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Analysis of the Spatio-Temporal Evolution of Artisanal and Small-Scale Gold Mining in Central Ivory Coast, West Africa

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Abstract

Ivory Coast is a country rich in base metals and precious minerals: gold, manganese, diamond, iron, bauxite, cobalt and nickel. These natural resources are exposed to destruction and fragmentation by mining activities. The artisanal and small-scale exploitation of gold are increasingly practiced in our rural areas. These activities escape often in the control and monitoring of the mining administration. In order to better constrain these activities on the environment, the present work used remote sensing imageries to see its spatio-temporal impacts in the rural world in central Ivory Coast. The results show that gold artisanal activities have been practiced since 2013 and are experiencing an increasingly important growth. We note a devastation of forests and savannahs, a pollution of surface water, as well as an increase in poverty in rural areas. These activities are practiced near habited areas (villages). This creates a reduction of cultivatable soil. Remote sensing imageries make it possible to quickly map areas at large-scale gold mining in time and space.

Keywords

Gold Panning, Artisanal Mining, Space and Time, Remote Sensing Imageries, Ivory Coast, West Africa

1. Introduction

Ivory Coast is located at the southern limit of the West African craton and is part of the ridge of Man. Precambrian rocks occupy 97.5% of the country's land area and include ores of gold, iron, manganese, bauxite, nickel, cobalt, diamond, copper... Artisanal mining that dates back to 18th century, according to Gaston

(1913), gained momentum at the end of the last century to become today one of the main socio-economic activities of the rural populations. Artisanal and small-scale gold mining is a widespread activity in the Ivorian territory, more especially in the center of the country (Ahoussi et al., 2020; Daï-Bi et al., 2020; Ouattara et al., 2021).

In view of the strong enthusiasm that these activities arouse, they may appear to be lucrative and have many negative impacts. It is to control the negative effects that the state has submitted its exercise to authorization (Code Minier, 2014; Alban, 2015). However, it is clear that several artisanal and small-scale sites are opening and developing irregularly, outside the conditions provided by the mining code. It is therefore often a question of clandestinity (Goh, 2016; Allouche & Mohamed, 2017). So, what are its spatio-temporal impacts in the rural world?

The use of satellite imagery for the identification and mapping of artisanal and small-scale mining sites in Côte d'Ivoire is under development. This technology has already been used to monitor the degradation of plant cover linked to mining activities in Cameroon (Tchindjang et al., 2016; Beak Consultants GmbH. 2021), in French Guiana (Gond & Petit, 2004).

The general objective of this study is to know the cartography of the exploitation gold zones in central Ivory Coast and to follow the evolution of this activity in time and space. So specific, it will be a question of doing: 1) *identification of gold panning areas by using remote sensing imageries*; 2) *an estimation of their areas*; 3) *an assessment of the impact of gold panning on the environment*.

2. Location of the Study Area

The exploitation of resources requires obtaining exploration authorizations, applications for operating permits... These last different authorizations are distributed on the Ivorian mining cadastral. These files, made up of administrative documents and techniques relating to mining authorizations and titles, are characterized by statistic data (geographical position, specific characteristics, holder, etc.) and data evolving (period of validity, renewal, transfer, etc.). According to the mining cadastral, the various artisanal and small-scale mining authorization points are identified in **Table 1** and **Table 2**.

Our study area is located in the localities of (**Figure 1**): Booré (Dimbokro), Bozi and Kouassi-Périta (West Yakro).

Table 1. Points of artisanal exploitation authorizations (AEA), (Sources: Ivorian Minier Cadastral, April 2021).

Number	Substances	Statut	Area (Ha)	Percentage
41	Gold	Active	728	77%
04	Gold	Renewal	93.2	9%
06	Gold	Inactive	149.2	14%
TOTAL			**1035.4 Ha**	

Table 2. Points of small-scale exploitation authorizations (AESI), (Sources: Ivorian Minier Cadastral, April 2021).

