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Open-Air Quarries in the Urban Commune of Zinder (South-East Niger): An Opportunity with Strong Externalities

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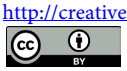


Open Access

Abstract

The framing of this theme would contribute to a better analysis of the benefits of open-air quarrying in Zinder, and should make it possible to understand and measure the socio-environmental externalities of this type of activity in an urban environment. The approach method consisted of carrying out surveys combined with field observations and interviews with the various stakeholders as well as the local population. The results obtained made it possible to identify both positive and negative impacts. The positive impacts are above all the advantages derived from these aggregate quarries, in particular, the creation of direct and permanent jobs and the increase in community income. The price of piling up a truck costs around 28,000 CFA ($56 CAN) and that of loading is around 10,000 F CFA ($20 CAN). This has the effect of removing young people (20 - 39 years old) from the circuit of migration outside the region and even the country. The possibility of using the extraction sites by the local population was identified, in terms of profits relating to fish farming, off-season crops, animal drinking and reclaimed plots. The study also noted negative externalities, such as the temptation of young boys to become involved in extractive activities for immediate gains at the expense of school attendance. Added to this is the upheaval in the topography of the urban landscape, pollution and nuisances (noise, visual and olfactory), while the disappearance or clogging of quarry ponds is the cause of frequent flooding in the neighborhoods. In short, corrective measures (e.g. the revegetation of sites) certainly make it possible to minimize the harmful impacts on the urban environment.

But, to improve the performance and organizational capacity of the quarrying industry in Niger, even stronger regulation, training and awareness of stakeholders prove to be the necessary measures.

Keywords

Open-Air Quarries, Urban Environment, Community Income, Externalities, Zinder

1. Introduction

In Niger, quarries are deemed not to be separated from land ownership or surface rights, they follow the conditions [1]. Ultimately, in the context of real estate explosion and critical poverty, unemployed individuals are moving towards the anarchic and illegal exploitation of quarries to get back into working life [2] [3]. Since then, the municipalities crossed by the RN1 (national road) have emerged as the most severely affected local authorities in the country [4] [5]. In this regard, the Niger Ministry of Mines [6] underlines that it is the regions of Maradi and Zinder that are prey to the problem of the artisanal quarry proliferation due to the induced effects of increasing urbanization.

Thus, the anarchic modes of exploitation in the city of Zinder gave rise to approximately 64 urban quarries sometimes presenting very steep, even vertical banks (2 to 10 m high) [4] [7]. And because these quarries have never been the subject of any development more than 50 years after their opening, they have gone from simple depression zones to deposits of various sizes [8]. Local areas for collecting runoff water, these urban quarry ponds are today transformed into veritable illegal dumpsites by municipalities to become breeding grounds for vectors of endemic diseases [4]. Among other things, to the problems of visual nuisance are added cases of drowning, injuries and loss of human life at the arrival of each rainy season [4] [8]. Nevertheless, recent surveys confirm that the exploitation of quarries in the urban fabric of Zinder, in addition to certain dues to the State [7], has a substantial weight in relieving the basic needs of households [9]. The fundamental challenge, in terms of externalities, is therefore strong [7] [9] [10]. This is the case of the lack of environmental monitoring of sites which, for many stakeholders and the local population, constitutes a major concern [7] [9].

However, in Niger, the legislative and regulatory texts are quite numerous and Niger seems ahead of many West African countries [1]. An example is Article 121 (Safety and Hygiene rules) in Title VI (Rights and Obligations attached to the exercise of mining or quarrying operations) of the Niger mining code [1] stipulating that "Any natural person or legal entity carrying out research or exploitation of mineral substances under this Ordinance is required to carry it out according to the rules of the art so as to guarantee the safety and hygiene of employees and third parties. The minimum safety and hygiene rules applicable to research and

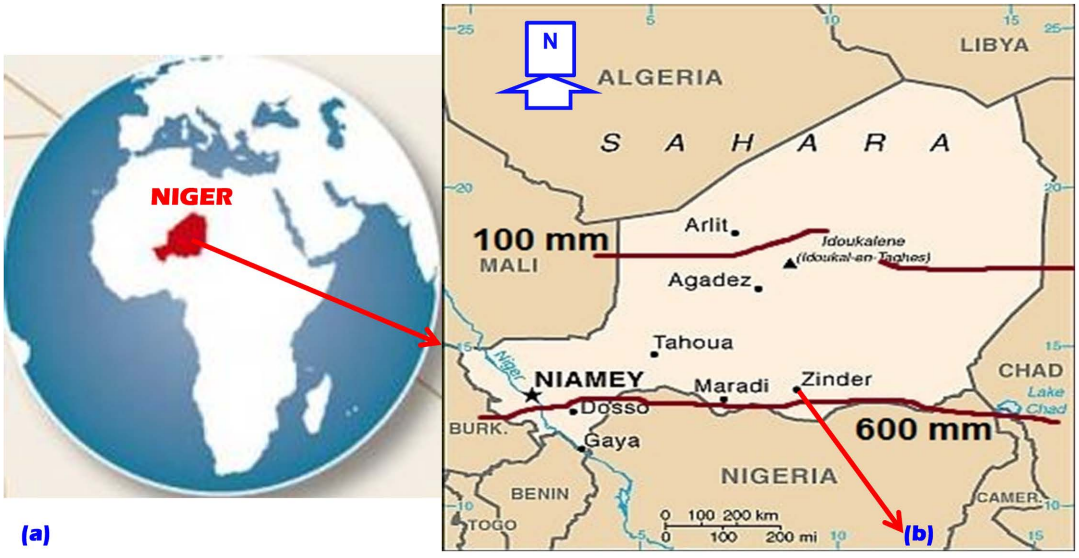
exploitation work, the provisions relating to health risks (silotic risks, ionizing radiation, etc.) inherent to mining or quarrying operations and the safety rules relating to transport, storage and use of explosives are provided for by legislative and regulatory means". Furthermore, Decree No. 93-044/PM/MMEI/A (March 12, 1993) establishing the terms of application of the Mining Law of 1993 [1] which clearly specifies in its article 58 that "Any holder of any quarry is required to rehabilitate the exploited sites as progress is made".

