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Original article

Collapse of underground galleries in gold-panning mines: Perception of stakeholders in the Doko Sub-Prefecture, Siguiri Prefecture, Republic of Guinea

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ABSTRACT

Artisanal gold mining is recognized as a long-standing activity in the Siguiri prefecture in general and the Doko sub-prefecture in particular. Despite its significant contribution to community development, it has disastrous consequences for both the environment and the lives of gold miners. The collapse of underground galleries as a result of gold panning is a phenomenon that plunges families into mourning in gold panning areas in Africa. Unlike other land movements, despite their dangerous nature, there has been almost no scientific interest in limiting the consequences of collapsing underground galleries in goldmines. Working to mitigate their effects is more than a necessity for those involved in gold panning.This study aims to understand the perceptions of those involved in gold panning regarding the conditions of occurrence and the main causes of underground gallery collapses, to formulate recommendations to the authorities and gold miners to minimize the risk of these accidents occurring and their impact. The methodology used was based on semi-structured and structured interviews. The results of this survey show that the human factor is certainly the main cause of accidents (collapse of underground galleries), but the design of structures without taking into account the study of the geomechanical properties of the ground, the weakness of the safety measures put in place, and the lack of involvement of the country's authorities are not negligible factors. This study identified the causes and consequences of these accidents, as well as the responsibilities of those involved.

KEY WORDS: artisanal gold mining, gold miners, gold exploration

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1. Introduction

The gold panning sector is undoubtedly one of the main sources of income for many families in areas where the activity is practiced in Africa. According to a study by DOUCOURÉ (2014) carried out in a gold mining village in Senegal, 92% of the population indicated that gold panning was their main source of income, compared to 4% for agriculture and 4% for trade. Gold panning is the main source of income for 20% of the population of Burkina Faso (MEDINILLA ET AL., 2020). In addition to its contribution to the community economy, gold panning enables farmers to acquire the logistical and financial resources they need to run their farming activities (SANGARE, 2016). In the Republic of Guinea, gold panning is practiced in fifteen (15) of the 33 prefectures. It remains the main activity of several communities in the Kankan region. According to PAGSEM (2017), gold production from gold panning in 2016 exceeded that of industrial

and semi-industrial production. In the same vein, CISSE (2019) states that gold exports from gold panning were estimated at 25,937,733 tons in 2017, compared to 17,157,294 tons from industrial and semi-industrial mining. According to EGIS INTERNATIONAL (2016), the gold panning sector generated 69.4 million dollars through the official circuit in 2009 and in 2016, it generated 395 million dollars (PROJEG, 2018). The Siguiri Prefecture, to which the study area belongs, has been the epicenter of activity in the Republic of Guinea for several centuries. In addition to the employment opportunities, it creates and its contribution to the national economy, it makes a significant contribution to the socio-economic development of communities (DIGBO, 2021; BOHBOT, 2017; SANGARE, 2016; NKUBA ET AL., 2019). This is achieved by increasing household incomes, building schools, health centers, and places of worship, installing water production units and electrifying villages (using solar panels and generators).

Although gold panning is considered an economic activity for both miners and the state (DOUCOURE, 2014; SANGARE, 2016; EGIS INTERNATIONAL, 2016; BOHBOT, 2017; PAGSEM, 2017; PROJEG, 2018; NKUBA ET AL., 2019; MEDINILLA ET AL., 2020; DIGBO, 2021), it represents a danger to the environment, society and the health of those involved. This is reflected in health problems, school dropouts, the disappearance of animal species, the drying up of watercourses, air pollution, and the degradation of arable land (CISSE, 2019). The phenomenon also affects the social, economic, and family life of gold panning areas (SIMON ET AL., 2016). Gold panning contributes to disruption of the environment, stagnation of water and asphyxiation of plants, collapse of underground galleries, modification of the landscape, abandonment of gravel heaps and overburden, increase in water turbidity, disruption of the flow regime of watercourses and increased risk of accidents (WATHA-NDOUDY ET AL., 2022; KONATÉ & DEMBÉLÉ, 2022).

Of the consequences mentioned above, the collapses that occur during extraction are even more worrying. Gold miners often extract the ore using shallow underground galleries. These galleries usually collapse on the miners, with disastrous consequences for people and their property. These consequences include loss of life, serious injury and stoppage of operations. Despite their consequences, collapsing underground galleries have not been sufficiently studied by the scientific community, even though they remain one of the major concerns of those involved in gold mining, the authorities and even health protection NGOs. Accidents (collapse of underground galleries) that occur on gold mining sites continue to sadden families in gold mining areas in Africa. Some statistics on accidents on gold-mining sites in West Africa are given in Table 1. Like other countries in the sub-region, the Republic of Guinea regularly records cases of collapse of underground galleries on gold mining sites. Some statistics on accidents in the Republic of Guinea are presented in Table 2. These landslides are mainly characterized by the collapse of gallery roofs.