Number	Substances	Statut	Area (Ha)	Percentage
84	Gold	Active	7009	76%
08	Gold	Renewal	664	7%
19	Gold	Inactive	1625	17%
	TOTAL		**9298 Ha**	

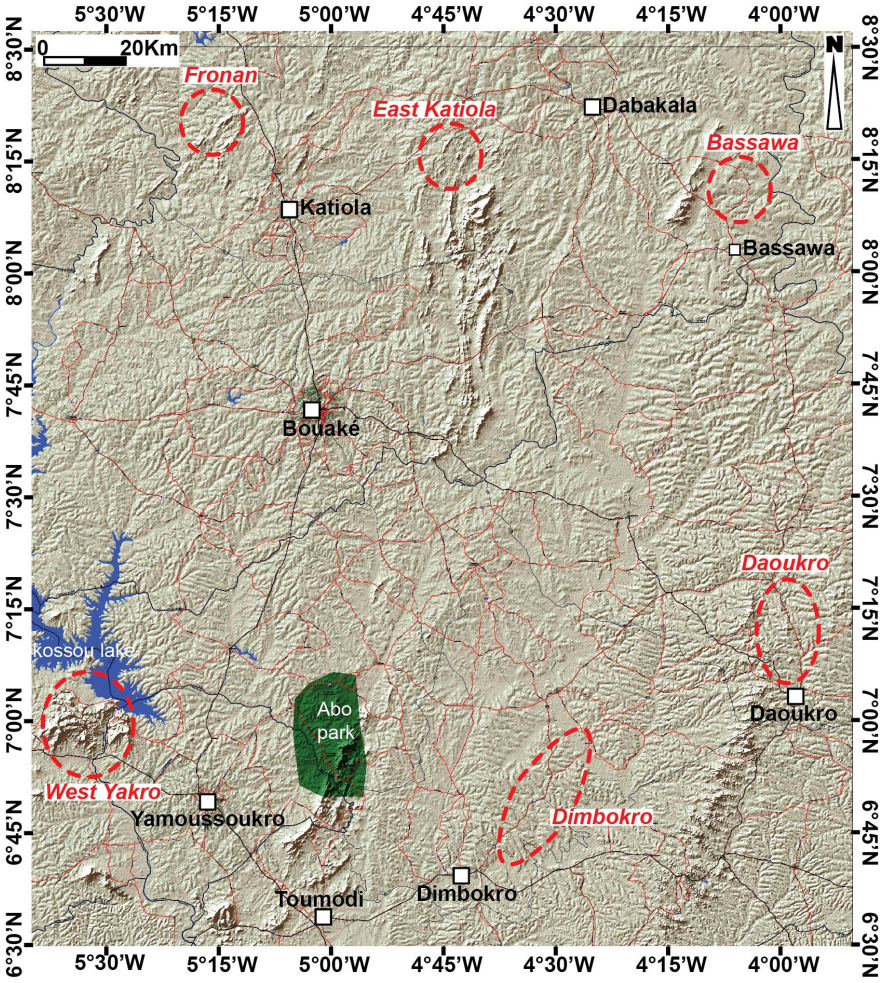

Figure 1. World_Street_Map (downloaded from Global Mapper) of Central Ivory Coast and location of some artisanal and small-scale gold mining activities in red.

3. Material and Methods

Remote sensing imageries permits to map gold mining zones and follow the development of this activity over time. Several images (Landsat type) have been acquired using Google Earth Pro software at different periods in order to follow the spatial evolution of artisanal gold ore washing areas. Recent Landsat 8 images from Sentinel 2 remote sensing were also downloaded at the web site: https://www.eos.com/landviewer/. These areas are identified and "contoured".

The occupied areas are calculated. A verification is then carried out in the field in order to ensure that these areas correspond to gold mining activities.

4. Results

Two regions (Dimbokro and Yamoussoukro), in central Ivory Coast are the object of this study. The results are presented as images over times. Thus, the occupation of gold mining activity zones in Booré (Dimbokro) experienced an area increase of 156 hectares between 2012 and 2019 (Figure 2). Also, the area of Bozi (West Yamousssoukro) observed an area growth of 5 hectares between January 2014 and March 2014, and 64 hectares between 2014 and 2019 (Figure 3). For the area of Kouassi-Périta (West Yamoussoukro), it has experienced an area increase of 70 hectares to 124 hectares between 2019 and 2020, and 184 hectares between 2020 and 2021 (Figure 4).

