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RESEARCH ARTICLE

ENVIRONMENTAL CHALLENGES ASSOCIATED WITH THE CLOSURE AND REHABILITATION OF A FORMER URANIUM MINE IN ARLIT, NIGER: THE CASE OF COMINAK

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ABSTRACT

Background: The closure of former uranium mining sites presents major environmental challenges, particularly in Saharan regions, where climatic and geochemical conditions may affect contaminant behaviour and the long-term stability of rehabilitation works. This study examines the environmental issues associated with the closure and rehabilitation of the former Compagnie Minière d'Akouta (COMINAK) uranium mine in Arlit, northern Niger. **Methods:** The study is based on the collection and documentary analysis of technical information concerning the closure of underground structures, dismantling of industrial facilities, waste management, and radiological and environmental monitoring measures. **Results:** The findings highlight the use of cement-stabilised backfill and filling materials to seal adits, vertical shafts and pits, with a reported volume of 46,699 m³ of filling material used for the structures concerned. Rehabilitation activities also included industrial dismantling, material sorting, specific management of asbestos-containing waste, and monitoring of certain backfilled structures. The analysis also emphasises the importance of radon surveillance and hydrogeological monitoring. Comparisons with other former mining sites indicate that radionuclide migration, radon emissions and structural instability may remain potential risks after closure. **Conclusion:** A major limitation is the lack of consolidated post-closure environmental monitoring data, which prevents a reliable assessment of the long-term effectiveness of the rehabilitation measures. Long-term monitoring adapted to the geological, hydrogeological and climatic conditions of the Saharan environment is therefore necessary.

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INTRODUCTION

Mining plays an important role in economic development through wealth creation, raw material production and its contribution to national revenue. However, mining and mineral processing activities can cause significant environmental impacts, affecting soil, water resources, air quality and landscapes, while generating large quantities of waste (OECD, 2023). These impacts may persist long after mining activities cease. Mine closure is therefore a complex process involving the securing of structures, dismantling of facilities, environmental rehabilitation, waste management and long-term monitoring (ICMM, 2025). It must also consider the future use of the site (Bălăceanu *et al.*, 2026). These challenges are particularly significant in uranium mining because of the presence of radioactive substances and the potential persistence of contaminants. Among the main environmental concerns are uranium mill tailings, which may retain uranium and other radionuclides from the uranium-238 decay chain. Depending on their physicochemical properties and environmental conditions, these elements may migrate into surface water and groundwater. Radon emissions and ionising radiation may also constitute exposure pathways for workers and nearby communities (Gunsinger *et al.*, 2013). Rehabilitation measures therefore need to ensure the containment of contaminated materials, the stability of structures and appropriate environmental monitoring. Several engineering approaches have been developed to limit contaminant dispersion and reduce exposure risks. For example, multi-layer covers incorporating sand, gravel and bentonite can reduce radon emissions from uranium tailings. Some configurations have achieved reductions exceeding 99 per cent under specific conditions (Auckland *et al.*, 2022). However, the long-term effectiveness of remediation systems depends on local

hydrological and geochemical conditions. Research at Elliot Lake has shown that radium-226 treatment through barite precipitation may become less effective when sulphate concentrations decrease, particularly during periods of heavy rainfall (Wiramanaden *et al.*, 2023). These findings underline the importance of site-specific rehabilitation measures and continued post-closure monitoring. These issues are particularly relevant to the former Compagnie Minière d'Akouta (COMINAK) uranium mine, located near Arlit in the Tim Mersoï sedimentary basin of northern Niger. The region is characterised by extreme aridity, with average annual rainfall of approximately 100 mm and potential evaporation estimated at 3,000–5,000 mm per year (Seigneur *et al.*, 2021). Uranium mining began at the site in 1978, and ore processing involved the use of sulphuric acid. The resulting tailings were deposited in a heap that was initially watered (Seigneur *et al.*, 2021). Studies have identified gypsum crusts locally enriched in uranium and highlighted the role of uranyl sulphates and phosphates in uranium mobility and immobilisation within the tailings (Déjeant *et al.*, 2016; Lahrouch *et al.*, 2022; Seigneur *et al.*, 2021). These processes are important for understanding the long-term environmental behaviour of the tailings.

