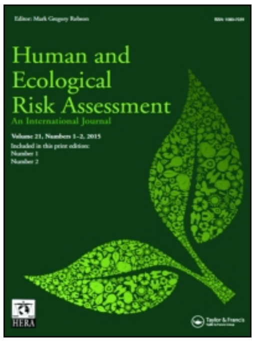

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Environmental impacts of gold mining in Essakane site of Burkina Faso

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ABSTRACT
In this study, environmental impacts on air, water, and soil pollution caused by the exploit of Essakane gold mine, which is located in North Eastern part of Burkina Faso were investigated. Analyses on drinking water were made in the laboratory to determine the concentration of essential chemicals used in gold mining. Dust fallouts have been measured to assess the level of air pollution. The results showed that exploiting of gold mine directly or indirectly contributes to air pollution in Essakane district. The use of chemicals such as cyanide (industrial gold mining) and mercury (artisanal gold mining) to obtain the gold from the ore constitutes a potential risk for the ecosystem, the local population's health, and livestock production. The results also showed that there is a significant degradation of natural landscape and topography of the soil by open-pits mining (industrial mine) and holes dug by artisanal miners.

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artisanal gold miner; cyanide; mercury; environmental impacts; mineral mining; open-pit mining

Introduction

Burkina Faso has a population of about 18 million and is located in the heart of West Africa. Agriculture is the main activity of the population but represents only about 34% of gross domestic product (GDP). Beyond the achievements of agriculture and the intention to diversify sources of income, the state turned to mineral resources of which the country abounds. According to Jennings (2002), mines account for a significant share of GDP of many developing countries and constitute the essential part of the exports and the foreign investment in these countries. For example, 25% of Guinea's and 5.9% of South Africa's GDP as well as the majority of foreign revenues of these countries are mining related (Benjamin 2001). In 2003, a very attractive mining legislation, including fiscal incentives, was adopted by the National Assembly of Burkina Faso to encourage foreign investment in the mining sector. Between 2007 and 2008, the gold sector took the opportunity to accommodate seven industrial mines, one of the most important is that of Essakane, operated by the mining company Essakane SA. Since 2010, the country has become the fourth largest African gold producing country after South Africa, Ghana, and Mali (Nicolas *et al.*

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2014). The industrial exploitation method that is used is the open pits. In addition to these industrial mines, the artisanal gold mining has been practiced all over the country, especially in the Essakane area.

According to Dotson and Hethmon (2002), the exploitation of open-pit mines and quarries has very visible effects on the environment. Site degradation, destruction of vegetation, and the disappearance of the native fauna are the most significant signs. Open-pit mines are also a common source of contamination of surface and ground waters, particularly in mines where leach mining and hydraulic mining are practiced.

Gold surface mining profoundly affected land use systems in the Wassa West District of Ghana. Analyses of Landsat images showed that the most widespread mining-related land cover changes in the region were farmland loss and deforestation. As farmers are often forced to relocate, they frequently clear forests for new farmland, suggesting marked spillover effects of mining into adjacent areas (Hilmar *et al.* 2011).

In the area of Essakane, mining activities (industrial and artisanal) have multiple impacts on the environment. These environmental concerns have led some authors, such as Organization for Community Capacity Building for Development (ORCADE) in 2006, Ouedraogo (2008), Boubacar (2012), to carry out the studies in the Essakane area.

In this study, the overall objective was to analyze the environmental impacts of mining activities in the Essakane area. The specific objectives were firstly to estimate and measure the pollution of air and water and also to assess the impacts on the ecosystem, health, and livelihoods of local people. Following these analyses, perspectives have been proposed.

Study area

The Essakane gold mine is located in the province of Oudalan, Sahel Region, approximately 330 km northeast of Ouagadougou, capital of Burkina Faso. The neighboring towns of the mine are Gorom-Gorom, located 42 km northwest of Essakane, and Dori, located 70 km south of Essakane. Geographical location is illustrated in Figure 1.