These remote sensing images contain savannas, soils and settlements, agroforests and plantations, forests and water bodies. The analysis of the results of the temporal evolution until today shows that the environment experienced a significant change with soil erosion caused by removal of canopy plant at artisanal gold sites (Dibal et al., 2016; Tchindjang et al., 2016).

A recent field visit (West Yamoussoukro, August 2022) shows an extension of the various gold panning sites (Figure 5). An area of over 447 Ha (April, 2021) increased to over 6834 Ha in August 2022; approximately an increase of more than 1500% in eight months. Despite certain operating authorizations granted by the mining administration, waste water after ore processing is discharged into the Bandama River and other waterways.

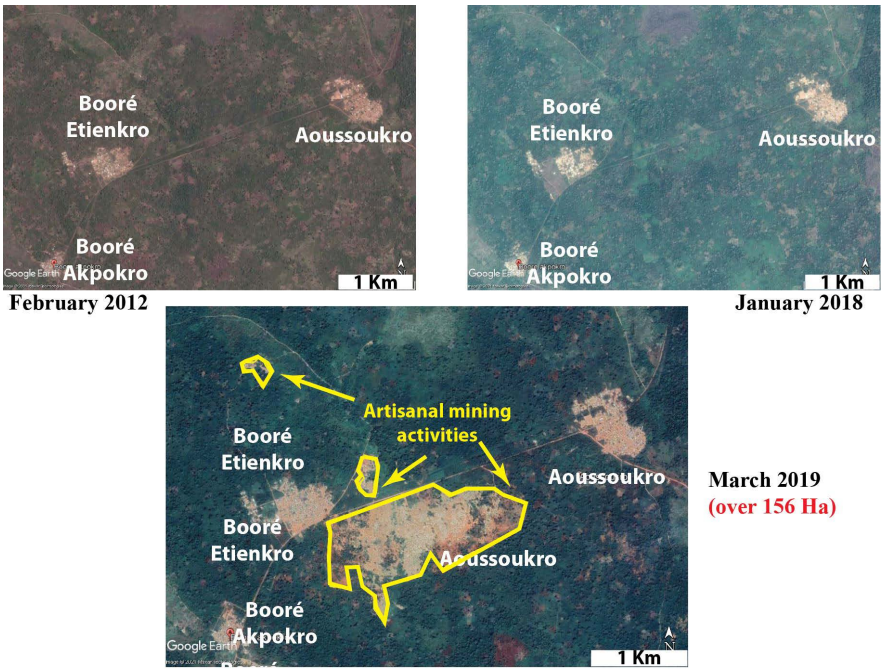

Figure 2. Spatio-temporal evolution of artisanal gold activities in the Booré area, Dimbokro between 2012 and 2019.