Faced with the reality of urban sprawl in sub-Saharan cities [3] [11], the natural geomaterials industry must nevertheless be part of a sustainable development perspective through actions to optimize resources but also services and infrastructure [12] [13]. In this context, this research aims to explore the aspects of the exploitation of open-air quarries in the commune of Zinder with the aim of highlighting the shortcomings, but also understanding what makes sense for territorial decisions and local debate in terms of well-being. More specifically, this involves: 1) Describing the organization and the characteristics of operational stakeholders in the urban fabric; 2) Examining the operating conditions of the selected sites; 3) Identifying the types of significant spin-offs and externalities linked to the local issues of open-air quarrying; 4) Checking the corrective measures after and during exploitation.

2. Material and Methods

2.1. Area of Study

The city of Zinder is located in the center-east of the Niger Republic between 13˚31' and 13˚54' north latitude and 08˚52' and 09˚51' east longitude, approximately 900 km of the capital Niamey (**Figure 1**). Former capital of the country, Zinder is the capital of the said region and the second city of Niger. The Urban Community of Zinder has five (5) municipalities (**Figure 1(b)** and **Figure 2**) with a total population of 409,353 over an area of 559.66 km^2 [14] [15].



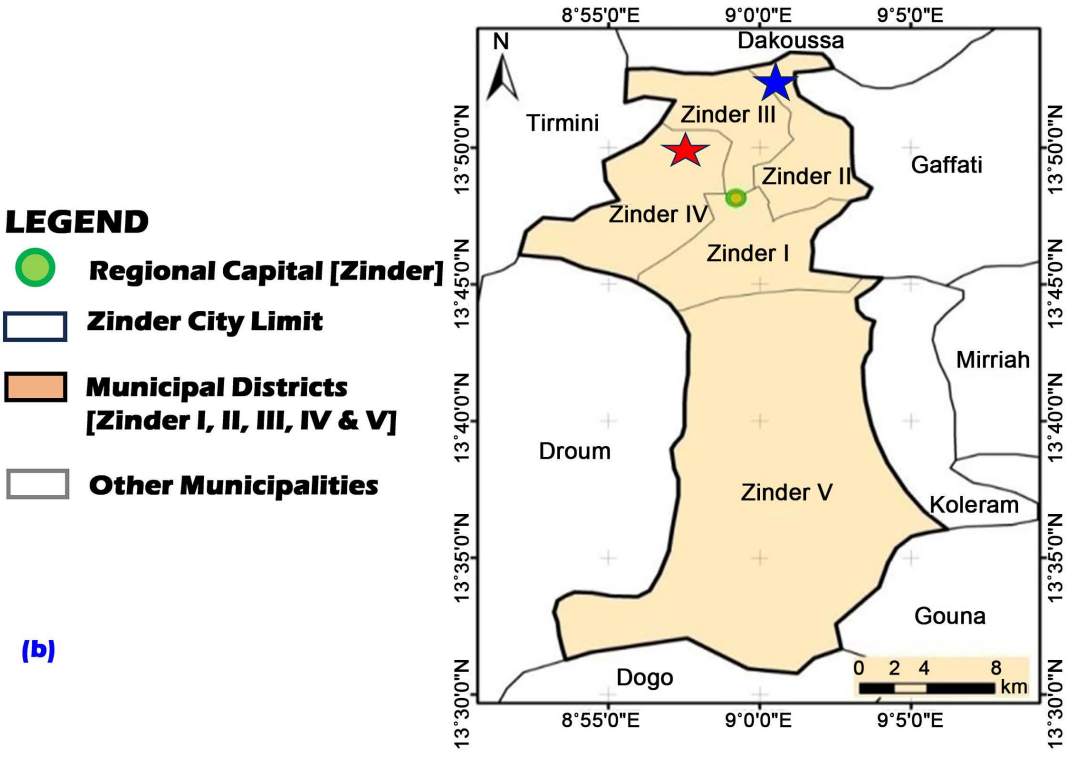


Figure 1. Maps showing (a) the location of Zinder city in Niger and isohyets 600 - 100 mm, and (b) administrative organization of Zinder city ([14], modified). The blue and red stars (b) represent, respectively, the sites of Bargouma (Zinder II: 13˚53'N and 9˚01'E) and Charé Zamna (Zinder IV: 13˚49'N and 8˚57'E).

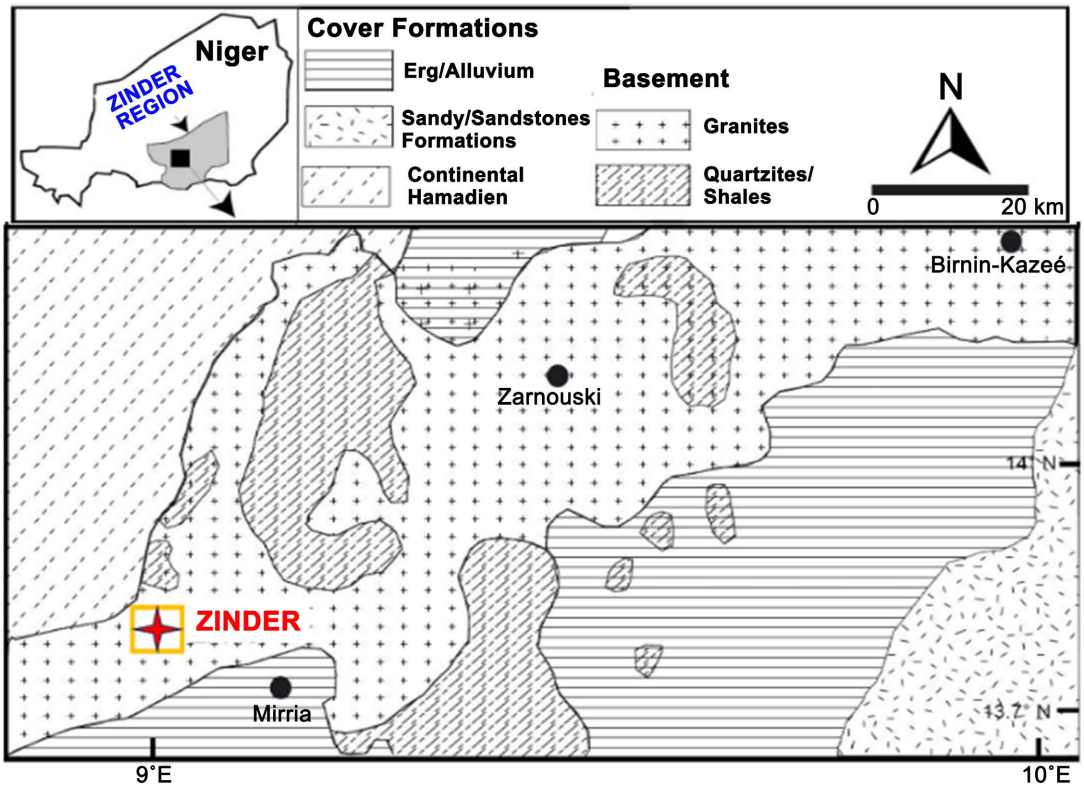


Figure 2. Geological characteristics of the city of Zinder and its surroundings ([17], modified).