Essakane is located in the Sahelian climatic zone, being north of isohyets 600 mm. The area is characterized by two seasons: a rainy season (not exceeding four months) and a dry season. The prevailing wind influencing the climate in Essakane is the Harmattan (Knight Piésold Consulting 2007).

The area is hydrologically found in the sub-basin of Gorouol river and Feildegasse river. The vegetation consists of shrub and grassy steppes with species such as *Balanites aegyptiaca, Acacia tortilis raddiana,* and *Cassia obtusifolia* and formations of *Mitragyna inermis* (Knight Piésold Consulting 2007).

Methods and materials

Surveys and observations

The surveys were carried out on the basis of questionnaires addressing four categories of people: those displaced from the mine, nurses from the Center for Health and Social Promotion (CSPS) of Essakane Site, artisanal miners, and workers from the Essakane gold mine. Except the nurses of CSPS, the choice of respondents was done randomly.

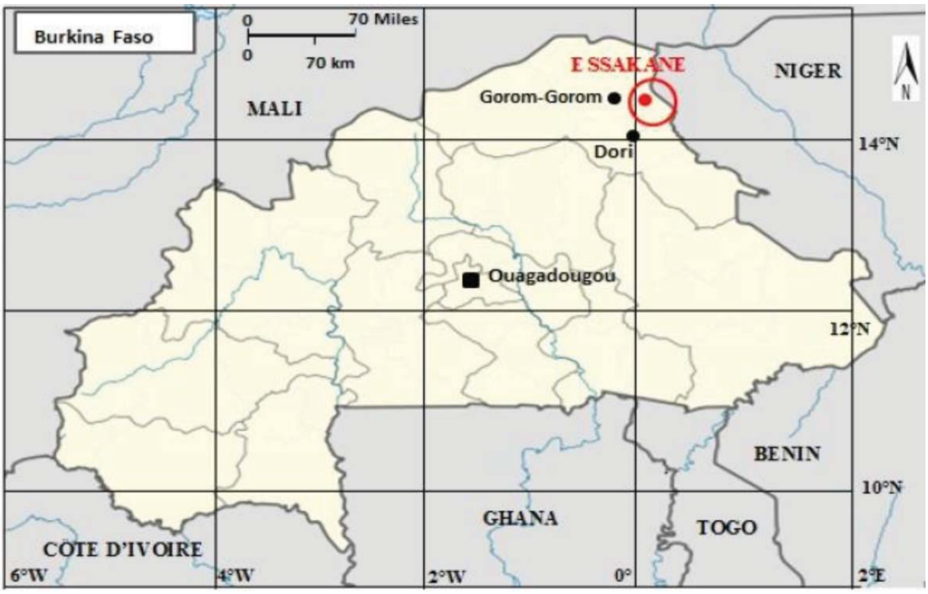

Figure 1. Location map of the Essakane gold mine.

The data collected allowed the preparation of tables and graphs using the MS Office Excel program.

Direct field observations were used to estimate the impacts of the artisanal and the industrial mining on the environment.

Sampling and laboratory analysis

Sampling of water

Water sampling was mainly from a well water (four pair of samples), from a fountain of drinking water (a pair of sample), and from surface (a pair of sample). Collection, transport, and storage of samples refer to protocol and procedure defined by the National Water Analysis Laboratory (LNAE) and the Laboratory Aina (LA). The coordinates of the sampling points were recorded in GPS Garmin Oregon 450 leveled in minutes.

Experimental procedure

Physicochemical analysis made in LNAE

Arsenic was determined with Arsenator Wagtech Wag-WE1 0500 by using kits. The conductivity was measured by using TetraCon 325. Cyanide was measured using the DR/3800 by the HACH method 8027, and total hardness was determined by Ethylene diamine tetra-acetic acid (EDTA) method.

Physicochemical analysis of mercury in LA

Mercury was determined using atomic absorption spectrometer after reduction with sodium borohydride.

