Mine Closure 2026 – AB Fourie, G Boggs, J Heyes & M Tibbett (eds)

doi:10.36487/ACG_repo/2615_145

Inventory of copper–cobalt mining waste in the Democratic Republic of the Congo: a baseline for environmental monitoring

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Abstract

The Democratic Republic of the Congo (DRC) is central to global copper and cobalt supply, yet the regional footprint of mining waste remains poorly documented despite its importance for environmental risk, mine closure and post-closure management. Here we combine documentary review, remote sensing and targeted field verification to establish the first harmonised regional inventory of tailings storage facilities (TSFs) and waste rock dumps (WRDs) in the Congolese Copperbelt. We identify 453 facilities, comprising 107 TSFs and 346 WRDs, and show that they are strongly concentrated within the main mining–urban corridor and commonly occur close to water bodies and settlements. A disproportionate share of the mapped waste footprint falls within the high-hazard class, while facilities of all hazard levels remain embedded in inhabited and hydrologically connected landscapes. To support practical use of the results, we also develop a dashboard (https://cartowaste.geoprojet-rdc.de) for facility visualisation and screening. Together, these outputs frame mining waste in the region as a cumulative exposure pattern and long-term liability, rather than only a site-level issue. The inventory and dashboard provide a baseline for environmental risk screening, closure planning and regulatory prioritisation. More sustainable mining waste management and eventual mine closure in the DRC will require moving beyond fragmented inventories and site-by-site oversight towards a regional, risk-based and life cycle approach.

Keywords: *tailings storage facilities, waste rock dumps, copper mining, artisanal and small-scale mining, remote sensing*

1 Introduction

The Democratic Republic of the Congo (DRC) is central to global copper and cobalt supply. In 2024 the DRC produced about 76% (213,000 tonnes) of global mined cobalt (Cobalt Institute 2025) and about 11% (3.3 million tonnes) of global mined copper (US Geological Survey 2025). This production is concentrated in the Congolese Copperbelt situated in the southeastern DRC. In this region, current and historical copper–cobalt extraction and processing have generated extensive mining waste facilities, including waste rock dumps (WRDs) and tailings storage facilities (TSFs).

For mine closure and post-closure management, these facilities are critical because they remain part of the environmental footprint long after active extraction or processing has ceased. International guidance treats

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TSFs and WRDs as long-lived sources of environmental and safety risk because physical instability, erosion, seepage, dust generation, acid drainage and metal leaching may continue through closure and into the post-closure phase (Global Tailings Review 2020; International Finance Corporation [IFC] 2007; World Bank 2021). In the Congolese Copperbelt, these processes occur within densely occupied mining–urban corridors and intensively used agricultural and riparian environments. Physical instability and the release or transfer of waste material therefore translate directly into water, soil and wetland contamination, with implications for ecosystem integrity and public health (Kaniki & Tumba 2019; Muimba-Kankolongo et al. 2021).

Recent incidents in central and southern Africa have demonstrated the practical consequences of inadequate control over mining waste. In August 2021 the Catoca mine tailings spill in Angola released contaminated water and tailings into the Tshikapa–Kasai River system, with extensive downstream water-quality impacts documented along the river network into the DRC (Ruppen et al. 2023). In February 2025 failure of the Sino-Metals Leach TSF near Chambishi in Zambia released approximately 50 million litres of acidic effluent into the Mwambashi–Kafue River system, with severe downstream effects on water supply, agriculture, aquatic ecosystems and community livelihoods (Kille & Zimba 2025). In November 2025 the failure of the Congo Dongfang Mining TSF in Lubumbashi released large volumes of acidic effluent that affected residential areas and the Lubumbashi River corridor, with reported impacts on aquatic biodiversity and local communities (ACP 2025).