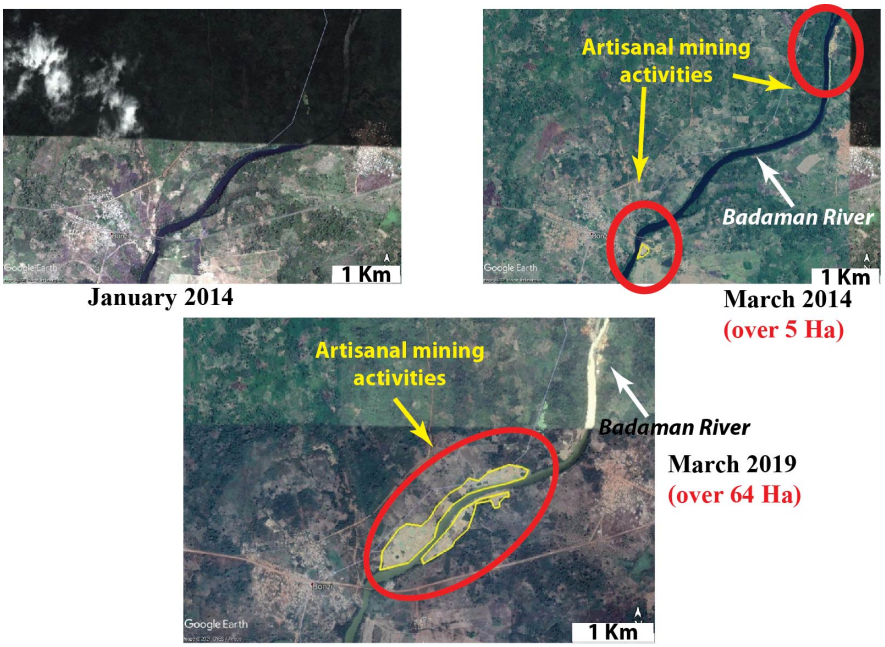

Figure 3. Spatio-temporal evolution of artisanal gold activities in the Bozi zone, West Yamoussoukro between 2014 and 2019.

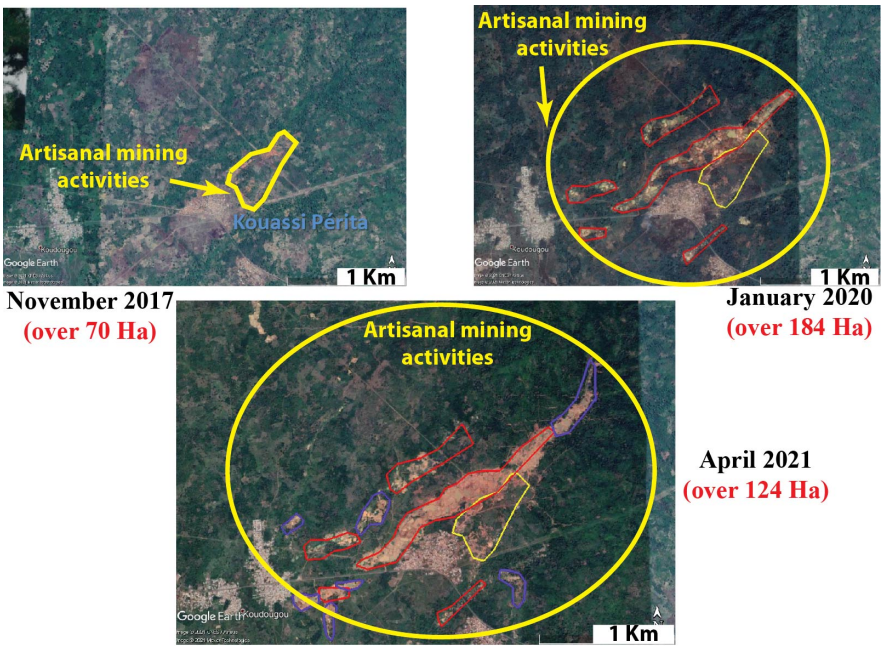

Figure 4. Spatio-temporal evolution of artisanal gold activities in the Kouassi-Périta area, West Yamoussoukro between 2017 and 2021.

5. Issues of Environmental Assessment

5.1. Generalization of Artisanal Mining

Artisanal miners exploit any form of profitable and technically accessible occurrence, therefore relatively shallow. They are preferentially interested in the detrital deposits of "placer" type (alluvial or eluvial), but also at the supergene part

Figure 5. Location of artisanal and small-scale gold activities (in dot orange) in the Yaouré Mounts (West Yamoussoukro). Background image from Landsat 8 (S2B_tile_20220122_29NRH_0_B04, B03, B02_).

of the primary deposits (laterite, saprolite, oxidized zone). These exploitations are still characterized today by rudimentary extraction and processing methods and very simple, such as shovels, picks, buckets, gourds, various metal parts, etc. The intervention of heavy machinery for the stripping of the waste rock is very exceptional. The precariousness of resources and technical short comings frequently lead to a dramatic skimming of the deposits (Hentschel et al., 2003; CIRDI, 2017).