Radiological exposure and environmental governance also remain important concerns in the Arlit region. An independent study reported an average estimated dose rate of 0.32 mSv/year at certain public sites and quarries, exceeding the reference threshold used in that study (Sidibé *et al.*, 2024). In addition, research in Niger has highlighted shortcomings in the consideration of local communities' environmental concerns and in institutional accountability for mining activities (Larsen &Mamosso, 2014). Experiences from other countries, including the rehabilitation of former uranium mining areas in Kyrgyzstan and the use of Technosols to support vegetation recovery, demonstrate the importance of adapted rehabilitation strategies (Arán *et al.*, 2022; Djenbaev *et al.*, 2025). In Saharan environments, however, water scarcity, limited vegetation regeneration and wind erosion make rehabilitation particularly challenging. Long-term environmental monitoring is consequently essential (Mussayeva *et al.*, 2026).

In this context, the closure and rehabilitation of COMINAK raise important questions concerning the safety of mining structures, waste and material management, radiological risks and the protection of environmental resources. Although previous studies have examined uranium geochemistry and environmental risks in the Arlit region, an integrated analysis of the closure operations and environmental protection measures implemented at the former COMINAK site remains necessary.
The overall objective of this study is to analyse the environmental issues associated with the closure and rehabilitation of the former COMINAK mining site in Arlit, Niger. Specifically, it aims to: (i) describe the main closure operations involving mining structures and industrial facilities; (ii) examine the management of waste, materials and potentially contaminated areas; (iii) analyse the environmental protection and post-closure monitoring measures; and (iv) identify the main challenges associated with rehabilitating a former uranium mining site in the Saharan environment.

MATERIALS AND METHODS

Overview and environmental context of the site: The former Compagnie Minière d'Akouta (COMINAK) uranium mining site is located near Arlit, in the Agadez region of northern Niger (Figure 1). It lies within the Tim Mersoï Basin, in a Saharan environment characterised by high temperatures, low rainfall and strong evaporation. These conditions are relevant to the assessment of closure works, backfill stability and environmental monitoring (COMINAK, 2020).

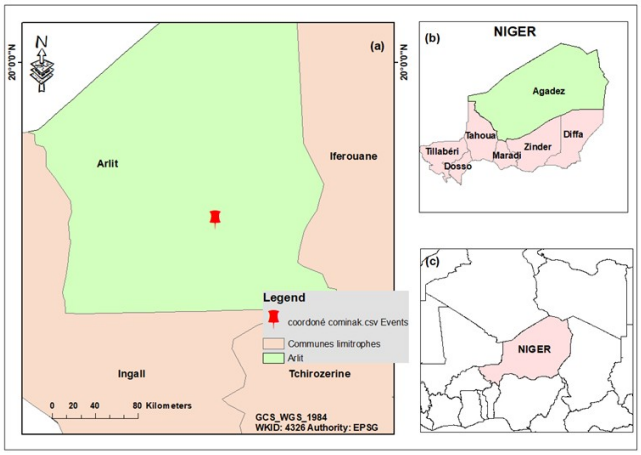


Figure 1. Geographical location of the COMINAK mining site in Arlit, Niger: (a) local study area, (b) location within Niger, and (c) location within West Africa.

The area receives approximately 50 mm of rainfall annually, while potential evaporation is estimated at 8 mm per day. Daytime temperatures may reach 50 °C, and the average altitude of the plain is approximately 410 m. There are no permanent watercourses, although temporary drainage channels, locally known as koris, occur during the rainy season. The main environmental characteristics are summarised in Table 1.