According to TRITSCH (2014), the phenomenon of underground cavity failure or landslide generally manifests itself in the form of localized collapses or sinkholes with surface effects and initiating mechanisms (collapse due to the collapse of a roof, or gallery vault, collapse due to the failure of isolated pillars , and collapse due to shaft collapse or shaft head failure), generalized collapses with surface effects and initiating mechanisms (chain failure of pillars due to crushing, sudden collapse of abandoned pillars resulting from roof failure, failure of pillars due to shearing or traction and generalized instabilities due to wall failure).

Table 1. Some statistics on accidents at gold-mining sites in West Africa

N°	Zone	Deaths	Date	Source
1	Abanko (Kidal region, Mali)	40	18/05/2021	www.sahelien.com
2	Sadiola, (Kayes region, Mali)	17	19/04/2018	www.Lecourier.vn
3	Sadiola, (Kayes region, Mali)	01	26/06/2020	www.studiotamani.org
4	Dohoun (Burkina Faso)	10	09/02/2023	https://www.lefigaro.fr
5	Namentenga (Burkina Faso)	27	17/10/2022	www.aa.com.tr
6	Côte d'Ivoire	03	16/06/2016	www.business-humainrights.org

Table 2. Some accident statistics in Republic of Guinea

N°	Zone	Deaths	Date	Source
1	Prefectures of Kouroussa, Mandiana, Dinguiraye and Siguiri	892	from 2013 to 2016	Cissé (2019)
2	Kounsitel (Gaoual)	17	03/03/2022	www.beninwebtv.com
3	Mandiana	03	31/07/2022	www.lelynx.net
4	Nora-Fadou (Siguiri)	08	06/10/2022	www.Africaguinee.com
5	Kintinian (Siguiri)	04	28/10/2018	www.voaafrique.com
6	Doko (Siguiri)	05	14/12/2021	Business & Human Rights Ressource Centre
7	Prefecture of Siguiri	483	2023	Local Red Cross

Ground movements (landslides, and boulder falls) have been the subject of several studies aimed at characterizing and preventing them. In a study by NOURY ET AL. (2020), the authors characterized underground landslides as suffosion/ subtraction of covering materials, downward disruption of an obstructed karstic conduit, rock failure above a limestone cavity, and upward extrusion of an obstructed conduit. Following a landslide in Cameroon that resulted in the loss of human life, the interruption of traffic on National Road No. 5, and the destruction of dwellings and plantations, ABOUBAKAR ET AL. (2013) were able to characterize the soils at the site, showing a clayey material with high porosity (> 29%), low cohesion (< 0.5 bar) and a high angle of friction (15°–22°). This situation is exacerbated by steep slopes (>30°), high rainfall (1400–2500 mm), and human activity (deforestation, poor farming techniques, uncontrolled urbanization). On behalf of GEODERIS, in a study of mining hazards, CHOQUET ET AL. (2020) found that only low and medium level "localized collapse" hazards are associated with isolated galleries and underground mining operations located at a depth of less than 35 m, as well as with identified shafts. According to PAQUETTE (2014) mentioned that convergence rods, extensometers, and fissurometers are suitable for monitoring and predicting deformations in underground cavities in the short or long term.

Regarding the safety of people and equipment in underground works, several authors have identified the causes of accidents before proposing solutions. According to authors such as DUDDECK, (1988); REMOND ET AL. (2006); POTHIER ET AL. (2022), collapses in underground structures are generally caused by water infiltration, irresponsible practices, lack of training and technical knowledge, faults in gallery design, faults in monitoring and maintenance, and the absence of adequate safety measures. Regarding safety, the authors recommended a number of studies, including geotechnical and hydrogeological studies, as well as regular monitoring and maintenance of installations. In underground work, determining a safety coefficient that takes account of the geotechnical characteristics of the ground is a key element in ensuring the physical integrity of workers (BONVALLET & CHAMBON, 1980). In their work, JOSIEN ET AL. (2010), found that taking into account the ultimate strength of pillars, the geometry of voids abandoned after mining, the index of massiveness and stiffness of overburdened benches, generally based on feedback from experience, and regular monitoring, combined with caution and rigour, can help to prevent the safety of miners and work equipment. In addition, empirical, experimental, and numerical methods have more or less proved their effectiveness in planning and carrying out underground work (POIROT ET AL. 2021; KERBATI ET AL. 2020).

To control and treat the risks associated with underground works (quarries), preventive methods (visual inspection and instrumented surveillance); passive protection methods (structural reinforcement, underpinning, deep foundations, and adaptation of networks and roads); active protection methods or techniques for spot reinforcement (bolting, encircling, shotcrete, artificial pillars); elimination of voids by tamping and elimination of voids by backfilling are used.

For his part, GIRAULT (1993) pointed out that digital imagery (a map of the evolution of the ground at two different dates) enables geologists and geotechnical engineers to understand the structure of disorders which, if they occurred, could have disastrous consequences for people and their property.