The management options available for TSFs and WRDs depend on the mining method, facility type and site-specific conditions. In underground mines, backfilling can reduce the quantity of tailings requiring surface storage by returning dewatered tailings underground. This practice is already established at major underground mines in the Copperbelt. For example, about 55% of Kakula copper mine tailings (situated on the larger Kamoa-Kakula concession) are returned underground as paste backfill and approximately 50% of zinc ore tailings generated by the Kipushi concentrator are mixed with cement and pumped underground as backfill (Ivanhoe Mines 2019, 2025). However, backfilling remains specific to underground mines and cannot materially reduce the extensive number of TSFs and WRDs already present across the region. Another management option is the re-mining of legacy waste, especially under present metallurgical and market conditions. A clear regional example is Eurasian Resources Group's (ERG) Metalkol operation near Kolwezi, which reprocesses historical copper–cobalt tailings. Approximately 100 million tonnes of tailings are expected to be reclaimed over a 14-year project life, with average grades of about 1.49% copper and 0.32% cobalt (ERG 2019). Reprocessing therefore has clear relevance for resource recovery and footprint reduction, but it also produces new residue streams that require engineered storage and closure planning.

Overall, environmental risk management, the assessment of re-mining potential, and closure and post-closure planning all depend on the same fundamental requirement: reliable georeferenced information on the location, extent and condition of TSFs and WRDs. The absence of a harmonised regional baseline for these facilities represents a major obstacle to achieving these objectives. Existing studies have documented contamination, exposure and metal recovery potential at specific sites, but they do not provide a consistent regional inventory that can support regulatory prioritisation and closure-related decision-making. As a result, the institutions responsible for environmental supervision and mining oversight in the DRC, including the Direction de Protection de l'Environnement Minier (DPEM), the Agence Congolaise de l'Environnement (ACE) and the Service d'Assistance et d'Encadrement de l'Exploitation Minière Artisanale et à Petite Échelle (SAEMAPE), continue to operate in a context of fragmented inventories and uneven documentation.

In response, the above DRC mining authorities and the Federal Institute for Geosciences and Natural Resources (BGR), working together in the German-Congolese development cooperation framework, undertook the present study to establish a regional inventory of TSFs and WRDs and examine their environmental risk implications. The objective is to provide a harmonised dataset for the Copperbelt to support environmental risk screening, guide the allocation of inspection and monitoring efforts, and help prioritise sites for rehabilitation measures or more detailed technical assessment.

2 Material and methods

2.1 Study area and regional mining context

This study was conducted in the Congolese Copperbelt, the principal copper–cobalt mining region of the DRC (Figure 1). The region is part of the provinces of Haut-Katanga and Lualaba and forms the northern segment of the Central African Copperbelt. The study area generally lies above approximately 1,200 m and is characterised by humid subtropical climates with dry winters and hot summers, as well as tropical savanna climates with dry winters, according to the Köppen–Geiger classification. Rainfall is strongly seasonal and concentrated between October and April, with a frequent peak in December to January. Mean annual temperatures in the area, including the urban basins of Lubumbashi and Kolwezi, are around 20–22 °C.