5.2. Mining Activity Destroys and Degrades the Forest and the Savannah

Forest degradation, although temporal, has several consequences for forests. It

can induce the opening of the canopy, loss of biodiversity, modification of the vertical and horizontal structure. Forest degradation also refers to uses that damage soils and vegetation, to such an extent that it prevents or greatly delays the regeneration of the forest after its abandonment. The development of mining sites and the influx of populations are putting strong pressure on wood resources. The digging of wells and trenches contributes to deforestation and destruction of plant cover in central Ivory Coast. For wood production necessary for the extractive activity (support of galleries, construction of ladders, diversion of rivers), and the satisfaction of current needs on the sites (wood for the construction of habitats, production of wood coal, firewood), the miners proceed to uncontrolled felling of trees of all species. All these actions lead to the weakening of the plant cover and the gradual disappearance of protected species. So, we are in the presence of real forest degradation (Dondeyne et al., 2009; Ingram et al., 2011; The World Bank, 2012; Kpan et al., 2014; Bagah et al., 2016; Tchindjang et al., 2016; World Health Organization, 2016; Harlow et al., 2019).

5.3. No Integrated River Management in a Region with a Rich Hydrographic Network

Mining activities, whether artisanal or small-scale, have negative impacts on water resources. At the level of artisanal mines, we note the disturbance of the hydrographic network by the destruction of certain tributaries of rivers (**Figure 6**).

This disturbance of the hydrographic network results in the loss of biodiversity of these aquatic environments. In addition to these impacts, artisanal gold mining and small-scale mining create several pits which consist in draining water from the alterites and those of fractures and cracks. The observations made during our various missions on small-scale and artisanal mines, cyanide and mercury are used, we can say that pollution of water is possible (Damayanti & Lutfie, 2009; Rakotondrabe et al., 2017; Abu Bakr El Siddig Ahmed El, 2018; Ahoussi et al. 2020; Sylvain et al., 2020; Ouattara et al., 2021).

Figure 6. Overview of a tributary of Bandama river destroyed in West Yamoussoukro through artisanal gold mining activities.

5.4. The Weakening of the Local Economy and Social Balance

The development of small-scale or artisanal gold mining in the central Ivory Coast creates competition with other land uses. Today, it can be said that clandestine artisanal gold mining is the main economic activity in these localities. This situation has negative effects on the local economy. The first negative consequence, at the economic level, is the abandonment of agriculture, with the inflation of food prices. We can also note the precariousness of the incomes of rural populations (Dibal et al., 2016; World Bank, 2020; OXFAM, 2021).

The localities of central Ivory Coast are seeing their populations increase because of mining activities. This large concentration of non-native populations, in an environment where there is a lack of socio-cultural roots and arable land. Social disorders constitute a major characteristic of major rush-type gold mining sites: healthy life style disastrous, drug use, prostitution, organized crime…

5.5. Insufficient Infrastructures

With the rapid increase in population, human pressure is increasing on basic infrastructures and social structures in place. Thus, for example, in Angovia and Allahou-Bazi (the two localities are contiguous), the drinking water points, the school group and the health center are responding today with difficulty to the requests of populations whose number has more than tripled in less than ten years.

6. Discussion

In Ivory Coast, local governance is provided for by the 2016 Constitution in its article 175. This article delegates powers to kings and traditional chiefs for the management of their localities. These are: "*The enhancement of customs*, *the promotion of the ideals of peace and development*, *social cohesion*, *non-jurisdictional settlement of conflicts in villages and communities and participation in the administration of the territory*".

Despite these formal constitutional powers, the local governance in Ivory Coast does not seem to be effective in practice. In reality, the local populations do not feel involved in the decisions taken by the State relative to their locality. Which sometimes creates the failure of community programs initiated by the government, such as the gold panning rationalization program in Ivory Coast. This program, initiated in 2013 over a period of three years to clean up, organize and supervise artisanal gold activities in Ivory Coast has not achieved its objectives. This is explained by the fact that after the eviction and closure of the clandestine sites initiated by the government, there is a growing of new clandestine sites with a recolonization of old evacuated sites. This situation gives rise to reflections on the factors which promote the expansion of clandestine artisanal gold activities in Ivory Coast.