Analysis of previous works mentioned above shows that there are several methods and techniques for dimensioning underground structures, as well as methods for preventing and protecting against the risk of accidents related to ground movements in the context of tunnel construction, the construction

of industrial underground mines and quarries, and slope stability. As for gold panning, artisanal gold mining galleries are built by miners without any prior study, the results of which could be used in the planning and construction of galleries and shafts, as well as the implementation of safety measures. This would help to adapt the dimensions to the geological context of the sites and protect people and their equipment during the work.

In the literature, despite the persistence and dangerousness of collapse in artisanal mining galleries, scientific studies aimed at minimizing their frequency of occurrence are rare or insufficiently documented. Aware of its consequences in gold panning areas, there is an urgent need for studies to propose solutions to limit its occurrence in Africa. However, any approach to find technical and scientific solutions to a phenomenon requires a preliminary study to gain a better understanding of it from those involved. The aims of this study were therefore to a) give a brief presentation of gold panning, b) gather the perceptions of stakeholders on the conditions of occurrence, the favourable periods, and the main causes of underground gallery collapse; c) propose solutions to minimize the risk of underground gallery collapses and their impact. To achieve these aims, the main techniques used were a field survey followed by direct observations (direct interactions with stakeholders and personal assessments). This work briefly identifies the favourable periods and the causes of collapses. Following this, recommendations will be made to the country's authorities and the actors directly or indirectly involved in gold panning in the region to minimize the occurrence of the phenomenon.

1.1. Presentation of the study area

The sub-prefecture of Doko, which is the subject of this study, is one of the 20 sub-prefectures of the Siguiri prefecture. It is located 50 km from the Siguiri prefecture at 11°47' north and 8°58' west longitude. According to the National Institute of Statistics cited by OMI (2021), the population of the Doko sub-prefecture was estimated at 86,782 in 2014, spread over an area of 2,826 km^2. In addition to the local population, there are several migrant gold miners and traders, both national and foreign (from Burkina Faso, Côte d'Ivoire, and Sierra Leone). Unlike many other sub-prefectures in the region, gold panning is the main source of income for the people of Doko.

In terms of climate and soil, the Doko sub-prefecture has a dry tropical or "southern Sudanian" climate, with two alternating seasons of unequal length. A dry season (November to May) and a rainy season (June to October) (Fr.weatherspark.com/Siguiri-Guinée, consulted on 20 June 2022). The soil is essentially lateritic, with the existence of ferruginous shells in places. Gravel, sand and fragments of shale outcrop in certain regions of the study area, particularly in the riverbeds and plains.

According to SIDIBE (2019), the local geology of Doko is dominated by Proterozoic Birimian rocks composed of turbidite-facies sedimentary sequences, volcanic meta and intrusive granites. Laterite has developed over a large part of the locality, ranging from thin offsets of unconsolidated cover of pisolitic fragments to indurated lateritic caps that form expansive flat areas.

There are no industrial mines in the Doko sub-prefecture. On the other hand, artisanal gold mining sites exist and regularly spring up in almost every village in the area. As a result, there is currently no reliable database either locally or nationally on the number of sites or the management of the sector.

2. Methodology

To achieve our objectives, we used a qualitative approach. During a 15-day field survey, we visited 10 gold-panning sites in the sub-prefectures of Doko and Kourémalen, in the Siguiri prefecture. The study area is shown in Figure 1. During the survey, we collected statistical data (number of landslides, number of victims, number of Red Cross agents) from local structures and authorities. We also made direct observations. The interview technique used during the survey is detailed in the following paragraphs. Institutional approval was obtained because a mission order No Ref/159/ISMGB/DG/2023 dated April 25, 2023, was established by the Higher Institute of Mines and Geology of Boké to carry out this research.