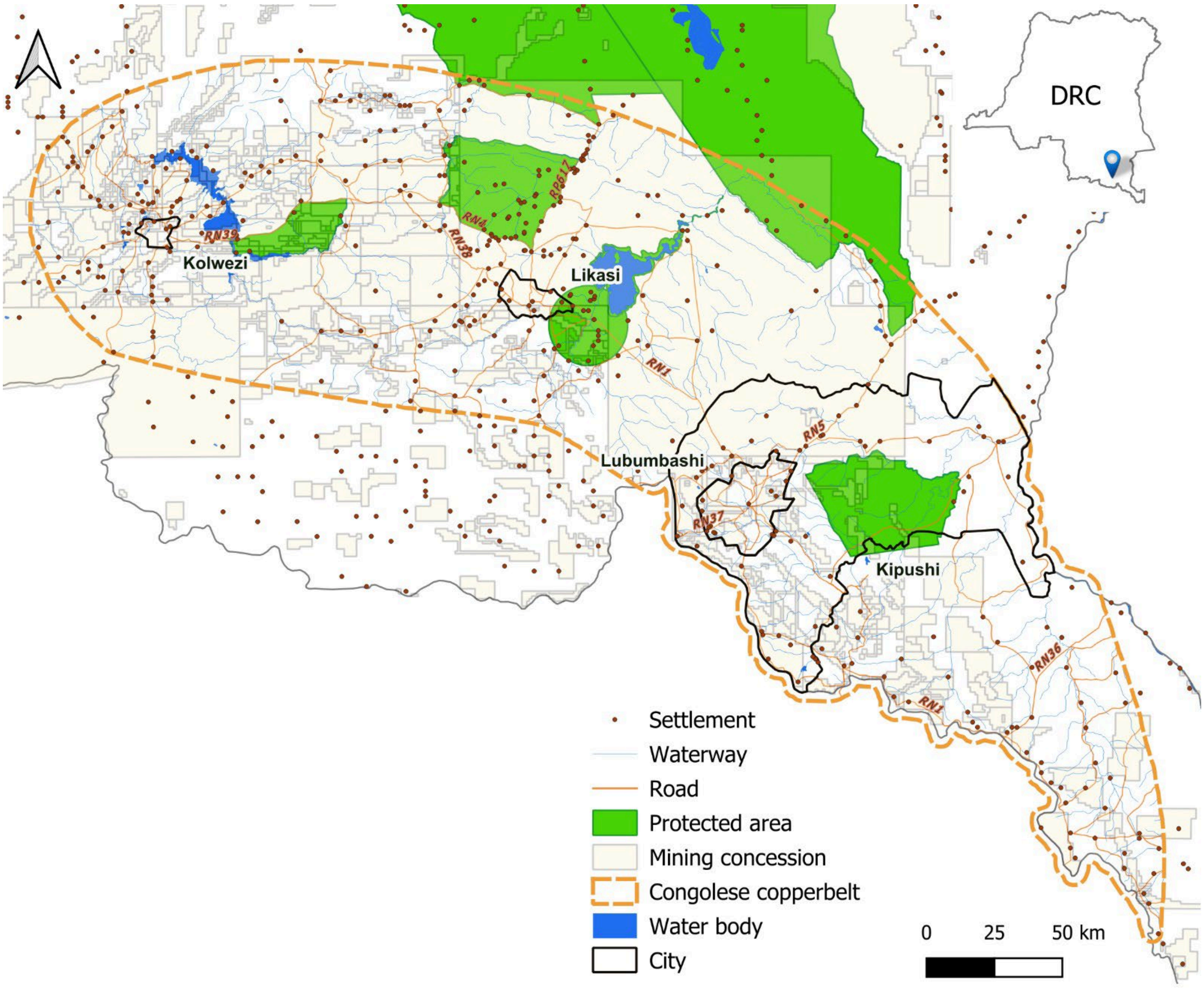

Figure 1 Map of the Congolese Copperbelt showing the extent of mining concessions in relation to protected areas (including parks, reserves and hunting domains), settlements, urban centres, roads, waterways and water bodies

The geology is dominated by Neoproterozoic sedimentary formations, notably carbonate-rich units, shales and sandstones, which host the stratiform copper–cobalt mineralisation (Cailteux et al. 2005). Dominant soil types are Plinthosols, Ferralsols, Acrisols and Alisols. Geochemical background values of copper and cobalt vary by lithostratigraphic unit and soil horizon. The highest non-anthropogenic background values measured in the study area are 134 ppm and 41 ppm for copper and cobalt, respectively (Kidinda et al. 2025). Natural vegetation is dominated by wooded savanna and woodland (Miombo), with riparian and wetland vegetation concentrated along drainage corridors and valley bottoms (Malaisse et al. 2016). Hydrologically, the study area includes both major regional rivers and smaller tributary systems of strong local importance. The Lualaba is a headstream of the Congo River, while the Lufira is one of its tributaries, joining it through Lake Kisale. The Kafubu and the Lubumbashi River networks are smaller catchment systems, but they are important for domestic water use, agriculture and other local needs. In the upper Lufira Basin, rivers and Lake Tshangalele also support fishing and fish consumption by local populations. These connected river systems receive run-off and mining-related inputs from densely mined landscapes, and previous studies have documented metal contamination in water, crops and aquatic environments in parts of the Congolese Copperbelt (Muimba-Kankolongo et al. 2021; Muhaya et al. 2017).