Particle measurement

The air quality in the study area was followed experimentally for seven days using two types of conical bowls to collect particles (dust fallout). A digital caliper and digital scale type JCS-B 15kg/0.5 g were used to measure the diameter (d) and weight of ground bowls, respectively. Two sets of conical bowls were used. First set consisted of six conical bowls with a 70 g initial mass and diameter was 15 cm, and second set of six conical bowls with a 79.5 g initial mass and each 17 cm diameter. By measuring the mass of the particles collected, combined with the base surface of the bowls, a Δ value (below) in g/cm^2 of the particles was obtained and can be converted to g/m^2 or ton/km^2.

$$\Delta = (M_2 - M_1) \div S$$

where S is the base surface of the conical bowl $= \pi \times \left(\frac{d}{2}\right)^2$

M_2 = mass of the conical bowl and collected particles

M_1 = initial mass of the empty conical bowl

Δ = Value of collected particles in g/cm^2 (or ton/km^2)

Results and discussions

Distribution of sample

The sample size is 89 people chosen randomly from four categories of persons as indicated in Table 1. Family heads, artisanal miners, and workers of the industrial mine are covering the risky people in the study area. Nurses of CSPS helped to show the number of patients and probable causes of diseases due to mining activities.

Artisanal miners' general characteristics in the study area

Most of the artisanal miners, as shown in Table 2, cannot read or write. They do not use clothes or protective equipment and do not have enough knowledge about the effects of mercury and cyanide on the environment and human health. The result is that they frequently fall ill or they can be severely injured or even die. Miserendino (2013) stated almost the same about the artisanal miners from Ecuador who were exposed to chemical hazards, safety hazards including noise, vibration, heat, lack of oxygen, and so forth Due to these inherent hazards, along with a lack of engineering expertise and appropriate protective equipment, there are accidents that can cause severe injury and even death.

Table 1. Distribution of the sample of the study area.

Category	Size
Family heads	31
Nurses of CSPS	8
Artisanal miners	27
Workers of the industrial mine	23
Total	89

Table 2. Distribution of the level of knowledge and age of the miners.

Artisanal miners	Reading and writing		Knowledge about the effects of mercury and cyanide		Protective clothing*	Age	
	Yes	No	Yes	No		≤18	>18
Women (%)	0	29.63	0	29.63	0	18.52	11.11
Men (%)	18.52	51.85	11.11	59.26	0	3.71	66.66
Total	18.52	81.48	11.11	88.89	0	22.23	77.77

*Glasses, shoes, helmet, clothes, gloves, etc.

Air pollution in Essakane zone

Direct observations in the study area were used to analyze the air pollution. The causes of air pollution in the study area are transportation and mining activities (industrial and artisanal). Regular transportation (frequency, every 15–30 min) of workers from different localities to the Essakane gold mine by bus via the only unpaved roads (dirt roads) leads to the formation of excessive dust in the area. The same result occurs with the continuous transport of hydrocarbons to the gold mine. During this study, respondents indicated that dust fallout is natural in certain periods of the year, but that produced by these buses and trucks are continuous. Some portions of unpaved roads were covered with molasses (black treacle). These are portions that extend from the beginning to the end of some villages. However, as before and after the village, the road is not paved or covered with molasses, chances of minimizing dust remain low. Reed (2003) in his research has shown that haul trucks create the majority (80–90%) of Particulate matter (PM10) emissions from surface mining operations.

In the Essakane gold mine, the work of perforation, blasting, loading, and transportation of ore, crushing, grinding, and energy production based on hydrocarbons have polluted ambient air in the area. To reduce this air pollution, water is sprayed to the mine by two tanks. Moreover, uses of mills [after the extraction and transportation of ore, recovery (or enrichment) of gold by artisanal miners generally involves the use of mills. In this study, 32 diesel mills for crushing ore were counted in the area. There is no electricity in the study area so the mills use the electricity produced by diesel engines. The surveys evaluated the amounts of fossil fuels and water necessary for the operation of these mills. Table 3 shows the average amounts of chemicals used by miners] by the artisanal miners increase the air pollution in the area.

The estimation of air pollution in the Essakane area was achieved through the collection of particles with conical bowls. The results obtained are shown in Figure 2. It

Table 3. Average water use and chemicals by artisanal miners.