The Urban Community of Zinder City lies entirely within the vast peneplain of the Pan-African province of Damagaram-Mounio [16] [17]. From a geological point of view, the Zinder region is characterized by sporadic outcrops of Pan-African basement, intruded by the Younger Damagaram Granite complexes, all topped by Cretaceous sandstone-clay sedimentary cover (**Figure 2**). Recent sandy deposits discontinuously cover the region, exposing in places the basement formations and the Cretaceous sedimentary cover. The relief of the Zinder region is made up of a succession of interfluves, the monotony of which is interrupted by sandy dunes, witness mounds, hills and plateaus (**Figure 2**). Hills, plateaus and witness mounds alternate with depressions in impermeable terrain (clay quarry ponds) [4].

The climate of the Zinder region is Sahelian and characterized by two distinct seasons: a rainy season which lasts between 4 and 5 months (May-June to September-October) and a dry season for the rest of the year (October-November to April-May). The cumulative rainfall is between 250 mm and 600 mm (**Figure 1(a)**) [9]. The City of Zinder does not have a significant density in terms of vegetation. The dominant species are mainly reduced to *Acacia nilotica*, *Commilifora africana*, *Calotropis procera*, *Leptadenia pyrotechnica* and *Maerua crassifolia* [14]. In fact, average daily temperatures are above 24˚C and maximum temperatures in certain months of the year (March, April) exceed 40˚C [4].

The hydrographic network of Zinder is essentially made up of river routes which are only active during the rainy season. There is no permanent watercourse, but there are several ponds, temporary ponds and permanent ones, the sites of which offer possibilities for off-season cultivation. In the 1960s, these ponds were small depressions where the city's runoff water temporarily stagnated. Over the years, they have all undergone significant surface expansion, in addition to deepening, due to strong urban growth increased demand for building materials, mainly banco (clay material or raw earth) [4] [7] [14].

Agriculture (rainfed and irrigated) and livestock breeding are the main economic activities of the population of Zinder. Commerce and crafts also represent a significant source of activity for the population of the region. The choice of the city of Zinder is explained by the fact that, since the installation of the Soraz oil refinery, the region of Zinder and its regional capital has been the site of a demographic boom (the most populated region of Niger which came to dethrone Maradi) [15].

2.2. Methodology

Data collection is based on indirect and direct observations [18]-[20]. Indirect data helped frame the relevant facts on the subject through various documentations. These include journals, articles, books, dissertations and theses. Direct observations consisted of: 1) interviews with the technical environmental service, 2) visits to neighborhoods for field observations and, 3) questionnaire surveys designed to assess reality of the exploitation of open-air quarries of geomaterials

(aggregates, laterites and soils).

The first field exploration visits in August 2019 [9], coupled with interviews with the city's technical services, made it possible to focus the sampling on the Zinder II and IV municipal districts among the five that make up the city of Zinder (**Figure 1(b)**). The choice of sample is explained by the fact that, during the last general population census [15], these two municipalities were those which recorded the highest demographic growth. Also, according to the local director of mines [9], communes II and IV are the most marked by the presence of a diversity of quarries, namely: functional quarries, quarry ponds and clogged ponds.

The field exploration visits ended in September 2019 with the selection of two open-air quarry sites and their positioning using a Garmin GPS (**Figure 1(b)**). The Bargouma (SATOM Company) gravel quarry and the Charé Zamna banco quarry (**Figure 1(b)**), which are the subject of this study, are found between homes due to the rapid urbanization of the two municipal districts: Zinder II and Zinder (IV) [7] [14]. The criteria for choosing sites include the mode of operation, notably reputation and age. In fact, the Bargouma quarry is relatively modern, while that of Charé Zamna (literally "sweep and settle down") is artisanal [9]. Therefore, Bargouma, located not far from the Zinder-Tanout-Agadez axis (**Figure 1(a)**), was created ten (10) years ago and occupies an area of nearly seven (7) hectares. On the other hand, the Charé Zamna quarry, located in Zinder IV not far from the Zinder-Maradi-Niamey axis (**Figure 1(a)**), has at least fifty (50) years old.

The questionnaire surveys are structured interviews carried out over a period of four (4) weeks in the communes of Zinder II and IV. During this stage (October to November 2019), the stakeholders (operators and owners n = 30) were approached in order to collect information on their activity. Subsequently, a survey was carried out among the populations (n = 50) located around the quarries. The criteria for choosing target people (men and/or women or surrounding area residents) include, first of all, obvious knowledge of the career by the person to be interviewed. Then, it was a matter of ensuring not only the exploitation activities of the person, but also the availability and willingness of the person to answer the closed and open questions asked. Overall, the questions focused on working conditions, the socio-economic and environmental impact, the health risks to which all these actors are exposed and their perceptions on optimization actions and corrective measures. The information collected from a total sample of 80 respondents is supplemented by working sessions with local mining and industrial leaders. These interviews should allow a comparison between the facts drawn from observation and field documentation, the perceptions expressed by the respondents and the points of view of the authorities in charge of mineral resources.

The continuous quantitative data collected were entered and processed using Excel software, so that they were expressed as citation rates (F). The citation rate F [19] for a given parameter is expressed as a percentage (%) and corresponds to the number of people (n) who provided the same answer out of the total number (N) of people questioned (operators and owners or local populations). These data

were analyzed and discussed by combining observations from previous work, and photos illustrating general conditions of urban spaces and activities in the operating areas from August 2019 to March 2024.

3. Results

Quarrying in the urban fabric seems to be a daily activity that takes place continuously throughout the week. Activities begin in the quarries from six (6) a.m. and only end in the evening between four (4) p.m. and five (5) p.m. According to the respondents, the exploitation of these quarries constitutes a springboard, in addition to a steamroller and stress in the face of the increasingly growing needs for gravels and sands for building.