Industrial mining in the Congolese Copperbelt operates at a very large scale. In 2024, 52 mines and processing operations each produced more than 10,000 tonnes of copper (Whitlock et al. 2026). However, in 2025 only 5 operations accounted for about 1.59 million tonnes, nearly 47% of total copper exports. Alongside industrial operations, artisanal and small-scale mining (ASM) of copper and cobalt also remains substantial in both production and livelihoods. In 2025 about 112,000 artisanal miners worked in 75 ASM sites; this is a minimum estimate as there were at least 15 additional ASM sites for which data are not available. Having previously mined cobalt, most artisanal miners recently switched to selling copper in 2025 due to regulatory and market developments. Collectively, annual ASM production amounted to around 7 million tonnes of ore, with an estimated copper content of 200,000 to > 300,000 tonnes. This indicates a major cumulative environmental footprint, especially as some ASM operations are undergoing semi-industrialisation and generating significant mining waste (Ombeni et al. 2026). In the Congolese Copperbelt, exploration and mining concessions form an extensive, near-continuous corridor that overlaps protected areas and lies in close proximity to dense settlement clusters, major urban centres, and numerous water bodies and waterways (Figure 1).

2.2 Methodology

2.2.1 General approach and scope

This study integrated 3 methodological components: document review, remote sensing and targeted field verification. The scope was to establish a regional georeferenced baseline of TSFs and WRDs rather than to undertake detailed site-level technical assessments. It did not include geochemical or geotechnical analyses; nor was it designed as a full environmental risk assessment. The study did not aim to establish or compare methods for the automated detection of mining waste. Instead, it focused on the identification and spatial characterisation of mining waste sites using multiple data sources. Data presented in this paper reflect the situation documented up to December 2025.

2.2.2 Documentation-based inventory

Documentation-based inventory was conducted using records and archives from DPEM, ACE, SAEMAPE and Cadastre Minier (CAMI), as well as available company reports. These sources were used to compile information onsite location, site name, facility type, operational status and other available characteristics of each waste facility. A total of 198 waste facilities were identified: 65 TSFs and 133 WRDs.

2.2.3 Remote sensing-based inventory

Remote sensing methods were applied to maximise the number of inventoried waste facilities. The input data consisted of Sentinel-2 Level-2A optical imagery (10 m), Sentinel-1 C-band radar imagery with vertically transmitted and vertically received polarisation and vertically transmitted and horizontally received polarisation (10 m), and the Copernicus digital elevation model (30 m). For the main inventory, median images were calculated for the April–October 2025 period in order to reduce cloud contamination and short-term surface variability. Several spectral indices were then derived from Sentinel-2 data, including the normalised difference vegetation index, bare soil index, normalised difference water index, and iron oxide index. Topographic information was extracted from the DEM and all layers were combined through principal component analysis (PCA). The first 3 components were retained as model inputs as, together, they explained 89% of the variance.

The training dataset was built from the documentation-based inventory. Two representative regions of interest, covering about 1,200 km² and 656 km², were selected, and PCA images were manually annotated to delineate TSFs and WRDs and convert them into segmentation masks. Small artisanal residues were excluded from the analysis because their footprint was too small for reliable detection at 10 m spatial resolution. The annotated dataset was then tiled into 256 × 256-pixel patches, yielding 108 training images and 108 corresponding masks, representing 312 annotated entities. These data were divided into training and validation subsets using a 75/25% split.

Facility delineation was performed with a U-Net semantic segmentation model using a ResNet34 encoder. The model was trained to minimise loss and maximise intersection over union (IoU). The best-performing model achieved a validation IoU of about 70%, with class-level accuracies of about 96% for background, 87% for TSFs and 73% for WRDs, while confusion between TSFs and WRDs remained < 0.5%. At 10 m spatial resolution, this performance is appropriate for regional screening because tailings, waste rock, bare ground, roads, construction surfaces and other disturbed land covers can have similar spectral and textural signatures. This model was used to identify mining waste at the scale of the whole Congolese Copperbelt, covering about 52,700 km². After inference, false detections were removed through post-processing. Building upon the remote sensing-based inventory, the operational status for each site was detected using the random forest algorithm in combination with various indices derived from median annual Sentinel-2 data calculated for the years 2019 to 2025. The workflow was implemented in Google Earth Engine, QGIS, and Google Colab.