Product	Unit	Total
Water	l/day/miner	950.6
Cyanide	g/day/miner	0
Mercury	g/day/miner	2.7
Diesel	l/day/motor	15
Oil	l/week/motor	6
Acid	ml/day/miner	20
Dynamite	g/week/gold well	612

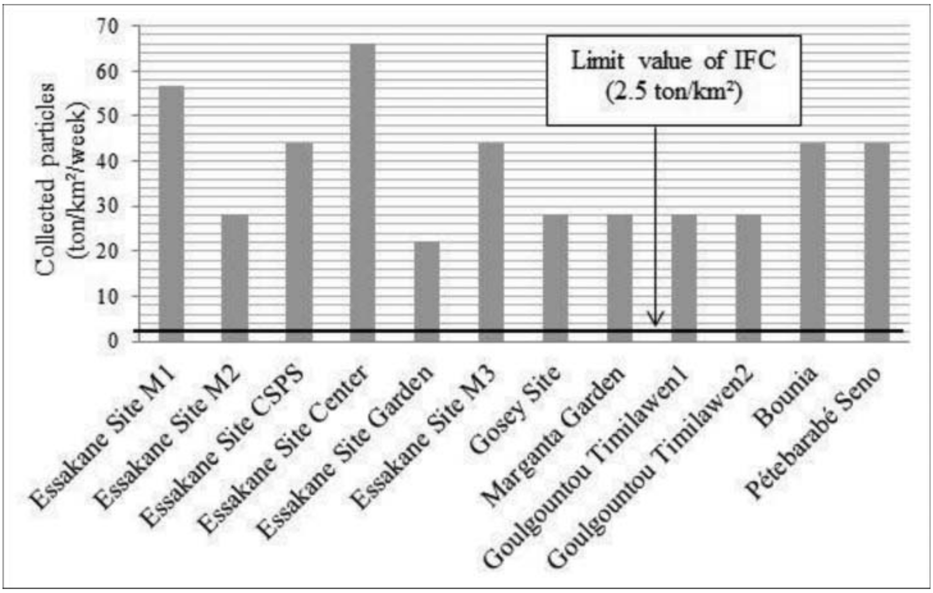

Figure 2. Particles collected according to the locality where the conical bowl was placed.

shows high values in six different places of which the largest was recorded at Essakane Site Center. The minimum value is 22 ton/km^2, whereas the maximum is 66 ton/km^2. All these measured values in one week (seven days) are well above the standard of International Finance Corporation, which provides a value of 10 ton/km^2/month that is to say 2.5 ton/km^2/week.

The studies done by the ORCADE (2006) in Essakane and Poura showed that the fumes from the mills contain air pollutants such as sulfur oxides (SOx) and volatile organic compounds that can affect human health, plants, and animals after a certain threshold. The results from a study done at Kanana (South Africa) showed that PM values for 24 hourly periods exceeded the 75 μg/m^3 maximum permissible limit for the South African Guidelines, for almost half the month (14 days) in April, 8 days in May, and 9 days in June. According to the World Health Organization Guidelines, WHO (2005) the results obtained in the months of April (26 days), May (17 days), and June (14 days) exceeded the maximum permissible limits of 50 μg/m^3 (Kaonga and Ebenso 2011). Also, Aragon and Rud (2013) stated that mining activities produce several air pollutants such as nitrogen oxides, sulphur oxides and particulate matter and moreover the main direct sources of air emissions are diesel engines for haulage, drilling, heating, and cooling, among others. Additionally, the processes and fragmenting of the rocks, followed by smelting and refining, generate substantial aerial emissions in large-scale, open-pit mining. In another study done by Momoh *et al.* (2013) at Mukula Mine, Limpopo Province, South Africa reported that particulate matter in the air ranged from 60.25 to 1820.45 μg/m^3. The lowest value of PM was more than four times the required World Health Organization (WHO)'s allowable level in ambient air, which the mine workers and locals would be inhaling. It can be easily concluded that the air pollution is the basis of respiratory disease in the study area, which will be discussed later. Continuous inhalation of mine dusts by mine workers and locals could result in pulmonary fibrosis, silicosis, and lung cancer.

