate water sources. This can make the water unsuitable for human and animal consumption, as well as for irrigating farmland. In addition, mining waste can contaminate nearby watercourses, affecting aquatic life.

3.1.3. Destruction of aquatic ecosystems

Gold mining often involves the dredging of rivers and streams, which disturbs aquatic habitats and destroys local ecosystems. This can lead to the disappearance of certain species of fish and other aquatic organisms.

3.1.4. Deterioration of air quality

Mining activities produce fine dust that can become airborne and cause air pollution. This can have adverse effects on human health, including respiratory problems.

3.1.5. Land erosion

Gold mining can involve the use of destructive methods such as open-pit mining and large-scale extraction. These techniques can lead to increased soil erosion, which can result in landslides and landscape instability.

3.1.6. Impacts on biodiversity and water resources

Biodiversity, which refers to the variety of species and ecosystems, is of crucial importance in maintaining the balance and stability of our planet. Unfortunately, certain human activities, such as artisanal gold processing methods, have a negative impact on this precious biodiversity. Artisanal gold processing practices can lead to significant destruction of natural habitats and ecosystems, putting many plant and animal species at risk.

This raises concerns about the preservation of species and their natural habitats (**(8); (9)**).

Processing methods have an impact on the ecosystem of gold panning areas in general, but particularly on water resources. According to the work of **(10)** artisanal gold mining generates several types of impact on water resources, including contamination by acid mine drainage (AMD), contamination by filtration of metals, contamination by direct dumping of chemicals, the effect of erosion and sedimentation of discharges and depletion of water resources.

This pollution, including mercury discharges, is carried by the current and affects an entire river basin. Some operators with greater technical resources (and the financial means to bribe the authorities) even mine gold directly on the Niger

by building dykes and using appropriate machinery, to the detriment of all the downstream inhabitants of this river, which is of major importance and crosses four countries**(11)**. This image shows the impact of artisanal gold mining on water resources.

Figure 5 Image of the impact of artisanal gold mining on water resources

3.1.7. Climate change

Climate change has become one of the most pressing issues facing mankind. Human activities, including mining, have a major impact on greenhouse gas emissions and contribute to global warming. Although artisanal gold mining is essential to local economies in some parts of the world, it has a significant impact on climate change. This activity releases considerable quantities of mercury, a powerful greenhouse gas, into the environment. The mercury amalgamation process used in artisanal gold mining is responsible for almost 37% of global mercury emissions. These emissions not only contribute to global warming but also seriously affect human health and aquatic ecosystems. It is crucial to understand and assess the impact of artisanal gold processing on climate change(12).

3.1.8. Water resources

Artisanal gold processing methods have a significant impact on water resources, both locally and globally. Artisanal gold mining is often associated with unsustainable mining practices that can lead to water and soil pollution (4). This raises a major issue in terms of environmental sustainability and the availability of water resources in regions where artisanal gold mining is practised. The impact of artisanal gold processing methods on water resources is a crucial issue that requires particular attention in order to reconcile economic imperatives with the preservation of the environment and aquatic ecosystems. Artisanal gold mining, while an important source of income for many communities around the world, poses significant challenges in terms of the management and conservation of water resources.

Figure 6 Impacts of artisanal gold mining on water resources

3.1.9. Impact on flora

Since the industrialisation of gold mining, flora and fauna have suffered serious deterioration. Soil fertility hinders the natural development of ecosystems. In the Siguiri region, the combination of traditional and industrial gold panning is having a negative impact on the soil, which was an important agricultural resource before the industrialisation of gold mining. The consequences of this deterioration are a reduction in agricultural activity and forest area, both of which are essential to the food self-sufficiency of the inhabitants of the Siguiri region**(11)**. In Guinea, for example, although the forestry code has been revised and numerous awareness-raising campaigns have been carried out in the country's mining areas, artisanal gold mining continues to be a major factor contributing to the deterioration of forest and wildlife resources in the Siguiri region in particular and in gold panning areas in general. Deforestation in this gold sector occurs mainly before and during ore production. The first impacts on forest resources in these localities are the clearing of land to facilitate the temporary construction of mining camps, the installation of workers (gold panners, traders, garage owners, etc.) and the cutting of wood to expand the gold panning site. Similarly, with current practices, the gold panning sector is increasingly becoming a major consumer of wood.

Figure 7 Impacts of artisanal gold mining on vegetation

3.1.10. Impact on the air

The effects of gold panning on the air are visible and frequent in the dry season. The activities of pounding, crushing and burning the gold to evaporate the mercury, as well as the movement of gold miners from the area of origin to the extraction and installation sites, produce dust that pollutes the air for humans, domestic and wild fauna. Once in the air, these dust particles fall because their atomic mass does not allow them to rise to the furthest layers of air on our planet. When the air cools at night, it pollutes thousands of hectares of forest, and animal watering and grazing areas are affected. The habitats of humans and wildlife are covered in dust, which can be coloured red or white depending on the type of soil. Mercury vapour travels considerable distances in the atmosphere, polluting thousands of kilometres. The pollutants affect plants and water. Several types of motorised vehicles pollute the air by emitting CO2. These include tricycles, tippers, motorbikes, crushers, grinders, motor pumps and electronic units, among others**(6)**.