3.1. Characteristics of Operators

The survey and field monitoring shows that 100% of direct actors are men. For these men, most of whom are heads of families, it remains the only job to do. Thus, the age of actors varies from 20 to 45 years; while 73% of the sample is represented by young men (20 - 39 years old). Women only intervene in the last stage of quarry operations, namely: marketing. For smallholders, the material is sold by the load or whatever volume is demanded. And, the selling price depends on its quality and quantity. This price is negotiated between the buyer and the operator. When the operator returns to the quarry to collect the material, it is the women at home who do the trading and sometimes go there to look for the skip drivers and even identify potential buyers.

3.2. Methods and Processes of Extraction of Quarry Materials

3.2.1. Semi-Industrial and Modern Operation

This method of extracting materials in the town of Zinder is carried out by the SATOM Company at the Bargouma quarry. It has the particularity of operating with a mechanical and electrical system, and does not require great physical effort from workers. The material exploitation process, organized by fraction of work per team, includes the following stages:

Stripping and Consolidation

The stripping consists of removing the exposed sand (**Figure 3**). It is a kind of sand borrowing which involves the successive and/or concomitant use of tracked graders, loader-transporters and loading trucks (or dumpers), under the supervision of qualified personnel. Stripping has the advantage of making the soil permeable, as it removes crusts from impermeable clay soils. As for tightening, this involves making piles of gravel, with the aim of consolidating the piles of materials into storage piles (**Figure 4**).

Screening and Transport

Screening is the process by which materials are sieved then separated into sands and gravels before being transported (**Figure 5**). After loading, transportation is the last and most important stage in the process, providing access to income

(Figure 5(a)). It involves the constant coming and going of loaded trucks carrying gravel and sand from the quarry.

Restoration of the site

According to manager, the projections for the restoration of the site are based on the seedlings of the most dominant local species (Figure 6). This is the case of *Calotropis procera* (Figure 6(a)) and *Acacia nilotica* (Figure 6(b)), given their great capacity for growth and soil fixation for good textural quality. Therefore, the most effective method for the moment is to bypass the adult species existing at the bottom of the excavations (Figure 3(c)).

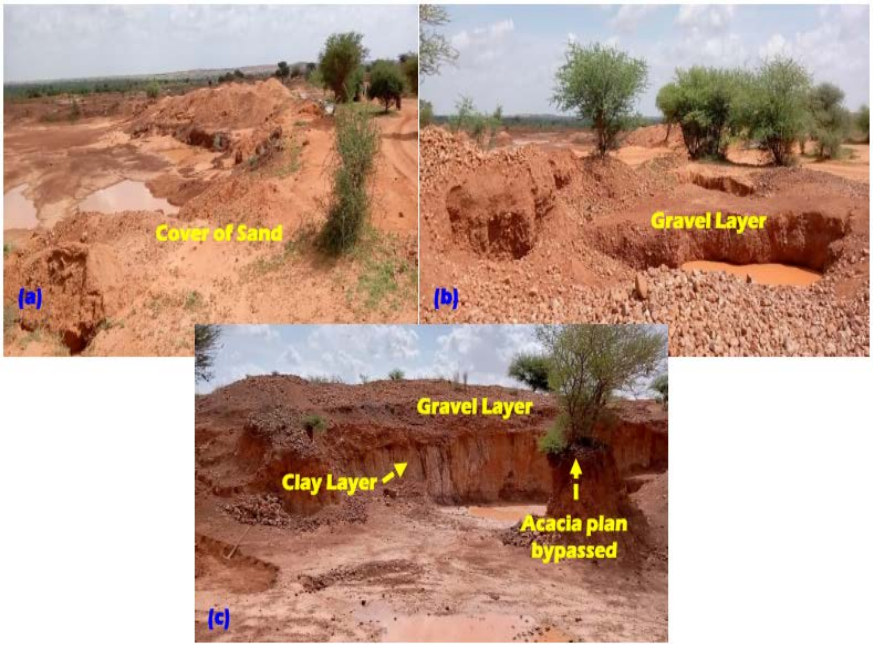


Figure 3. The different phases of stripping at Bargouma exposing the surface layers of sands (a), gravels (b) and the deep clay cover (c). Note that (a) incision of gullies, (b) deepening of trenches and (c) shallows becoming retention basins for overflowing water from the koris (wadis) are all possibilities for flood control by the quarry sectors borrowed materials.

(a) (b)

Figure 4. Tightening of piles of aggregates stacked in Bargouma. (a) Track grader in tightening phase. (b) Pile of stacked aggregates.

Figure 5. Screening of aggregates for the separation and transport of gravels and sands in Bargouma. (a) In the foreground, the Quarry Manager supervising and in the background on the left a loader-transporter feeding the first screen. (b) A dump truck collecting sand. (c) Transport of gravel by Bargouma operators.

Figure 6. Limited restoration of a site in Bargouma by maximizing the establishment of (a) *Calotropis procera* and *Acacia nilotica* plants.

3.2.2. Classic or Artisanal Exploitation

It seems convenient to distinguish here two (2) categories or subgroups of artisanal exploitations which are the primary or traditional quarries (**Figure 7(a)**), on the one hand and on the other hand, the quarries of second generation which are developing today on the former semi-industrial exploitation sites of Bargouma (**Figure 7(b)**).

Unlike semi-industrial quarry exploitation, working conditions are very difficult in the artisanal exploitation of banco quarry ponds, particularly in terms of professional safety and the daily experience of the actors. These are jobs that require physical strength, rudimentary technology, endurance, caution and patience. This mode of exploitation requires a lot of physical commitment from operators.

This is the case of the operators of Charé Zamna, a quarry of more than 50 years de facto swallowed up by the city.

Figure 7. Categories of artisanal mining quarries. (a) First generation quarry in the Charé Zamna area and chisel extraction. (b) Second generation career in the semi-industrial site of Bargouma.

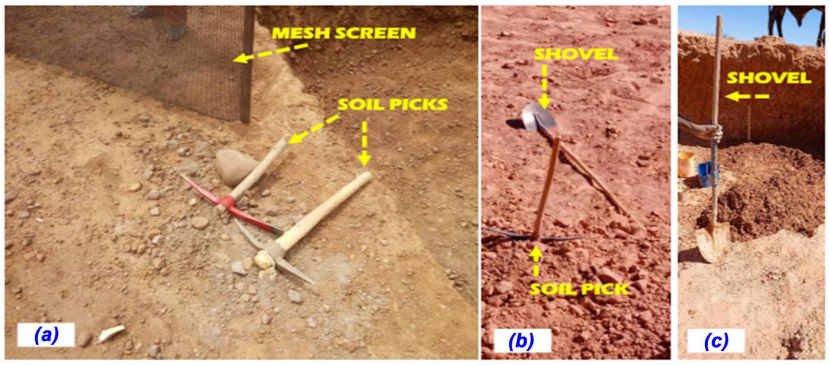


Figure 8. Artisanal exploitation and some instruments used. Extraction with (a) soil pick and mesh screen and (b) soil pick and shovel, and (c) shovel in Bargouma.