Table 4. Results of analysis of well water.

Parameter	Unit	PBS 0°06.156′E 14°20.976′N Pétebarabé Seno	EMSF2 0°01.352′E 14°22.940′N Essakane Site	EMSF1 0°01.482′E 14°23.522′N Essakane Site	BN 0°05.457′E 14°20.034′N Bounia	MGT 0°02.264′E 14°21.250′N Marganta	Allowable Limits (WHO)
		Codes of samples and details of sampling points					
Arsenic	μgAs/l	<1	<1	3	**12**	3	10
Conductivity	μS/cm	553	641	730	665	749	1 100
Cyanide	$mgCN^{-}/l$	0.014	0.007	0.004	0.003	0.012	0.07
Mercury	μg/l	<2	<2	<2	<2	<2	6
Total hardness	$mgCaCO_3^{-}/l$	**285**	**327**	**320**	**303**	**338**	**200**

Bolded values are above the given limits in the table.

Water pollution in the study area

Analytical results of the drilled well water samples are presented in Table 4. These results show that concentrations of cyanide and mercury are not higher than the WHO standards. However, arsenic (sample coded as BN) is greater than the WHO standard. Weathering of gold, sulfide ores, is widely known to result in the generation of free acidity (low pH), and the liberation of trace metals, including arsenic. As discussed early in Table 3, gold miners are using acids in large amounts, and the pH is reduced severely. Straskraba and Moran (1990) showed that As concentration changed between 0.012 and 19.0 mg/L in the gold mining areas of Western USA, which were higher than WHO standards, and pH values can be low as 4.3. In another study, from 29 groundwater samples, As (dissolved) exceeded the values established by the WHO (0.01 mg/L) in 41% of the monitored sites. The maximum concentration of arsenic found in one observation well was 0.45 mg/L (Wurl *et al.* 2014**)**.

According to Table 5, the analysis of the surface water sample taken at the Gorouol river showed that the different chemical (arsenic, cyanide, and mercury) levels do not exceed WHO standards.

The studies done by the ORCADE (2006) in the Essakane gold mine showed that mercury concentrations were between 15–32 μg/L and are higher than WHO standards. The studies conducted by Knight Piésold Consulting in 2007 in Essakane area indicated that arsenic levels were ranging from 11 to 27 μg/L for Gorouol and Feildegasse rivers from 12 to 430 μg/L for well water, which are higher than the WHO standards. These arsenic values are higher than those of the present study as explained earlier in Table 5. In another study performed by Ansa-Asare *et al.* (2015) in river

Table 5. Results of surface water analysis.

Parameter	Unit	EMSG E 0°01.584' N 14°22.846' Fleuve Gorouol	Allowable limits (WHO)
		Codes and coordinates	
Arsenic	μgAs/l	<1	10
Conductivity	μS/cm	158	2 000
Cyanide	$mgCN^{-}/l$	0.001	0.07
Mercury	μg/l	<2	6
Total hardness	$mgCaCO_3^{-}/l$	63	200

system of Ghana, 43% of the samples (6 of 14) were over the limits of WHO, and in the same study, free CN– concentration in River Pra at Akim Brenase is 11.9 times that of the WHO value and 3.5 times that of the USEPA guideline value. The high arsenic content in Bounia may be due to mining activities including the stripping of soil, and ore enrichment process usually generates a mobilization of unwanted toxic metals such as arsenic compounds with rainwater seeping into the groundwater. During this study, it was noted that there was no High density polyetylene (HDPE) geomembrane application for the tailing storage facility (TSF) of the gold mine. That TSF yielded in 2010, causing the death of some pets belonging to the villagers living near the mine (Boubacar 2012). This incident was the source of tensions between residents and the gold mine. Also tensions related to water use exist between local people and the gold mine. The results of the physicochemical analysis of various parameters and pollution indicators presented in this study have shown that the concentrations were below the WHO standards, except arsenic levels. However, the levels of these parameters in the waters of the study area should be subjected to regular monitoring.