Table 1. Environmental characteristics of the COMINAK site

Parameters	Data
Location	Arlit region, northern Niger
Climaticcontext	Extremely ariddesertenvironment
Averageannualrainfall	Approximately 50 mm over the last 20 years
Potentialevaporation	Approximately 8 mm/day
Average annual night-time temperature	Approximately 29 °C
Daytimetemperature	May reacharound 50 °C
Average altitude of the plain	Approximately 410 m
Geologicalcontext	Tim Mersoï Basin
Permanent watercourses	None in the region
Temporarywatercourses	Koris during the rainy season

Table 2. Main aquifers identified in the COMINAK area

Aquifer	Characteristics	Environmentalsignificance
Guezouman	Mineralised zone of the COMINAK deposits	Relevant to understanding mine drainage water
Tarat	Mineralised zone mined by SOMAÏR at Arlit	Major aquifer supplying Arlit, Akokan and industrial areas
Izegouande	Basal sandstone unit of the Izegouandane Formation	May be affected by works providing access to underground mining operations
Teloua 1	Basal sandstone unit of the Teloua Series	Identified within the regional hydrogeological context

The hydrogeological context is also important because several aquifer formations occur in the study area. These include the Guezouman, Tarat, Izegouande and Teloua 1 aquifers. The Tarat aquifer is particularly important because it supplies water

to Arlit, Akokan and some industrial facilities. Their main characteristics and environmental significance are presented in Table 2 (COMINAK, 2020).

Data sources: This study is based on documentary information concerning the closure and rehabilitation of the former COMINAK mining site. The data were obtained mainly from technical design documents, operational procedures and work-monitoring records. The principal sources included the site redevelopment project (COMINAK, 2020), the radiological monitoring plan for Arlit and Akokan (COMINAK, 2015), the procedure for monitoring and refilling blocked ventilation shafts (COMINAK, 2023), and technical documents concerning the closure of mine shafts and the treatment of structures GT 255 and GT 303 (Ousmane, 2024a; Ousmane, 2024). Information on asbestos removal from the workshops was also considered (Christian, 2021).

These documents provided information on:

- Closure of underground mining structures, adits and ventilation shafts;
- Backfilling of pits and boreholes;
- Dismantling and rehabilitation of industrial facilities;
- Management of waste and materials generated during dismantling;
- Radiological monitoring and environmental surveillance.

The information was compiled to describe the rehabilitation operations, identify the closure techniques used, quantify material volumes where data were available and compare interventions according to the types of structures concerned.

Data analysismethod: A descriptive and thematic analysis was conducted to examine the closure operations and their environmental implications. The information was organised into four categories: environmental and hydrogeological conditions; closure of underground structures; dismantling and industrial waste management; and environmental risks and monitoring measures. Quantitative data, including structural dimensions, depths and backfill volumes, were extracted from the technical documents and organised in tables. Qualitative information was classified according to the main risks identified, particularly hydrogeological, radiological and geotechnical risks, together with the corresponding prevention and monitoring measures. This approach enabled the comparison of closure techniques with the characteristics of the structures and the associated environmental management measures. However, the study relies exclusively on documentary sources and does not include an independent sampling and analysis campaign of soil, groundwater or materials. Consequently, the findings describe the operations and risks documented in the available sources; they do not constitute an independent assessment of the site's environmental condition after rehabilitation.

RESULTS

Closure and rehabilitation of underground mining operations: The closure of underground mining operations at the COMINAK site involved the sealing and backfilling of adits, access shafts, ventilation structures and associated openings. The techniques used included cement-stabilised backfill, reinforced concrete structures and argillite from the TEJIA formation.

Closure and backfilling of adits: The two main adits were secured through the installation of cement-stabilised plugs, reinforced concrete walls and backfilling of the remaining sections. The closure design took into account the local hydrogeological configuration, particularly the presence of the Izégouande, Tarat and Guézouman formations. The position of the sealing structures was therefore considered in relation to these geological and hydrogeological conditions (COMINAK, 2020). The technical specifications indicate the use of cement-stabilised plugs and reinforced concrete walls, together with TEJIA argillite for backfilling the remaining sections of the adits and associated underground structures. The principal quantities and characteristics are presented in Table 3 (COMINAK, 2020; Ousmane, 2024a).