The activities of crushing, grinding and digging generate highly charged and dangerous dusts. During mercury processing, the mercury-rich ore mixture is burnt in the open air, resulting in the production of mercury vapours that are released directly into the atmosphere**(13)**.

3.2. Socio-economic impact

The socio-economic importance of artisanal and small-scale mining of precious minerals has been discussed by many authors. It provides employment, supports the livelihoods of the rural poor and contributes to national income through taxes, export earnings and the supply of raw materials to local industries (e.g. the jewellery industry). According to the World Bank, an estimated 100 million people worldwide depend on artisanal gold mining for their livelihoods.

Despite the economic gains of artisanal gold mining, it is known to cause safety, security and environmental problems such as mercury contamination, land degradation, pollution and damage to biodiversity. It is also said to be the cause of

land disputes and violent clashes between artisanal and small-scale miners and large-scale mining companies and/or government security forces also describe the hazardous nature of the environment and its impact on health and safety of workers and surrounding communities and attribute these problems to lack of knowledge, poor technology, economic restrictions, lack of enforcement and inadequate environmental legislation.

3.2.1. Economic growth and employment

The sustained increase in the production of goods and services in an economy over a given period is called economic growth. The growth rate of gross domestic product (GDP) is generally used to measure this. Sustained economic growth can lead to job creation, as businesses need more labour to meet the growing demand for goods and services. Artisanal gold mining can contribute significantly to the economic expansion of a region or country and thanks to the taxes and royalties collected, artisanal mining activities can help miners, suppliers, traders and local governments earn money. By creating direct and indirect jobs**(14).**

3.2.2. Public health

Given the health risks associated with artisanal gold processing methods, public health in relation to these techniques is an increasingly important issue. Artisanal gold processing, which is often carried out without adequate equipment or protection, exposes workers and surrounding communities to a variety of hazards, such as high levels of mercury and other toxic substances. Exposure to mercury in artisanal small-scale gold mining is the biggest public health problem associated with this activity, and negative health effects such as neurological, kidney and respiratory disorders can result from this exposure**(15).** According to **(16),** only 75% of mining communities in Guinea's gold mining areas are located within 3 km of a health centre, and the national average is 1 nurse per 3,000 inhabitants, which means that health services in mining areas are of relatively poor quality. Malaria is the most common disease, killing the largest number of adults in 75% of mining communities, followed by STIs and lung disease. Malaria is also the main childhood disease that kills the most people, followed by diarrhoeal diseases and malnutrition.

3.2.3. Education

In a report entitled (Underlying the presence of children on artisanal gold mining sites in rural areas of Burkina Faso), gold panning has an ambivalent impact on family ties and on children's education (socialisation). It can, to a certain extent, strengthen family ties and promote the education of children for those who are aware of it, but it can also cause the dislocation of social ties and disrupt children's development. However, it is the second aspect that is much more present in the study areas. Whether formal or informal, gold panning has had a significant impact on the education system. Indeed, family education is in decline due to the questioning of the authority of the ancestors, which was once considered to be the foundation of the social order. The diversion may be due to the fallout from gold mining, but also to the effects of drug use**(17)**. According to **(18)** in Burkina Faso the national policy has been a failure because mining encourages children to leave school, empties training centers, and only the elderly remain in the villages", said one respondent, who saw his own cousin drop out of college at an advanced level to work on a mining site at Kalsaka in the north. Nationwide, the exact number of children who drop out of school to work in the mines remains undetermined, but many schoolchildren are thought to work mainly in artisanal mines, crushing stone, sieving tailings, carrying water and cooking.

4. Conclusion

Artisanal gold ore processing in Africa has a considerable impact on the biophysical and socio-economic environment of the region. Pan washing, fire smelting and the use of chemicals such as mercury can cause considerable damage to the local ecosystem. Discharges of toxic substances into watercourses can contaminate drinking water, affecting the health of local populations and surrounding biodiversity. In addition, artisanal mining practices can lead to deforestation, soil erosion and the loss of agricultural land, which has a negative impact on the livelihoods of local communities.

Although artisanal gold mining can provide employment and income opportunities for local people, it is often associated with unsafe working conditions, exploitation of workers and socio-economic land disputes. In addition, competition for access to mining resources can lead to social and political conflict within communities.

In order to reduce the negative impact of artisanal gold mining on the environment and local communities, African governments need to introduce strict regulations. Promoting environmentally friendly extraction techniques environmental protection, raising awareness of health and safety risks and building the capacity of local stakeholders can help to mitigate the harmful effects of this activity on fragile ecosystems and vulnerable populations.

Compliance with ethical standards

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Disclosure of conflict of interest

There are no conflicts of interest in this work, and the authors wish it to be published in this journal.

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