Impacts on population health

The surveys over nurses working in CSPS Essakane Site enabled, as shown in Table 6, to have a general idea of frequently encountered diseases and their likely sources. Directly or indirectly mining is the source of some diseases. The most frequently encountered disease is malaria (47.45%). In fact, mosquitoes are reproduced in stagnant water of the area (puddles, dam, and waters of Gorouol). During the present study, the construction of a network of gutters was observed in Essakane Site. These gutters are covered with removable slabs that are broken in some places (Supplementary Figure 1). The places that are not covered with slabs are open for filling wastes dragged by the wind. Any failure in the drainage system of water results in stagnant water in which mosquitoes can grow and constitute the source of malaria in the study area. The responsibility is up to the Essakane gold mine that was the basis for the relocation of local people, to ensure the development, the sanitation, and the proper functioning of the drainage system of the water in the area.

After malaria, acute respiratory infections (ARI) are the most commonly encountered among patients (20.79%). According to WHO, the air pollution is a major environmental risk for the development of ARI, lung cancer, and asthma. The most usual type of ARI is silicosis. Silicosis is a type of pneumoconiosis, which is particularly associated with dust exposure in gold mines. It is an incurable occupational lung disease caused by prolonged or intensive inhalation of tiny respirable particles of crystalline silica dust. Nelson (2013) reported that in South Africa, from 1975 to 2007, the proportions of white and black gold

Table 6. Rate of frequently encountered diseases at CSPS.

	Rate (%)	Probable sources of disease
Diarrhea	13.21	Lack of hygiene
Acute respiratory infection	20.79	Excessive dust, drugs, chemicals
Malaria	47.45	Mosquito bites
Skin affection and wound	11.92	Drugs, chemicals, lack of hygiene
Other	6.63	Other
Total	100	

mine workers with silicosis increased from 18% to 22% and from 3% to 32%, respectively. Steen *et al.* (1997) also concluded that overall prevalence of pneumoconiosis was 26.6–31.0% among the gold miners of Botswana. These percentages of ARI are consistent with the miners of Essakane. It can be easily said that dust from mine is the main reason of air pollution and ARI.

Diarrhea (13.21%) and affections of the skin and wounds (11.92%) are caused by lack of hygiene, the use of drugs, and chemicals.

Impacts on soils

In this study, field observations revealed major impacts of miners on soils of the area as it can be seen in Figure 3. Over large areas, sterile holes (devoid of gold) were abandoned by the miners. Indeed, they often use gold detectors but for various reasons (quality or capacity, interpretation of the signal from the detector, and so forth), the probability of locating the precious metal may be low.

Based on the work done by Ouedraogo (2008) on the impacts of gold mining in Essakane, a specific area was followed between 2007 and 2008. This area has been terribly affected by the miners in 10 months. Figure 4 illustrates this situation. Impacts identified in this study are consistent with those of the Ouedraogo.

Industrial mining in the Essakane District is made according to the extraction of mine using the open-pit method. The most significant effect of this method is the degradation of the natural landscape and topography of the land area. This degradation will be intensified by satellite pits (small pits around the main pit) and Falagountou's pit, which is the part of expansion of the gold mine. The soil clearing for the construction of mining infrastructures causes a disturbance of the soil of the project site, the loss of *in situ* structure, and modification of the chemical and physical properties. Accidental oil spills from earthmovers have potential environmental impact as soil contamination. The achievements of the access roads to the mine result in the loss of agricultural land (ESIA 2012). Emel *et al.* (2014) revealed that over 13 million m^3 of material has been removed from the main mining pits at Geita Gold Mine in Tanzania, whereas over 81 million m^3 of material has been deposited elsewhere in tailings piles and waste dumps. Leiva and Morales (2013) performed mercury

Figure 3. Photos of gold holes dug by miners. (A) Gold hole near the roots of *Acacia tortilis*. (B) Abandoned sterile holes (devoid of gold).