2.2.4 Field verification

Field verification was carried out at 11 facilities in Haut-Katanga and Lualaba to validate the remote sensing-based inventory. At each site, GPS coordinates, geotagged photographs, facility type, operational status, evidence of erosion or standing water, hydrological setting and proximity to settlements were recorded. Because the field campaign covered only 11 facilities it should be interpreted as targeted qualitative verification rather than a statistically representative accuracy assessment of all facility types, operators, age classes and landscape settings. Following fieldwork, the remote sensing outputs were reconciled with documentation-based inventory and field observations to produce a harmonised regional inventory of 453 facilities. Examples of visited TSFs and WRDs are shown in Figure 2.

Figure 2 Examples of mine waste facilities observed during field visits in the Congolese Copperbelt. (a) A tailings storage facility; (b) A waste rock dump

2.2.5 Facility characterisation and data analysis

Identified TSFs and WRDs were populated with information related to their physical and morphological attributes, environmental setting, geochemical and risk-related attributes, and land-use context. This information was obtained from diverse sources including GIS analysis (e.g. facility footprint, distance to the nearest water body, distance to the nearest settlement, vegetation cover), company reports, field visits and expert knowledge (e.g. facility age, operational status, construction method).

To support environmental risk screening, hazards and exposures were each scored on a 3-level ordinal scale (1–3). Hazard classification was based on slope steepness, facility footprint area, the presence of ponding water, vegetation cover, dust-generation potential and facility life cycle status. Exposure reflected proximity to nearby receptors, including rivers, settlements, croplands, protected areas and population (Winkelmann-Oei et al. 2023; IFC 2007; Global Tailings Review 2020). Hazard and exposure scores were classified into 3 ordinal categories (low, medium and high) using tertiles calculated separately for each facility type. These classes are a screening and prioritisation tool; they are not quantitative estimates of failure probability, contaminant loading, exposure dose or site-specific environmental risk.

To support the practical use of the inventory results, a web-based dashboard was developed as a visualisation and screening tool for TSFs and WRDs (https://cartowaste.geoprojet-rdc.de). Its purpose is to make the harmonised geospatial dataset more accessible for environmental supervision, closure planning and the identification of priority sites by enabling interactive exploration of facility attributes and spatial relationships. The dashboard was built in R software and implemented as an interactive Leaflet/HTML interface, allowing users to visualise mapped facilities, filter them according to key variables, inspect site-specific information and compare selected facilities.

3 Results and discussion

3.1 Spatial distribution and the operational status of mining waste sites in the Congolese Copperbelt

The inventory is almost evenly divided between Haut-Katanga (236 facilities) and Lualaba (217 facilities), giving a total of 453 mapped facilities across the Congolese Copperbelt. Of these, 107 are TSFs and 346 are WRDs (Figure 3a). To our knowledge, this constitutes the largest regional dataset currently available on mining waste in the Congolese Copperbelt. This is particularly significant in a context where corporate disclosures remain limited. As of 2026, the Global Tailings Portal, which relies on company-reported data, identifies only 10 TSFs in the region. For Congolese institutions responsible for the supervision and oversight of mining activities, our dataset provides a much-needed regional overview to support the follow-up of company waste-management practices and closure planning. It also offers a strong baseline for other stakeholders interested in evaluating the re-mining potential of legacy waste, an issue that is receiving growing attention internationally as mine wastes are increasingly viewed as secondary resources (Kursunoglu et al. 2025). However, our inventory should not be considered exhaustive. Some facilities, particularly historical deposits inherited from earlier phases of mining under the state-owned company Gécamines and its colonial predecessor (Union Minière du Haut-Katanga), were probably not captured. In many cases, older tailings were not stored in well-engineered facilities and may today be partially obscured by vegetation cover or converted to other land uses, making their identification more difficult through remote sensing. Facilities are markedly concentrated around the principal mining–urban nodes of Kolwezi, Likasi and the Lubumbashi–Kipushi axis (Figure 3b), which constitute the main centres of extraction and mineral processing.