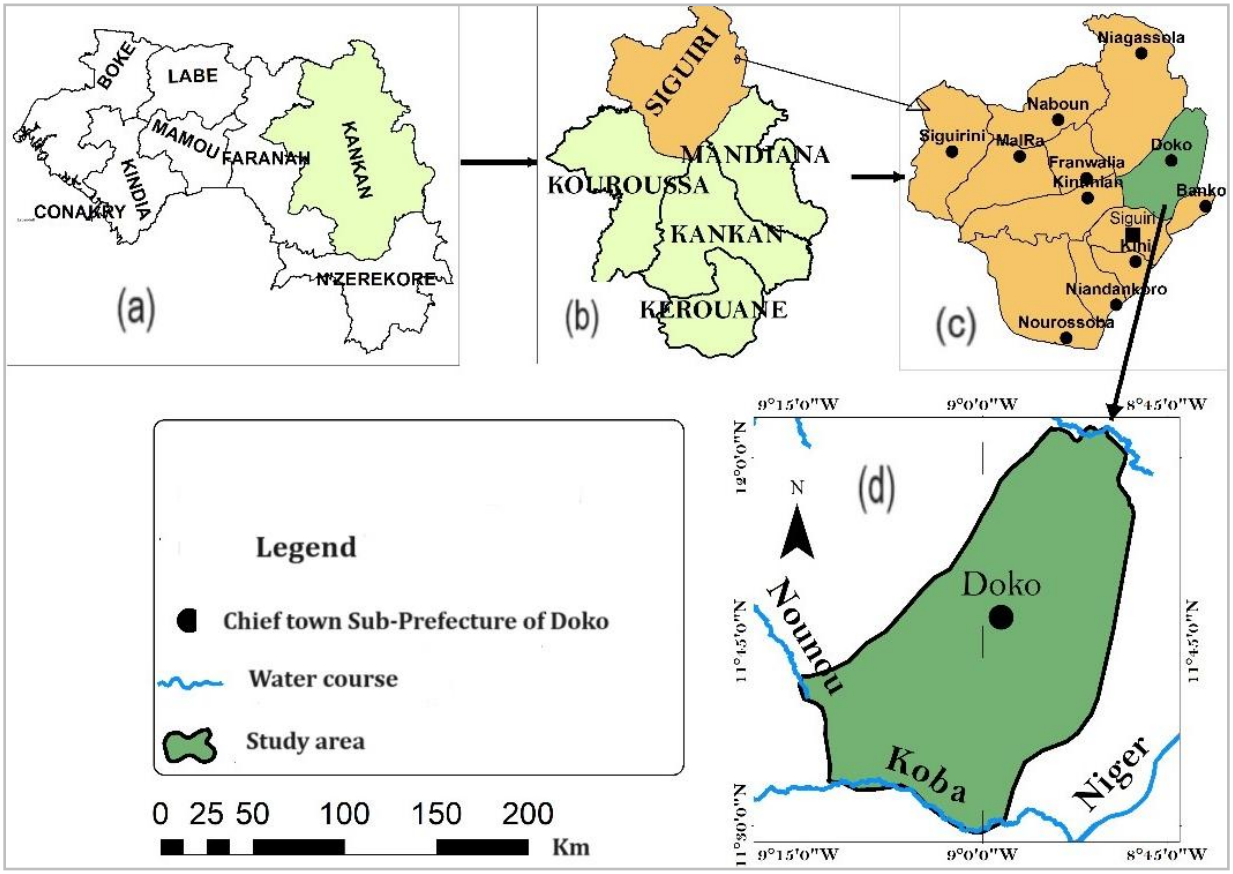

Fig. 1. Presentation map of the study area; (a) map of Guinea; (b) map of Kankan region; (c) map of Siguiri prefecture; (d) map of sub prefecture of Doko

A survey is defined as structured and methodical work that, using well-defined concepts, methods, and procedures, makes it possible to gather targeted information relating to the perceptions, opinions, and ideas of population units within the framework of a project, program, policy, (FRANKLIN & WALKER, 2010). This survey of the main stakeholders (Tombolomas, Kaladjantis, Red Cross, Fadasseinas), directly involved in gold panning was supported by the authorities at the High Institute of Mines and Geology of Boké, the administrative authorities at the Siguiri prefecture and the Doko and Kourémalen sub-prefectures, also the traditional chiefs in the study area.

Semi-structured interviews and semi-structured observation were the main data collection techniques. According to FASSIN (2009), it is unacceptable to carry out sociological work without combining the interview method with direct observation, a way of analyzing what we see and what has been said by the actors surveyed. According to STATISTICS CANADA (2003), semi-structured interviews provide a high level of understanding of one or more complex situations that are the subject of attention or studies, while semi-structured observation is used to gather information on the causes and intensity of a phenomenon without having pre-established criteria. Since the aim of our work was to gather the opinions of artisanal gold miners on the causes, consequences and solutions to be considered to mitigate the phenomenon of accidents (landslide) on gold panning sites, we chose semi-structured interviews and semi-structured observation as the main research techniques in this work. Indeed, according to ROSKAM ET AL. (2009), observations and interviews are qualitative approaches that offer the researcher rich and open information. PINSON & SALA PALA (2007) argue that the semi-structured interview is a relevant and indispensable tool for those who want to know about public action in its historical and synchronic dimensions. With this in mind, our interview concerned the entities listed in Table 3.

Table 3. Survey statistics

N°	Actors types	Number of actors	Subject of the interview
1	Ministry of Mines and Geology	1	Texts governing the gold panning sector in the Republic of Guinea
2	Siguiri Prefectural Department of Mines and Geology	3	Level of involvement of Prefectural authorities in the allocation and management of gold panning sites
3	Siguiri Prefectural Red Cross Committee	3	Statistics on accidents in the Siguiri Prefecture
4	Rural Commune of Doko	1	Level of involvement in site management
5	Traditional chiefs	3	Discussions on the choice of gold panning sites; the organization of the sites; the causes, preventive measures, consequences and management of accidents
6	Doko Local Red Cross	30	
7	Doko Health Centre	3	
8	Tombolomas (site police)	50	
9	Women	30	
10	Kalandjantis (tunnel diggers)	50	
11	Donsos (site supervisors)	10	
12	Damanfètis (landowners)	2	
Total		186	

During the interviews, focus groups of 5 to 10 people were formed. People were chosen according to their experience in the field and their origin (Guinean, Malian, Burkinabe, Sierra Leonean and Ivorian nationals). The pre-established interview guide was the main tool used during the interview. The questionnaires were drawn up by the stakeholders' fields of action. The signed agreement written by the administrative and local authorities of the study area to carry out this research involving communities was obtained. Direct observation enabled us to measure the dimensions of the visited sites (depth of wells, spacing of wells and lines, height of galleries and roofs) and the behaviour of the gold panners. According to ARBORIO (2007), among the survey methods used by sociologists, direct observation is the technique that provides the best understanding of the realities of stakeholder practices.