Figure 9. Transport by animal-drawn cart in Charé Zamna (a) and Bargouma (b) and by small motorized vehicles (Bargouma).

Generally, the extraction of the material (Figure 7 and Figure 8) by hand is done using instruments such as chisels (Figure 7(a)), soil picks and mesh sieve (Figure 8(a) and Figure 8(b)), the shovel (Figure 8(c)) and daba, the hoe, etc.

Transport is most often carried out by animal-drawn cart (Figure 9(a) and Figure 9(b)) and, sometimes, by small motorized vehicles Figure 9(c)).

3.3. Materials Extracted: Uses and Tax Revenues of the Community

Here are two types of materials from quarries: aggregates and banco clays. In the aggregates, depending on the size of the constituents, we distinguish between gravels (light and gray) and sands (Figure 10). According to the respondents (80%), the most popular material remains gravels, with a quotation rate of 50% and 30%, respectively for light and gray gravels. Clays and sands are the least used, with a rate of 13% and 7% respectively of the materials exploited. The field investigation shows that the extracted clays are used in the manufacture of terracotta or dry bricks which can still be used in Hausa housing and that the sand and gravel are used as concrete elements for modern buildings and hydraulic structures. As construction materials for hydraulic structures and roads, quarry extracts are used during land leveling (sand), as backfill (gravel of 1 to 4 mm in diameter) and as filters (gravel of more than 4 mm in diameter).

(a) (b)

(c) (d)

Figure 10. Typology of materials exploited on open-air quarry sites. (a) Light gravels (more than 4 mm in diameter); (b) light gravels (1 to 4 mm in diameter; (c) sands and (d) banco clays.

Although quarrying is done informally, municipalities earn income from this activity (Table 1). The tax is levied only for the transport of sands and gravels, and depends on the volume loaded, *i.e.* 1000 F CFA ($2 CAN) for 12 m^3 and 500 F CFA ($1 CAN) for 6 m^3.

Table 1. Income scenario based on sands and gravels mining.

Periods [Taxes]		Municipal income per truck (F CFA)
Passage	A load	1
	Tax	1000
Day	Number of passes	9
	Tax	9000
Week	Number of passes	63
	Tax	63,000
Month	Number of passes	270
	Tax	270,000
Year	Number of passes	320
	Tax	3,240,000

3.4. Dimension of Impacts Linked to Quarry Exploitation

3.4.1. Impacts on Elements of the Physical Environment

The atmospheric component of the environment is the most impacted throughout the mechanical operating chain. The direct activities that pollute the air include operations related to stripping or sweeping (Figure 3), tightening (Figure 4), through sieving gravel (Figure 5), loading and passing trucks (Figure 5(c)). The particles resulting from these activities that contribute to air pollution are nitrate molecules, carbon monoxide, carbon dioxide and fine soil particles. The other cause of pollution comes from truck exhausts.

Table 2 shows the assessment results, based on the 50 respondents, of the extent of the impacts on the soil, the vegetation and the fauna.

Table 2. Perceptions of impacts according to populations living near quarries.

Impacts according to respondents	Citation rate
Dust, noise and odor	33%
Land degradation	28%
Destruction of vegetation	25%
Destruction of wildlife	14%

It appears from these results that the dangerousness of aerosols, concomitant agents of mechanized quarrying, on ecosystems remains a concern of the stakeholders interviewed. Dust fallout (33%) on the surrounding plant cover, during the passage of loading trucks, affects its physiological activity, and therefore the

reduction in photosynthesis. This same truck traffic also has an impact on the structure of the soil through compaction phenomena. Soil quality is not only affected by semi-industrial mining activities such as stripping and gravel extraction (28%), but the use of a large strip of arable soil exposes them to runoff and violent gullies upstream with intense water flows downstream (**Figure 11(a)**). Furthermore, observation of the sites shows that most traditional operators in Bargouma operate and extend their material extraction activities on private lands (**Figure 11(b)**).

(a)

(b)

Figure 11. (a) Morpho-pedological vulnerability to water erosion. (b) Second generation quarry on undeveloped land in the Bargouma sector. Plot markers are placed there.

3.4.2. Impacts on the Human Environment

As with any semi-industrial site, the homes closest to Bargouma are exposed to dust and noise from passing trucks. Thus, the frequency of incessant truck traffic, linked to intense operating activity, would aggravate the deterioration of sound quality in the area. According to the site manager, exposure to noise and vibrations led to a reduction in the hearing capacity of workers and residents of the

neighborhoods crossed by the trucks. Also, referring to the stories of agents and workers in the semi-industrial system, the risks of accidents and respiratory pathologies are unequivocal. The wearing of safety equipment at all times by operators is there to reduce the risk of accidents and illnesses (Figure 12(a)). Likewise, ravines left after exploitation and overflowing with water in the rainy season are responsible for drownings and especially diseases such as malaria (Figure 12(b)).

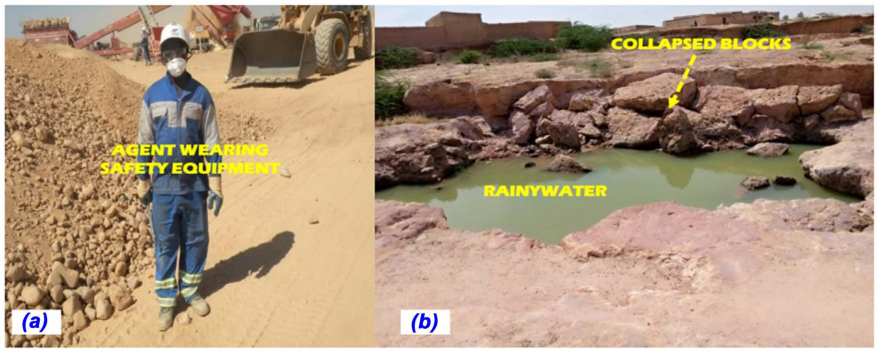


Figure 12. Working environments and conditions in quarries. (a) Modern extraction at Bargouma. (b) Artisanal extraction at Charé Zamna showing collapsed blocks and stagnant water can be a source of disease.