These phenomena are both social, economic and political. The social reasons for the expansion of clandestine gold panning are summarize in these points: 1)

the feeling of legitimacy of the landowner to offer his land in return for a cost; 2) *the diversity of actors strongly dominated by migrants and natives*; 3) *the only economic reason for the expansion of clandestine gold panning is the ease of the marketing of the ore and its profitability*; 4) *long administrative procedures that discourage actors from legality*; 5) *the weakness of traditional authority face of this phenomenon*; 6) *in addition to these difficulties for the village chief, there is the corruption of certain officials*; 7) *accentuation of social inequalities in rural areas* (*poverty*); 8) *Decline of cultivable land*; 9) *health risks and accidents*; 10) *difficulties in the rehabilitation of mining sites after exploitation.* These phenomena are common in other countries (Amara Mining PLC, 2015; Wandan et al., 2015; Goh, 2016; Sana et al., 2017; United Nations, 2020; World Bank, 2020; Serwajja et Mukwaya, 2021; Tampushi et al., 2022).

The health risks are great for children who are affected by dust and noises. Among the physical risks and constraints to which children are exposed on mining sites (Kéita, 2001), we will note: 1) *diseases and silicosis, due to fine dust*; 2) *the risk of deafness from the permanent noise of the pestle or hammer*; 3) *fatigue and intense efforts to crush and grind the ore*; 4) *the risk of injury from shards of stone in the eyes*; 5) *various eye and dermatological conditions*; 6) *child prostitution*.

Regarding the artisanal exploitation of alluvial deposits, it mobilizes a team composed of ten people, working in the assembly line, in two different groups. The first group consists of five to seven persons; they are well diggers, in charge of take turns digging the mine and raising the ore from the shaft using a pulley or by simple human pull. It is the most exhausting task of the artisanal mining activity. It is performed only by men.

The second component of the artisanal miners is constituted of women (02 to 03 persons) responsible for washing the ore supplied by the well diggers (Ibrahim et al., 2020; Rutherford, 2020). In general, the artisanal miners work under the close supervision of the representatives of the land owner and of the "site manager" whose role is to prevent the theft of the gold produced.

Concerning children, they intervene in the clandestine gold mining sector, either on their own behalf or on behalf of their parents. In the first case, the children offer their services to the managers of the "construction sites" and their job is to transport the ore from the well to the washing sites or to crush and sift the ore. Compensation children's daily allowance is variable, but rarely reaches 2000 CFA francs (~3€). Children who work on behalf of their parents represent land owners; they are responsible for monitoring gold production, particularly at the ore washing stage, to prevent the theft of the precious metal. In general, children who live in villages miners do not go to school and the rare educational structures around the sites are often deserted.

As the sites are rarely permanent, groups of minors migrate very quickly to other sites, according to new discoveries or rumors. In these conditions, children suffer and live in a family atmosphere disturbed by arguments, alcoholism and parental violence.

Land degradation by gold mining activities is the most visible from environmental point of view (Kéita, 2001; Bagah et al., 2016; Tchindjang et al., 2016; Harlow et al., 2019). The plant cover of the sites is degraded by the action of the excavations. The gold washers clear the vegetation before digging the earth. In this logic, all the herbs and the trees are cut down.

The degradation of cultivable land has leads to a decline in timber production and agriculture. What is particularly problematic for the right to food of communities. Mining activities and the use of cyanide for gold mining has polluted the drinking water resources of communities, giving the water a red tint (Rakotondrabe et al., 2017; Sylvain et al., 2020).

7. Conclusion

Spatio-temporal remote sensing imageries have made it possible to determine the real impacts of the mines in the process of land occupation and its degradation in central Ivory Coast. Artisanal and small-scale mining activities have negative impacts on the environment, particularly on plant cover, biodiversity, soil and water resources.

From all that follows it would be appropriate to remember that the clandestine exploitation of gold not promote a sustainable economy. In traditional gold mining techniques in central Ivory Coast, the risks and dangers of the environment translate into deforestation, destruction of plant cover and soil, pollution of water resources by the use of chemicals in the treatment.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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