The data collected during this research was qualitative. According to KOHN & CHRISTIAENS (2015), qualitative research is often associated with issues that are difficult to quantify during the data collection and analysis phase. This is the case for the present study. One of the advantages of qualitative research is that the data collected is rich and significant explanations are obtained about the phenomenon studied (KOHN & CHRISTIAENS, 2015). As far as data processing is concerned, given the diversity of sites and actors, we have taken the points of convergence without forgetting to point out the divergences that recur in the interventions concerning a given question. Indeed, there are no clear universal rules for qualitative data analysis procedures; the approach depends on the design and objectives of the research (KOHN & CHRISTIAENS, 2015). This qualitative analysis enabled us not only to understand the gold panning sector, from research to exploitation; but also, to understand the stakeholders' perceptions of the phenomenon of accidents on gold panning sites.

For the fieldwork, questionnaires for the various stakeholders were drawn up using the KoboCollet tool; a digital camera was used to take images; and a notebook was used to take notes.

3. Results and discussion

3.1. Presentation of gold panning

3.1.1. Artisanal gold exploration

Unlike an industrial mine, opening an artisanal mine, especially a gold mine, requires traditional knowledge. Since the dawn of time, miners have used mystical, botanical, and other clues based on observations of the presence of certain elements and the orientation of plants. According to the gold panners, these methods have proved effective over the centuries and on several sites.

The presence of old gold panning sites is an indication of the existence of gold in the area, and the site is sometimes subject to new exploitation. According to the traditional chiefs, Tomboloma and Kaladjantis we interviewed in our study area, the

presence of plant species whose names in the national Malinké language and scientific names are respectively: Sö (*Isoberlinadoka*), nèdè (*Parkia biglobosa*), Sé (*Buturospermum parkii*), Djoun (*Mytragyna inermis*), Badi (*Carcocephalus esculentus*), Gbein (*Pterocarpus érinaccus*) and Sindjan (*Cassia sibériana*) in one area indicates the possibility of finding gold in that area. We did observe these plants at the sites we visited, but the most abundant were: Sö (*Isoberlinadoka*) (see Fig. 2) present at all the sites visited (10 sites) in the area, Badi (*Carcocephalus esculentus*) (see Fig. 3) present at 8 sites, Gbein (*Pterocarpus erinaccus*) (see Fig. 4) present at 7 sites. In addition to the first two techniques, since the dawn of time gold panners have believed in and used empirical knowledge in the search for gold. This is the case of Crono, a mythical object, a tool traditionally designed and used by gold panners. This object is attached to a rope and pulled along the ground by someone. According to the practitioners, the difficulty or impossibility of pulling the tool on a site indicates the possible presence of gold in the ground. The operators agree that this tool is effective for choosing sites for gold panning and that it has been used to discover several sites that are being mined and others that are being mined. In the same way as Crono, geomancy, in particular the sand game for site selection, is still used today. The techniques mentioned above are always followed by the drilling of 2 to 3 test wells.

Fig. 2. Sö (*Isoberlinadoka*)

Fig. 3. Badi (*Carcocephalus esculentus*)

Fig. 4. Gbein (*Pterocarpus érinaccus*)

On the question of clues to the search for gold, one gold miner said: "*We don't have modern tools for searching, nor do we have the knowledge of those who are educated, but in our approach, we follow in the footsteps of our ancestors such as Crono, which is becoming increasingly rare. Also, we use the presence of certain plants, old sites and fragments of whitish-colored pebbles (quartz). In most cases, we don't fail*".

3.1.2. Organizational structures of Gold Panners

For many observers, gold panning appears to be an unorganized, even anarchic activity. This is only an appearance; because gold panning is very closely linked to the organizational forms of village, community, and family structures. Artisanal activity is based on a set of customary rules accepted by all. These verbal prescriptions constitute coherent and original systems of organization. Their organization remains deeply marked by the community spirit, an essential element of customary rule as a source of law.

On the gold panning sites in the Doko sub-prefecture, the existing structures are almost similar. These include:

Doukoloti (Landowner): the owner of the site on which gold panning takes place. He is the highest authority and the main coordinator of activities on the site. He may not be present on site, but he always has a share in the ore mined on his land.