The socio-economic benefits of the open-air quarrying industry in Zinder's urban fabric are mainly to job creation for the surrounding and urban population. Modern gravels quarrying began only a few years ago by road construction companies employing local workers (17 to over 200). From then on, the semi-industrial quarry of Bargouma, due to its proximity to the villages, benefits the local populations. Thus, after the semi-industrial stripping of gravels from surface sand and gravel by the SATOM Company, owners of quarries acquired by purchase and squatting were identified (Figure 11(b)). At the level of each quarry owner, teams of workers sifting and loading gravels and sands take turns daily. A team of drivers ensures the transport of product to the customer. The survey shows that 72% (compared to 28%) of respondents are among the beneficiaries of this initiative.

In short, the activity allows operators to earn income following employment (Table 3). Thus, the surveys carried out among operators made it possible to calibrate on average the daily quantity of material (gravels or laterites) taken by the operator as well as the unit price of loading a truck.

Table 3. Estimated gains received by the holders of quarries.

Actor (Action)	Revenue per trip (F CFA)	Transport Structures	Daily recipes for three trips (F CFA)
Operator (Piling up of materials)	28,000	Truck	84,000
Operator (Loading of materials)	10,000 1000	Truck Chart/Small vehicule	30,000 3000

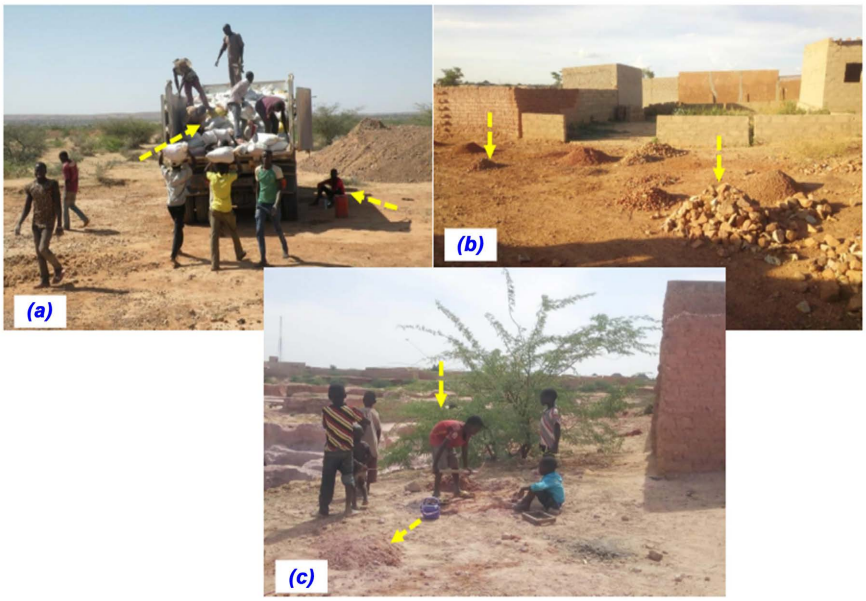


Figure 13. (a) Loading of gravel on truck at the Bargouma quarry showing a distribution of work with a "rest" break for certain workers. (b) Pile of gravels for sale in front of the gates and sides of the residences of the populations living near the quarries. (c) Children from the neighborhood in the confines of the quarry ponds of Charé Zamna.

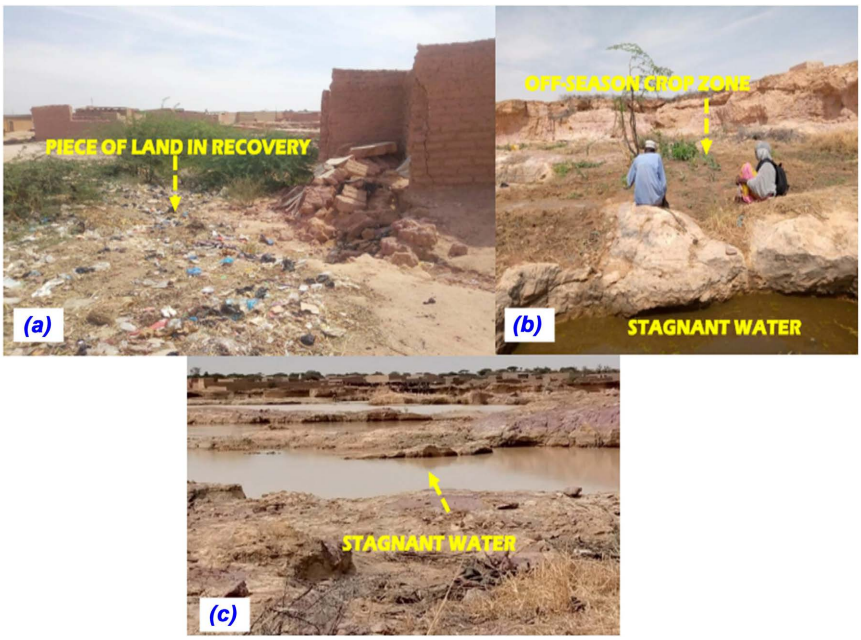


Figure 14. (a) Clogging in progress of a quarry pond to recover plots of land. (b) and (c) Fish farming and animal watering (Charé Zamna quarry).

Beyond the financial benefits that these activities provide to operators, 58% (compared to 42%) of respondents say they are capable of calculating socio-economic added value from these activities (Figure 13). Indeed, certain actors have finally endeavored to highlight that social cohesion has also been strengthened not only between operators, but also within the local population (Figure 13(a)). While

the extraction task is exclusively reserved for physically strong men, valued and empowered women act mainly at the end of the marketing chain in front of the residences (**Figure 13(b)**). The fact remains that certain children (**Figure 13(c)**) in the neighborhood intervene in multiple ways, in and near the quarries. These children find themselves caught by the temptation of seeking immediate gain for the benefit of school or even an even better future as a citizen.

The quarries as they are exploited in the urban fabric of Zinder or found in quarry ponds serve as sites for recovering plots of land after clogging (with waste; **Figure 14(a)**). The field survey indicates that fish farming is also practiced on the sites, like irrigated off-season crops. Moreover, with the plans stagnated, breeders also go there to water their herds as well as stray animals of the local population (**Figure 14(b)** and **Figure 14(c)**). It was also noted that the deepening of quarry bottoms and the incision of ravines during rainwater runoff produce lowlands in the Bargouma sector probably has the effect of forming natural basins to limit overflow water from the koris (wadis) (**Figure 3**).