Table 3. Main works for sealing and backfilling the adits

Work carried out	Technicalspecifications	Reportedquantities
Cement-stabilised plugs	Length: 25 m in each of the two shafts	1,020 m³
Reinforcedconcretewalls	Thickness: 5 m in each of the two shafts	204 m³
Backfilling of remaining sections of adits and associated structures	TEJIA formation argillite	46,699 m³
Support walls in galleries	Concrete, 40 cm thick	Quantity not specified
Plug locations	Sections R10, R6 and R0	R10: 200 m; R6: 120 m; R0: entrance

Backfilling of the access pit: The access pit to the underground workings was backfilled in successive layers. The first consisted of TEJIA claystone, followed by mixed-size aggregates sourced mainly from the TAMAMAMAIT and MORADI areas. A final layer of TEJIA argillite was placed to form a slightly domed surface. The distribution and quantities of the materials used are summarised in Table 4 (COMINAK, 2020; Ousmane, 2024a).

Table 4. Materials used for backfilling the access pit

Materials used	Role in backfilling	Reported volume
TEJIA claystone (first layer)	First layer, up to elevation 413	Approximately 4,500 m³
Mixed-size aggregates (TAMAMAMAIT, MORADI, etc.)	Intermediate layer, up to elevation 420	Approximately 25,000 m³
TEJIA claystone (final layer)	Surface finishing, forming a slight dome	Approximately 1,500 m³
Total	All materialsinstalled	Approximately 31,000 m³

Closure of vertical structures: The closure programme also covered concrete holes (TAB) and large ventilation holes (GT). According to the available technical records, 54 concrete holes had been identified, most of which had been filled, while seven remained to be treated. The specified closure material consisted of standard backfill containing 3% cement by weight. Large ventilation holes were treated using a combination of large blocks, cement-stabilised backfill and TEJIA argillite. The technical documentation also reports the backfilling of 305 GT and provides for regular monitoring of settlement and material compressibility. The main specifications are presented in Table 5 (COMINAK, 2023;

Ousmane, 2024). Specific technical interventions were also documented for structures GT 255 and GT 303. These involved adjustments to the dimensions of the blocks used and the rate at which they were placed (Ousmane, 2024).

Table 5. Characteristics and closure measures for vertical structures

Structures	Specifications	Closuremeasuresreported
Concreteholes (TAB)	Diameter: 0.45 m; average depth of remaining holes: 241 m	Standard backfill containing 3% cement by weight
Concreteholesr ecorded	54 in total; 7 remained to be filled according to available data	Most of the structures had been filled
Large ventilation holes (GT)	Diameter: 2.40 m; average depth: approximately 250 m	60 m³ of large blocks at the base, a 20 m cement-stabilised backfill plug, followed by TEJIA argillite
Backfilled ventilation holes	305 GT	Monitoring of settlement and backfill compressibility

Dismantling of industrial facilities and waste management: The redevelopment of the site included the dismantling of ore-processing units, chemical installations, buildings and associated industrial equipment. Operations in the industrial area involved demolition, removal of equipment and utilities, and clearance of the affected areas. Materials generated during dismantling were sorted according to their type. Metallic materials were collected in a dedicated storage area within the tailings pond, while concrete rubble was broken into pieces of controlled size. Large-diameter cables were stored separately. Particular attention was given to asbestos-containing materials, especially Panocell panels identified beneath certain roofs. These materials were removed, double-wrapped and placed in a designated storage area pending appropriate disposal (COMINAK, 2020; Christian, 2021).

Radiological surveying and management of potentially contaminated areas: Radiological surveys formed part of the redevelopment operations and focused on identifying areas potentially affected by contamination from previous mining and processing activities. The areas concerned included ore storage zones, reagent storage and handling areas, hydrocarbon storage facilities and other former industrial locations. Excavations and test pits were also planned or carried out in selected areas to investigate possible chemical or hydrocarbon contamination. These activities were included in the site's radiological survey and environmental management arrangements (COMINAK, 2015; COMINAK, 2020).