Figure 4. Photos of the area examined by Ouedraogo (2008). (A) The area in July 2007. (B) The same area in May 2008.

analysis on the soil samples of Andacollo, which is located in the Coquimbo region of Chile and at least one site over 14 was contaminated at a mercury concentration of 13.67 ± 1.4 mg/kg, which was above the international recommendations that were set by the Canadian Council of Ministers of the Environment's soil quality guidelines (CA-SQG) and the Dutch guidelines (NL-RIVM). At least four of the fourteen sites in this study were within the control and tolerance levels of these recommendations. Moreover, Aragon and Rud (2013) pointed out that increased mining activity between 1998/99 and 2005 decreased the productivity of farm lands near to the mines 40% relative to the lands away from the mining areas. The work done by ORCADE (2006) and Bazié (2008) on the gold mine at Poura showed that open pits were abandoned without rehabilitation after the mine closure. As a reminder, the conceptual closure plan of the Essakane gold mine provided a transformation of open pits into water lakes usable by the local population.

Impact of mining activities on fauna, flora, and livestock

Impact on flora and fauna

Stripping of soil during the construction phase of the gold mine especially has impacts on flora and fauna. Surveys conducted among the local population allowed to identify the plant species that were abundant before the gold mining project at Essakane and whose number has decreased with the project. These are the following species: *Balanites aegyptiaca*, *Acacia seyal/Acacia raddiana*, *Zizifus mauritiana*, *Tamarındus indica* and *Adansonia digitata*. Open-pit mining often involves the removal of natively vegetated areas and is therefore among the most environmentally destructive types of mining (ELAW 2010). The realization of the holes by artisanal gold miners also contributes to the destruction of certain plant species.

The destruction of plant species and disturbance of wildlife habitats by mining activities have resulted in the migration or disappearance of most mammals (gazelles, hares, and warthogs) that existed there. The number of reptiles such as the Nile monitor (*Varanus niloticus*) present along the river between Gorouol Inabao and Essakane Site is decreased because of the degradation of the area (Knight Piésold Consulting 2007). It is the same for avian

Table 7. Average number of animals per household before and during the gold mining project.

Type	Oxen/Cows	Goats	Sheep
Before the project	11	23	23
During the project	4	9	5
Difference (negative impact)	63.63%	60.87%	78.26%

fauna. In a study carried out by Durand (2012), it was observed that the aquatic macroinvertebrate studies in the Tweelopiespruit River (South Africa) determined that the diversity and number of invertebrates diminished with the deteriorating water quality the closer one got to the mine.

Impact on livestock

Livestock is one of the most important activities in the study area. Table 7 shows the results of surveys conducted among heads of families (or head of household) on their farming activity before and during the gold project. These surveys have shown that gold project has a potential impact on livestock. In fact, the gold mine has engulfed a big part of the grazing area and the local population has not found one that is better. They were forced to buy hay at high prices for livestock feed. Moreover, the accidental release of certain chemicals used in the gold mining process gets the situation worse. It was noted that it is strongly recommended to kill and bury animals that cross the grid of gold mine to graze there.

In early September 2011, at Kalafalla and at Essakane Site, the deaths of an ox, five goats, a sheep, and thirty vultures were noted on the same day. The Minister of Animal Resources who visited the scene of the tragedy said that investigations would be conducted to determine the cause of death of these animals. However, the deaths were explained as being due to poisoning from a cleaning product used at the mine (Aimée 2011).

During the present work, not far from the gold mine residue park, cattle that died was identified and photographed in Supplementary Figure 2. From a comparison to similar events that took place around the mine, this case may be due to chemicals.

On 29 July 2011, a truck carrying two containers (20 feet each) of cyanide toward the gold mine Inata falls on the basin forming the weir of Djibo's dam. This incident led to the death of fish in the dam. The country's authorities have suggested to the people of Djibo to not drink and to not give water to pets from the dam for a while (Amadou 2011). This incident shows that, also for other localities, mining has impacts on the environment and pose a risk to the ecosystem and the health of local populations in a direct or indirect way or accidentally.

Mining activities in the Essakane District, directly or indirectly, have a potential impact on livestock.