3.4.3. Alternative Actions and Corrective Measures in the Field

Table 4 shows the few corrective measures and optimization actions implemented under the aegis of the Central Town Hall and the Zinder Mines Directorate, the Office of Environmental Assessment and Impact Studies (BEEEI), and the Regional Environment Directorates for environmental and social aspects.

Table 4. Respondent perceptions of corrective measures.

Corrective action issues	Citation rate
State tax revenues	27%
Health and Safety	18%
Vegetation and Fauna	18%
Smell and Smoke	15%
Goods and infrastructure	12%
Soils	10%

4. Discussion

The new urbanity in the municipal districts of Zinder maintains a strong dependence on natural aggregates [9]. Since then, the extractive activities of materials for construction and public works have left a set of 64 open-air quarries in the urban fabric [7]. Such geomaterial quarries are today the most essential type of neighbor in the peripheral districts of the Zinder city. According to Niger's mining law [1], all these quarries can be classified into temporary quarries (validity of six months non-renewable) and permanent quarries (validity of five years renewable indefinitely). Using the site topographical elements, Adamou *et al.* [7] found that urban quarries in Zinder are mainly composed of ponds, hills, flat lands and vacant spaces. As observed during field surveys, quarries vary in size (small, medium and large), while there are only two methods of extracting materials. These include materials extracted in a modern (mechanized) manner and materials extracted in

an artisanal manner (traditional, rudimentary or manual). Findings state that open-air quarry operations (modern or artisanal) have effects on all components of the environment which can be estimated in terms of positive impacts (main benefits) and negative externalities. Externality is defined [21] as the undesirable and uncontrolled effect of an economic agent on another agent or another economic process. The externality (or external effect) is therefore the concept which makes it possible to account for the interdependencies, outside the market, between individual utility functions [22]. In the field of the environment, Zuindeau [22] specifies that the typology is based on a second division: the main vector of externality can be an activity (production, consumption, etc.) or on the contrary a rupture of activity. In this regard, the negative impacts linked to extractive activities and the symptomatic situations of the cessation of exploitation (abandonment or inactivity, loss of jobs or any worrying activity on the sites) constitute negative externalities.

4.1. Main Benefits of Urban Natural Aggregate Quarries

In the municipal districts of Zinder, the modern and artisanal exploitation of open-air quarries constitutes a useful access to employment for the active population (73% of young people), in addition to a significant tax contribution to the municipality (**Table 1** and **Table 3**). Thus, in terms of income generated and as demonstrated by Bahari *et al.* [3] in Niger, Kouamé *et al.* [18] in Ivory Coast, Hervé Thiery [23] in Benin and Turyahabwe *et al.* [24] in Uganda, the exploitation of quarries as local resources is an essential development opportunity. Similarly, Salissou Ousmane [9] demonstrated that Zinder's aggregate quarries constitute an undeniable guarantee of household food security and, to a lesser extent, the empowerment of women.

Findings state that around the modern site of Bargouma, activities focused on the artisanal exploitation of aggregates have taken precedence over agriculture and the development of plots. Thus, the exploitation of secondary quarries on private plots near semi-industrial quarries (**Figure 11(b)**) is done without the slightest conflict over space occupation between landowners and operators. Such an observation supports the comments of Bahari *et al.* [3] reporting that in the confines of the Niger River in Niamey, "we are gradually witnessing a new type of land transaction, consisting of transforming fields into quarries for the production of aggregates". And, these authors specify that "The reasons put forward come down to the nature of the gravelly substrate (therefore marginal to agriculture) but also and above all the significant income mobilized".

While this income contributes to the functioning of the city, aggregate extraction in Bargouma quarrying site was reported bring together operators (companies or individuals), transporters and drivers as well as contractor-clients who use these products. These various relationships and compromises reveal that the quarrying industry constitutes a rampart for strengthening the social fabric in the operating areas. Hervé Thiery [23] had reached the same results and concluded by saying that "the exploitation of clay (in the commune of Agbangnizoun, South Benin) impacts the social life of operators and has contributed to the reduction of certain social

phenomena such as theft, youth rural exodus, insecurity, trafficking children, etc.".

In this interface of jobs and services that the extraction of materials offers to the population, the quarry industry takes over the land of Bargouma by making it change its value and function and by directing rainwater in places (**Figure 3** and **Figure 11(a)**). Indeed, the mechanized stripping of soil crusts and the deepening induced by the artisanal extraction of old gravel pits in Bargouma (north-east of Zinder) are causing the sites to evolve into infiltration surfaces and water retention crevices (**Figure 3**). As the City of Zinder is built on a slight slope inclined from North to South [2], the bumpy landscape of Bargouma offers an opportunity for better control of runoff water passing through the city downstream. This idea corresponds to the notion of "domestication of watercourses" by Bahari *et al.* [3] for whom open-air quarries appear as a protection measure against flooding.

Likewise, the expanded quarries located in the Charé Zamna districts are, among other things, reconverted into rainwater and wastewater retention tanks (**Figure 12(b)**). The local population also benefits from fish farming, off-season crops and animal drinking (**Figure 14(c)**). Also, when the oldest quarries are blocked after too much waste [4] [8], many are converted into plots of land (**Figure 14(a)**). For Salissou Ousmane [9], the systematic transformation of abandoned quarries into subdivided plots is indicative of a redevelopment of extraction sites, but can be explained by even greater land speculation in certain districts of Zinder.

The sprawl of the city of Zinder is therefore justified by the increasing integration of quarries, formerly peri-urban, into the urban fabric [7]. We can admit that the type of quarries can vary in space (flat terrain, hills) [7] and in time (active quarry or not) [25]. When quarry operators were asked to rate the value or usefulness of materials, respondents indicated that the most popular materials remain gravels (80%), while clays (13%) and sands (7%) are the least used (see Section 3.3.). We consider that the type of materials exploited also depends on time, either the banco and kaolinites [25] which made it possible to perpetuate the architectural beauty of the ancient city of Zinder (**Figure 15**), or the aggregates (gravel and sand) which until now support the influence of modern real estate [3] [9].

Figure 15. Banco houses in the Birni district (Sultan Palace district of Damagaram) with decorations on the facades. These figures, in addition to symbolizing certain realities, present a living testimony of the traditional architecture and the know-how of the masons of the locality and easily allow us to recognize the house of a notable, of a marabout, of a warrior, of a rich person, etc.