Post-closureenvironmental monitoring arrangements: The monitoring provisions documented for the post-closure period cover the stability of backfilled structures, radiological conditions and hydrogeological changes. For large backfilled ventilation shafts, regular inspections are planned to assess settlement and the compressibility of the filling materials. A specific procedure also provides for monitoring sealed ventilation shafts and refilling them where necessary (COMINAK, 2023). Radiological monitoring includes surface radon measurements at selected former mine openings and areas affected by underground structures. Hydrogeological monitoring takes account of the gradual rise in groundwater levels within former mine workings following the cessation of pumping. The technical documentation also refers to a five-year probationary monitoring period after the end of mining operations. However, the available sources do not provide consolidated post-closure monitoring results that would allow quantitative assessment of changes in groundwater quality, soil quality or radioactivity levels following rehabilitation.

DISCUSSION

Stability of underground structures and residual environmental risks. The closure of underground structures at COMINAK relies on cement-stabilised backfill, reinforced concrete and filling materials intended to ensure long-term stability. These techniques are consistent with approaches commonly used in underground mine rehabilitation. Cemented paste backfill is recognised for its ability to stabilise underground voids, limit ground movement and contribute to the management of mining residues (Sheshpari, 2015; Trumić *et al.*, 2026). Its mechanical strength and relatively low permeability may also be advantageous under complex underground conditions (Liu & Sui, 2023). Nevertheless, the long-term performance of backfill materials depends not only on their initial strength but also on their behaviour under mechanical stress and progressive deformation. Liu and Sui (2023) demonstrated the mechanical stability of cement-stabilised backfill through a three-year monitoring programme, while Raffaldi *et al.* (2019) showed that substantial deformation can modify its mechanical behaviour. Similarly, Wu *et al.* (2026) highlighted the influence of interactions between rock masses and backfill materials on the long-term stability of underground structures. These findings support the monitoring provisions documented at COMINAK, particularly the assessment of settlement and compressibility in backfilled ventilation structures. Such monitoring is essential to determine whether the closure structures maintain their stability over time.

Beyond structural stability, the effectiveness of mine closure also depends on controlling residual radiological and hydrogeological risks. The case of the rehabilitated Beshtaugorskiy site illustrates how inadequately sealed mine openings may remain sources of radon emissions. Miklyaev *et al.* (2024) reported high concentrations of radon decay products and elevated gamma dose rates in affected areas. This demonstrates that the installation of closure structures does not necessarily eliminate radiological exposure pathways. At COMINAK, the planned monitoring of radon around selected former mine openings is therefore relevant. However, without consolidated measurement results, the actual effectiveness of these measures cannot be established. A similar concern applies to groundwater protection. Following the cessation of mine pumping, rising water levels may modify hydrogeological conditions and facilitate the mobilisation of radionuclides. Subbotin *et al.* (2025) reported increased uranium concentrations in drinking water near the former Grachevskoye mining site in Kazakhstan. Furthermore, Ibrayeva *et al.* (2026) identified an annual ingestion dose associated with radium isotopes exceeding the reference level used in their study. These findings underline the need for continued monitoring of groundwater quality, particularly uranium and radium concentrations, after mine closure.

Industrial decommissioning, hazardous waste management and health protection: The dismantling of COMINAK's

industrial facilities represents an important component of environmental rehabilitation because it involves not only the removal of obsolete infrastructure but also the management of potentially hazardous materials. The sorting and separate storage of dismantling waste, particularly metallic materials, concrete rubble and asbestos-containing components, are consistent with the need to prevent uncontrolled environmental dispersion. The management of asbestos-containing Panocell panels deserves particular attention because damaged or improperly handled asbestos materials may release fibres that pose risks to human health (Marian *et al.*, 2021). Their removal, double packaging and separate storage at COMINAK reflect a containment approach intended to limit exposure during dismantling. However, temporary storage does not necessarily resolve the long-term disposal issue. Marian *et al.* (2021) discuss thermal inertisation as a possible treatment for irreversibly transforming asbestos fibres, although its application depends on technical, economic and regulatory conditions. The importance of appropriate decommissioning also extends to surrounding communities. Deiana and Giua (2023) reported reductions in mortality following the closure of certain mining waste storage facilities, suggesting potential public health benefits from effective environmental management. Conversely, abandoned mining sites without adequate safety measures may continue to expose nearby populations to environmental hazards (Jadhav *et al.*, 2025). The case examined by Panov (2023) further illustrates that physical rehabilitation alone does not necessarily eliminate long-term radiological risks. Industrial dismantling, hazardous waste containment and environmental monitoring should therefore be considered complementary elements of mine closure.