Impact on archaeological resources and cemeteries

Surveys and interviews with local people helped to note that there is no sacred land or groves in Essakane. However, cemeteries are engulfed and protected within the scope of the gold mine. Archaeological excavations were initiated by the Essakane gold project in order to minimize the project's impacts on archaeological resources (ESIA 2012).

Archaeological excavations carried out in the Essakane District by Millogo (2010) revealed four types of relics: tools in cut and polished stone, ceramics, metallurgy paleo, and funerary art. Artisanal gold mining has disrupted these materials, which are evidence of ancient occupation of the area.

Impact on livelihoods and relocation of local populations

During the study, 99% of the heads of families relocated said that they are not happy with their new life. They were forced to move even though they were very associated with their old environment. The heads of families have simply responded to the question "for whom is it operated the Essakane gold mine" that it was not in operation for them because they cannot provide the daily basic needs. This situation led them to appeal to the FIAN Foundation (Foodfirst Information and Network) to help them. They pointed out that before they lived thanks to their fertile agricultural lands and gold wells.

According to World Bank's data, the value for adjusted net national income per capita (current US$) in Burkina Faso was 537.47 US $ as of 2011. This indicator is rising in value year after year due to gold exports. But referring to the final report of Economic Analysis of Mining Sector Links Poverty and Environment (2011), 700,000 persons are directly concerned (directly actors) by artisanal gold mining and generally 1.3 million people get their income through that activity. Only 42% of these people (directly actors) earn money above the poverty line which is 143.02 US $. Others (58%) are living below that poverty line.

Ramirez (2013), director of documentary film titled "Prosperity on Earth," said that it was enough to stay for two days in Essakane to realize that the local population is poor and really suffers. The director also said that the gold extracted from Burkina Faso can feed all of the Burkinabe if it had been used for the benefit of people.

This poverty of the local population is contradictory to Article 14 of the Burkina Faso's Constitution (The natural wealth and resources belong to people. They are utilized for the amelioration of their conditions of life).

Conclusions and perspectives

The surveys showed that the artisanal miners in the area are predominantly illiterate and do not have enough knowledge about the effects of chemicals such as mercury and cyanide. The mills used to crush gold ore, transportation, and mining activities (industrial and artisanal) are a potential source of air pollution, soil, and water. The risk of drinking water pollution is high. There exists a competition between local people and the gold mine for the use of water resources.

The results also showed that the air pollution level is high and that there was considerable degradation of the natural landscape of the area by the artisanal gold miners and industrial open-pit mining. Fauna, flora, livestock, and archaeological resources are considerably influenced. In addition, the degradation and loss of agricultural lands (farmlands) and grazing areas apply heavy loads on the livelihoods of the local population.

Faced with this situation, the following perspectives have been proposed to the exploitation of gold mines, especially the Essakane's, in order to improve the living conditions of local people and enable the sustainable development of Burkina Faso: beyond inspections by industrial mine, the water quality in the study area must be followed strictly and regularly with state officials for that purpose; data from the environmental monitoring of the area must be submitted monthly to public authorities and also made available to the population; precautions must be taken to prevent importation, transportation, distribution, and sale of chemicals (mercury, cyanide, acids, and so forth) used in the gold mining process; the Ministry of Mines and Energy and structures affiliated with it must establish an educational system of good operating practices for gold and technical assistance to artisanal miners, to those of the semimechanized and those of the small-scale mining so the adverse effects of mining on the environment and on themselves will be decreased; violations of the Environment Code, Mining Code and its implementing texts committed by mining companies must be punished according to the provisions in force; the Mining Code of 2003, although its attractiveness will be reduced, should be revised to have a much more respectful nature to the environment; roads between Dori and Essakane (70 km), Gorom-Gorom and Essakane (42 km) should be tarred to reduce excessive dust due to continuous flow of vehicles in connection with the industrial mine; considering the dam built on the Gorouol river and the other three in the gold mine, during the rehabilitation of the mine, open pits should not be transformed into lakes but should be closed to receive their initial plant formation; moreover, open pits should be underlined by geomembrane to protect the groundwater; mining companies should help to academic studies in order to decrease the environmental impacts of mining.

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