4.2. Socio-Environmental Externalities and Mitigation Actions

The aggregates production industry in the quarry sites of Zinder has been reported to be attractive in creating and maintaining jobs [9]. This employment advantage mainly concerns men (100%) who work on the sites. In Kenya, Kasyoka Wambua *et al.* [26] had almost achieved the same results and concluded by saying that many men (90%) were involved in quarrying due to masculinity nature of the task. In Zinder, this left men (heads of households) in the maze of aggregate extraction all day long. Thus, the rise of minor operators at the end of the materials processing chain can be explained by the absence of authority at home, just like the temptation to imitate parents when these children come to acquire a taste for the meager income from the sale of the sweat of daily toil. It is therefore useful to note that in the least well-off families, the extractive materials industry is for young boys in complete competition with school. It is as well as in Dilala (Democratic Congo), 26% of children working in extractive areas have dropped out of school compared to 14% for children not required to participate in an activity damaging [27]. Turyahabwe *et al.* [24] too reported that, for 30% of the respondents, stone quarrying in Petta (Eastern Uganda) has accelerated school dropout rates and increased the level school absenteeism.

The results of this study also show that the extraction process is not responsible for any natural vector of direct odor release, other than the exhaust gases and fumes from extraction machines and transport trucks operating at diesel fuel. Unfortunately, the clogging of certain quarry ponds with rubbish creates not only visual nuisances but also odors due to the putrefaction of the waste [8] [14]. This is in accordance with Mamadou [25] who reported that the various wastes piled up in the Ramin Kwaya quarry (Zinder II) are always mixed with the wastewater, excreta and rainwater to form a heterogeneous mixture prey to the production of pestilential odors and greenhouse gases. Also, as noted by Adamou *et al.* [7], the disappearance by clogging of ponds further explains the episodes of flooding in the city of Zinder. Likewise, Amadou Malam *et al.* [28], in an analysis of the flood risk situation before and after the pond developments in 2018, come to the conclusion that "sudden rains create floods in the city of Zinder". Indeed, the problem of rainwater evacuation is certainly related to the insufficiency and lack of sanitation of the collection networks, but it still remains a substitute for the persistent siltation of ponded quarries [8].

It is interesting to note that, despite the multiple advantages of a certain proximity and availability of aggregates in the city, several challenges seem to reduce the chances of perpetuating the gains resulting from the exploitation of the sites. These challenges relate to the creation of new depressions on flat terrain rather than on hills (**Figure 11(a)**). Likewise, with the exception of bypassing adult trees (**Figure 3**), we note that most of the open sites are abandoned after exploitation without any restoration. This result is similar to the observations of Adamou *et al.* [7] in Zinder, DRM/DI [5] in Maradi, Bahari *et al.* [3] in Niamey as well as those of Turyahabwe *et al.* [24] in the Tororo district of Uganda. According to Mamadou

[25], one of the manifestations of negative externalities around the site of the Ramin Kwaya quarry, closed in 1976, includes the feeling of living in the deep refuge of banditry and that of an ideal cache of dangerous products like drugs and banned gasoline.

In order to correct the impacts, particularly the damage caused to property and infrastructure, the city should (for 12% of respondents) implement an arbitration procedure and complaints management system. Likewise, to correct the loss of State tax revenue, the following measures were proposed by 27% of those questioned, namely: (1) regularizing the payment of materials extraction taxes and (2) providing documents administrative requirements for the exemption from the exploitation of granite quarries and laterites. Finally, emissions of abnormal odors and smoke will be avoided by (1) regular maintenance of truck engines and field equipment, particularly mechanical excavators, and (2) compliance with the ban on burning on sites. And indeed, like all cities in the world [18] [23] [24] [26] [29], if the city of Zinder is full of illegal and legal quarries [7], the possibilities of development into natural or agricultural spaces or even areas for spreading sludge or retaining rainwater are more than various. Therefore, the city of Zinder should further analyze its Land Development Plan (LDP) and pay particular attention to the articulation between the LDP and other spatial planning and management tools; to ensure that the document addresses the issues surrounding the influence of urban quarries.

After all, Zinder is a wonderful geological museum [9]. Among the qualities that define the attractiveness of natural geomaterials in the city, there is unequivocally this great diversity of facies with a variety of intrinsic characteristics [7] [9]. In this vein, the precise characterization of different geomaterials is a major issue to enable a comparative study determining their behavior in service for the choice of the best quarry [12] [13] [30]. To be able to make the correct characterization of the aggregates, not only the mineralogical composition and surface condition are required, but also the geometric, physical and mechanical characteristics [31].

5. Conclusions

This work emphasized the systematic effects and externalities (positive and/or negative) of the extraction activities of natural geomaterials taken from numerous quarries hidden within the urban fabric of Zinder City in order to mitigate them.

Zinder, stronghold of the Sultan of Damagaram, is the most populated city in Niger after Niamey, the national capital. The city of Zinder is also this landscape punctuated by countless granite rocks covered with alterites highlighted by the construction and public works materials extraction industry. Thus, the satisfaction of needs for aggregates, sands and clays through the sustained exploitation of open-air quarries has become a large-scale socio-economic activity following a strong sprawl of the city and especially the installation of the oil refinery (Soraz).

Semi-industrial or mechanized operations are responsible for the stripping of

large layers of hardened or lateritic soils. In this way, these operations are the origin of clouds of dust, but they have the great advantage of freeing up more surfaces for water infiltration from groundwater recharge. At and around the old mechanized gravel pits, artisanal extraction subsequently gave rise to secondary artisanal pits so deep that they constituted natural defenses against flooding.

Modern sites deepened by artisanal exploitation (or second generation artisanal quarries) as well as first generation artisanal quarries, which once gauged for water, are there for numerous services to the community (gardening, fluids for making banco bricks, beverages, etc.). When they are emptied of their water, these sites serve as illegal dumping grounds for waste and various fluids. Our results show that the sites thus blocked once again become objects of land speculation. Such a break in extraction activity or clogging of a site, on the other hand, carries real social externalities, in terms of accentuating flooding in the city of Zinder.

From the results of the field investigation and the documentation exploitation, it appears that in addition to the absence of the limits of the perimeter to be exploited, there is no documentary reference on the authorization for opening, exploitation and the end quarry operation. Likewise, there is a flagrant lack of control and administrative, even technical, monitoring of activities on the site by the mining and environmental services. The challenge is no longer to chase away operators, especially since they participate in socio-economic development, but to bring them towards a more formal and legal framework, in order to move from artisanal exploitation to mini-industrial exploitation respectful of the environment, hygiene and health rules.

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Conflicts of Interest

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

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