Tombolomas (Police): they are responsible for policing the site and dictating work rules. They ensure that customary laws are respected and punish offenders. They ensure that activities run smoothly. The Tombolomas chief is appointed by Doukoloti or by the local traditional chiefs, who in turn recruit the other members, taking into account their moral probity. The Tombolomas team has its share of ore in each hole on the site. A tent is often set up on the sites to house the team.

Red Cross: this is an association of experienced gold panning volunteers who generally have no academic training or training in occupational health and safety techniques. They have extensive experience in gold panning and are familiar with the land they work on, so they help to ensure the safety of gold miners by carrying out regular pit diagnostics and rescuing accident victims. The structure is recognized and works in synergy with the Siguiri prefectural committee of the Red Cross. In 2022, the number of volunteer workers on site and registered was 1,600. The number of agents in our study areas is estimated at 700. Recognized for their skills, they intervene under invitation and free of charge on sites in the sub-prefectures of Doko and Kourémalen, in the prefecture of Siguiri, and neighbouring countries in the event of a landslide. To ensure the continuity of the Red Cross's activities, young people with no experience are signing up to be apprenticed in collapse of underground galleries prediction, diagnosis, and accident rescue techniques. As well as artisanal mines, the team also responds to floods, epidemics, and fires. They generally wear red caps. The Red Cross team is paid by granting a safa. Figure 5 shows a Safa (alignment of wells).

Donsos (Hunters): they provide site security at night and during shutdown periods.

Women: in the gold production circuit, they are mainly responsible for bringing up the ore, transporting it to the washing basin or the river if it is not too far away (tricycles are used), bathing and processing the ore. Alongside these mining production activities, women also play an important role in ancillary activities, such as cooking, petty trading and supplying the sites with food and water.

Fadadsseinas: there are generally 3 to 4 of them per wells. They are responsible for digging the shafts vertically from the surface down to the ore.

Kaladjantis (those in charge of excavating the ore): this is a team of experts or people with experience in the field who work after the Fadasseinas. They extract the ore in the form of galleries, following its direction and respecting the requirements of the site.

Niadô (Owner of the pit): this is the person who bought the pit for a symbolic franc. The Niadô finances the basic needs of the Fadasseinas until extraction of the ore begins.

Diatis (Balance traders): this is a group of people, often organized, who buy gold from gold panning on the sites themselves or in the villages where the activity is practiced. Figure 6 shows Diatis (Balancers) place.

3.1.3. What is forbidden on the sites

Access to gold panning sites in the study area is open to all and is governed by the rules that all miners must accept before setting up. Violation of these rules is subject to penalties. The main prohibitions are:

- sexual intercourse and theft on the sites;
- access by children to mine shafts;
- access by shoemakers and the introduction of dogs on active sites;
- working on the sites on Mondays and Fridays (optional for some).

3.1.4. Dimensions of structures

The spacing of the wells and lines is not based on any prior study. Furthermore, taking into account the observations and assessments of the miners on the nature of the land, the Damans and Safas are spaced apart. The survey revealed that, depending on the fragility of the sites, there are two types of

sites or land. Fragile sites and resistant sites. Stakeholders remain divided on the dimensions to be adapted, taking into account the different types of land. Most of the miners were in favour of spacing out the structures when the site was fragile, while the others were of the opposite opinion. Table 4 and Figure 7 illustrate some examples of shaft sizing for artisanal gold mining in the study area.

Fig. 5. Safa (line) (aligning the wells)

Fig. 6. Diatis (balancers) place

Table 4. Some of the dimensions of the sites visited

Village	Site name	Depth of wells	Well spacing	Line spacing	Gallery length
Banfèlèdougou	Lit majeur Niger	1.5-5 m			
Doko	Espagne	8-15 m	2-4 m	18-23 m	9- 12 m
Doko	Bayèrèni	8-10 m	2-3 m	15-20 m	8-15 m
Tombôkô	Kolifoloni	The mesh is irregular. There are wells 7 to 10 m deep, with circular or square openings. Pitis and Trèssès (sustained wells 100 to 300 m deep). NB: a 100 to 300 m well takes 1 to 3 years to operate.			
Salla	Kôbôni	The wells are projected between the old wells. They are 7 to 10 m deep. The length of the galleries varies.			
Silabada	Dadjanfè	20-25 m	2-3 m	22-26 m	11-13 m
Kourémalen	Sodassibé	1.5-3 m	2-4 m	6-10 m	3-5 m
Kourémalen	Kôfra	10-15 m	1.5 – 2.5 m	14-16.5 m	7-8 m
Namakoumana	Djiwoulouni	7-10 m	1.5-2.5 m	8-15 m	4-7 m

Fig. 7. Spacing of extraction wells (In general, the distance between wells varies between 1.5 m and 3 m)

3.2. Accidents at gold panning sites

3.2.1. Definition of accidents in artisanal mines according to gold miners

Gold miners define accidents in the context of gold panning as any collapse of the roof of artisanal mining underground voids causing loss of life and/or injury. This definition of accidents does not include all accidents recorded on sites. Furthermore, it defines the most dangerous case of accidents.