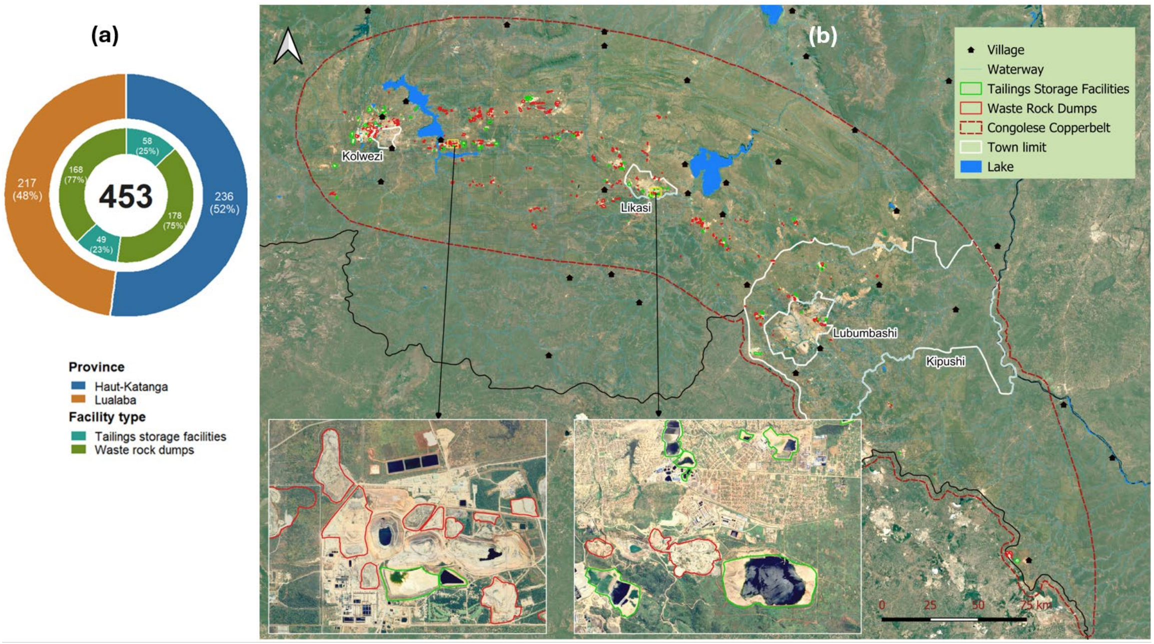

Figure 3 Inventory of tailings storage facilities and waste rock dumps in the Congolese Copperbelt. (a) Summary of the inventory by province and facility type; (b) Spatial distribution of mapped facilities

In these areas, environmental exposure is likely to be both territorial and cumulative because multiple TSFs and WRDs coexist within the same hydrological, ecological and settlement systems. Their environmental significance therefore cannot be understood only at the level of individual facilities. Rather, oversight should address mining waste landscapes and cumulative exposure zones, where several facilities may jointly influence the same rivers, soils, ecosystems and nearby communities (IFC 2007; Global Tailings Review 2020). This spatial concentration also raises an important liability question because the cumulative impacts generated by clusters of facilities may extend beyond the responsibility attached to any single WRD or TSF. Such cumulative and long-term liabilities must therefore be explicitly addressed in the legal and regulatory framework. This is consistent with recent mine-closure literature, which argues that closure decision-making needs to be elevated from the individual site to the regional scale, where cumulative impacts and post-mining liabilities are more fully expressed (Measham et al. 2024), and with the DRC mining regulations which link rehabilitation, closure and post-closure obligations to operator responsibility.

A relatively small number of very large TSFs and WRDs dominate the mapped waste footprint. For TSFs, the total mapped footprint is 9,487 ha, of which only 15 facilities (14%) account for 50%; for WRDs, the total mapped footprint is 13,212 ha, with 40 facilities (12%) accounting for 50% (Figure 4).