Long-term monitoring and limitations in assessing rehabilitation performance: The findings of this study show that the COMINAK closure programme incorporates several measures addressing the main environmental risks associated with former uranium mining operations. These include the monitoring of backfill settlement, radon surveillance, hydrogeological monitoring and the differentiated management of industrial waste. Such measures are consistent with concerns identified in studies of other former mining sites, where structural instability, radionuclide migration and residual contamination may persist after closure (Miklyaev *et al.*, 2024; Subbotin *et al.*, 2025; Mussayeva *et al.*, 2026). However, the existence of monitoring provisions does not in itself demonstrate the environmental effectiveness of rehabilitation. In the present study, the available technical documentation does not provide a consolidated series of post-closure results that would allow changes in groundwater quality, radiological conditions or structural stability to be assessed quantitatively. This constitutes an important limitation when evaluating the long-term performance of the measures implemented at COMINAK. The five-year probationary monitoring period mentioned in the technical documentation should also be distinguished from the longer period that may be required to assess environmental risks at former uranium mining sites. As highlighted by Mussayeva *et al.* (2026), certain contamination processes may persist for several decades. Consequently, post-closure monitoring should be adapted to the evolution of environmental conditions rather than restricted to an administrative timeframe. In the Saharan environment, where extreme aridity and specific geochemical conditions may influence contaminant behaviour and the durability of rehabilitation structures, sustained monitoring is particularly important. The long-term success of COMINAK's rehabilitation will therefore depend not only on the technical quality of the closure works but also on the availability of reliable monitoring data and the continuity of environmental surveillance.

CONCLUSION

This study examined the main environmental issues associated with the closure and rehabilitation of the former COMINAK uranium mining site in Arlit, Niger. The analysis highlighted the technical measures implemented to secure underground workings, backfill adits and vertical shafts, dismantle industrial facilities and manage the resulting waste, including asbestos-containing materials. These operations contribute to reducing structural, environmental and health risks following the cessation of mining activities. However, physical closure and rehabilitation works alone cannot guarantee the long-term environmental safety of the site. The presence of uranium-bearing tailings, the potential migration of radionuclides, possible radon emissions and changes in groundwater levels following the cessation of pumping remain important concerns. These risks require particular attention in the Saharan environment, where low rainfall and high evaporation rates may influence contaminant behaviour and geochemical processes.

Comparison with other uranium mining sites confirms that radiological, hydrogeological and geotechnical risks can persist for several decades after mine closure. Consequently, the effectiveness of rehabilitation must be assessed not only through the completion of closure works but also through reliable and continuous environmental monitoring. A major limitation of this study is the absence of consolidated post-closure monitoring results that would allow an independent assessment of groundwater quality, radiological conditions and the long-term stability of rehabilitated structures. The findings therefore describe the documented closure operations and environmental protection measures without demonstrating the complete elimination of residual contamination. Long-term monitoring should consequently be strengthened, particularly through regular analysis of radionuclides in groundwater, radon measurements, monitoring of settlement in backfilled structures and verification of the integrity of closure systems. Systematic recording and evaluation of these results are essential for adapting management measures and ensuring the sustainable protection of natural resources and local populations. Ultimately, the closure of COMINAK should be considered a long-term environmental process rather than simply the physical securing of former mining facilities. Its success will depend on the durability of the rehabilitation measures, the continuity of environmental monitoring and the effective management of residual risks in the challenging Saharan environment.

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