3.2.2. Types of accident in artisanal mines

According to the gold miners, several types of accidents occur on the sites, including: collapsing gallery roofs; blocks falling into the galleries or the lower part of the roof falling; accidents related to the use of work equipment (pickaxes, crushers, etc.); children falling down wells; water or mud invading the well. Gold miners agree that the most disastrous consequences are roof collapses and water or mud invading the well.

3.2.3. Causes of accidents (collapses of underground galleries)

Collapses of underground galleries are becoming more and more frequent on gold mining sites. According to those directly concerned, they are mainly due to two main factors:

Human factors. These are:

- Abusive use of narcotics, leading to disregard for safety instructions and the cutting of supports (pillars);
- The operating method;
- Lack of experience (most of the victims were foreigners with no experience in the profession);
- Crushing of pillars by the weight of the roof;
- Lack of attention to the sites;
- Insufficient plots of land (which encourages a high concentration of gold miners in one area);
- Too many gold miners in the same mine;
- The use of gold detection equipment in the mines.

Natural factor. Ignorance of the nature of the site is mainly the only natural factor. In addition to these two main factors, gold panners name divine will as one of the main reasons for accidents of all types. On the question of divine will, one Kalandiati said: "*Beyond the causes we have mentioned, everything that happens to man emanates from the divine will. Accidents, whether the cause is human or natural, are of divine will, which is why we make sacrifices before exploitation*".

3.2.4. Warning signs

Almost all gold miners agree that underground gallery collapses are usually preceded by one or more of the following signs: falling gravel and rock fragments; cracks forming in the roof and/or pillars; small rumbling noises (sound signals); swelling of the working area and sometimes jets of muddy water very close to the face. As one respondent stated: "*All cases of underground gallery collapses are preceded by the signals. It is the experts in the field who notice the fact. When the remark is made, everyone is evacuated from the shaft. Some underground gallery collapses that cause casualties are due to a lack of regular diagnosis of the shaft, while others are due to the inattention of the Kaladiantis, who sometimes refuse to comply when it comes to evacuating the property even though the warning signs are present*." The clandestine exploitation of used and abandoned areas causes many more victims than the previous cases.

3.2.5. Existing regulations to mitigate the phenomenon on the sites

Several safety measures are in place on the sites to mitigate the phenomenon. Preventive measures include: spacing out wells, banning the digging of abandoned wells, regular diagnosis of mining galleries by the Red Cross team, reinforcing certain pillars with blocks, supporting them in places with wood,

and disciplinary sanctions against recalcitrants. In addition to these measures, since the majority of residents are believers, offerings are sometimes made to be under divine protection. According to them, these sacrifices are a way of minimizing the risk of landslides on the sites.

Although aware that the human factor is the main cause of landslides or collapses of underground galleries, those directly concerned unanimously believe that sacrifices can mitigate the phenomenon.

3.2.6. Types of sites vulnerable to underground gallery collapses and favourable season

According to the gold miners we met, there is no specific site where underground gallery collapses occur. They occur in all types of sites and at all times of the year. However, all say that the rate is higher in the dry season. This is due to the plethora of gold miners in the area during this period, while in the rainy season, some abandon the area in favour of agriculture. In addition, certain geological formations are known to be vulnerable to underground gallery collapses. In the national Maninka language, they are called Bodjanlon (waterlogged clay soil), Baya-baya (sandy-clay soil), and Douabo (gravelly clay). According to a source from the Prefectural Red Cross, accidents in artisanal mines are a recurring phenomenon in Siguiri, and he told us: "*Whether there are victims or not, every day, we record at least one case of underground gallery collapses on the sites. There is at least one case of accidents on the gold panning sites in the prefecture of Siguiri. It is when there is a death that we talk about it.*"

3.3. Consequences

The social and environmental consequences of gold panning are considerable. Accidents, particularly the collapse of underground galleries, are the main cause of mourning for several families per year, leading to lifelong disabilities and serious injuries. During our visit to the study area, we witnessed a collapse of underground galleries at the Sodassibé site (Kourémalen military site), resulting in 3 deaths and 5 serious injuries. The interlocutors stated that in addition to the loss of human life and injuries, the cessation of activities had an impact on the economy of gold miners. According to the Siguiri prefectural committee of the Red Cross, in the first quarter of 2023, 35 deaths were officially recorded, minus the injuries. In 2022, 65 deaths were officially recorded in the Siguiri prefecture.

4. Discussion

Analysis of the survey results and our observations in the field clearly show that, despite the sector's contribution to the national economy and to improving communities' living conditions, gold panning is a sector left to its own devices. This is due to the absence of the country's authorities involvement in site selection and management, the lack of environmental and safety monitoring of gold panning activities, and the absence of up-to-date data on the sector. This situation is contrary to the laws governing gold panning in the Republic of Guinea, in particular the MINING CODE (2013) and the DECREES MINISTRY, (2017a,b) of the Minister of Mines and Geology relating respectively to the artisanal mining regime and plot allocation procedures, and to the creation, allocation, composition and operation of the artisanal mining monitoring committee, dated 10 November 2017. This phenomenon is not unique to the Republic of Guinea. Despite the existence of legislation, insufficient monitoring of this legislation on the ground by the relevant authorities and technical services is a reality in several African countries where this activity is practiced, such as the Democratic Republic of Congo (NKUBA ET AL., 2019; MUSAO, 2009), the Republic of Congo (WATHA-NDOUDY ET AL., 2022) and the Republic of Burkina Faso, where in some places gold miners negotiate with landowners to obtain authorization to mine a plot of land (MEGRET, 2008; BOHBOT, 2017; MEDINILLA ET AL., 2020).

In its organizational aspect, the gold panning sector is perceived by several social entities as a world without law or organization, where certain miners destroy the natural ecosystem, and others enrich themselves. Despite the absence of the State in most cases, like any group or association of people, gold panning sites are worlds that function according to a traditional organization where each miner plays a role and where traditional norms are established to maintain a climate of peace, social cohesion and worker safety. This study enabled us to understand that gold panning is a world made up of people from different geographical origins and diverse cultures. The sites in the study area are organized in such a way that structures are set up without distinction of origin or religion. Several entities are set up with specific roles. According to

studies by DIGBO (2021) and SANGARÉ ET AL. (2016), this form of structuring is found in other gold panning areas in the Republic of Guinea and other neighboring countries.

In the case of accidents, according to the IMO (2021), the work of national and international foreigners (from neighboring countries) on the sites without any real preparation or information on the tools and working methods is one of the main causes of accidents affecting the health of gold miners. While cases of death and injury on the sites are the main health problems raised by gold miners in our study area. MONIKUTIDOO (2010) quoted by CISSE (2019) adds that in addition to the risks of landslide and injury, inhalation of iron oxide and silica dust has disastrous consequences for the health of gold miners. NGUYEN-THANH ET AL. (2003) and DIARRA (2008) have shown that accidents (collapse of underground galleries), in addition to the loss of human life, have harmful consequences for the health of gold miners through trauma (back and limbs) and vertebro-medullary fractures. On the question of the frequency of accidents, most of the people we spoke to said that accidents in gold panning areas occur in all seasons, but the dry season has the highest rate because there are too many people panning for gold at this time of year, when there is no agricultural activity. On the other hand, TOURÉ (2016) found in his study that the highest rate was recorded in June (winter season) and that this result could be explained by the extreme mobility of gold panners. The difference between these two studies could be explained by the level of involvement of the populations in the regions studied in the agricultural sector. The miners in our study area are more involved in agricultural activities than those in the other areas. The gold miners interviewed in our study area stated that the landslide were mainly due to a lack of experience on the part of the miners, stubbornness on the part of others, the use of narcotics, the use of metal detectors, failure to comply with the safety instructions issued on the sites, etc. The geological context (nature of the petrography) is also a factor. The geological context (petrographic nature of the layers) of the site cannot be ruled out, according to some gold miners.

Globally, according to TYCHSEN & CHARLES, (2019), in many West African mining countries, gold panning activities are carried out on illegal sites without respect for good practice standards with regard to environmental protection, emissions control, restoration and rehabilitation of mined sites, protection of biodiversity and preservation of natural habitats, protection of the health and safety of stakeholders, etc.

From the above, it is clear that the ills from which the gold panning sector suffers in our study area are similar in almost all West African mining countries.

To make artisanal mining a genuine economic lever that takes into account the sustainable development objectives of countries and communities, as well as the health and safety of those involved, we recommend the following:

- Application of legislation governing the gold panning sector in the country;
- Prohibiting the use of narcotics on sites and the use of metal detectors on sites;
- Formalization of safety instructions on sites;
- Education, awareness-raising and training for those involved in the sector;
- Reinforcement of Tomboloma teams to ensure compliance with security instructions;
- Support the Red Cross in its role of providing security and protection for gold miners;
- Strengthen the skills of the Red Cross team in risk diagnosis and first aid techniques;
- Establish a standard for sizing wells, taking into account the geomechanical properties of the soil;
- Create income-generating activities to reduce the number of gold miners on the sites.

5. Conclusions

The main focus of this study was to understand the perceptions of stakeholders about production conditions and the main causes of accidents (collapses of underground galleries) on gold panning sites. It was concluded that despite the employment opportunities gold panning creates a major contribution to local and national development. The accidents that result from it, causing human and material damage, remain a major concern for stakeholders, the administrative authorities, and for the civil society.

Those involved in artisanal gold mining are aware of the dangers of the phenomenon, know the warning signs, have an idea of the main causes, live with the consequences permanently, and several safety measures are in force.

The results of this survey show that the human factor was certainly the main cause of accidents, but the design of structures without taking into

account any study of the geomechanical properties of the soil, the weakness of the safety measures in place, and the absence of the State are not negligible factors in the production of accidents on gold panning sites.

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Data availability statement

The datasets are available on request.

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