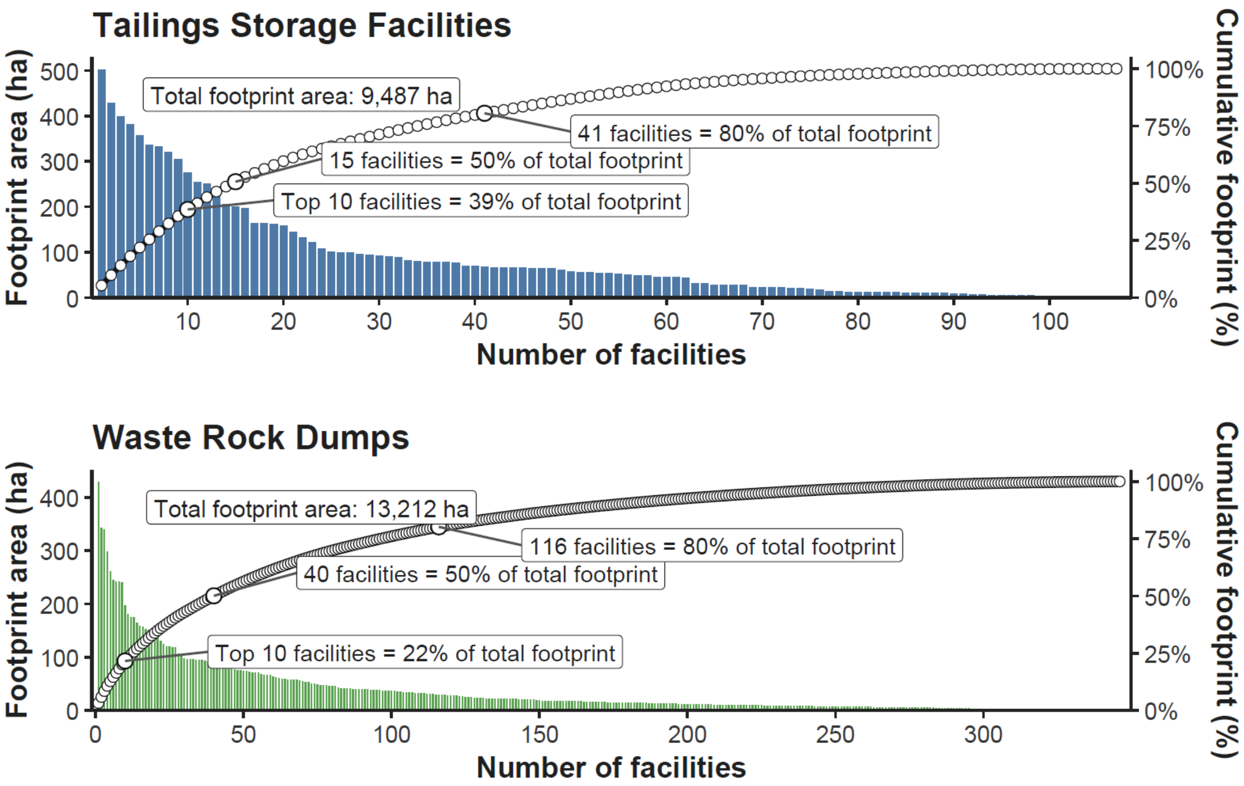

Figure 4 Ranked footprint distribution of tailings storage facilities and waste rock dumps in the Congolese Copperbelt

However, environmental supervision and regulation cannot focus only on these prominent sites because a large footprint does not necessarily correspond to the highest environmental risk (Winkelmann-Oei et al. 2023). Risk is also shaped by other factors, including geotechnical and geochemical characteristics, hydrological connectivity, proximity to settlements and other sensitive receptors, and the likelihood of erosion, seepage, dust generation or instability (IFC 2007; Kaniki & Tumba 2019). In this sense, footprint is an important indicator of the scale of the waste burden but is not, on its own, a sufficient proxy for environmental significance or closure priority.

Most mapped facilities are operational (74%), some are closed (25%) and only a small proportion are abandoned (1%) (Figure 5). The large proportion of active facilities suggests that waste-related liabilities are still being generated. This underlines the importance of closure planning and implementation, which must be progressively integrated into ongoing operations rather than deferred to the end of mine life cycle. However, closed facilities should not be equated with risk resolution, since closed TSFs and WRDs may continue to generate seepage, dust, erosion, run-off or stability concerns. In practice, closed facilities represent a transitional category in which a key dilemma arises as to whether they should proceed to final rehabilitation or remain available for future re-mining of residual metals. While re-mining may reduce long-term legacy volumes and recover additional value from mine waste, the literature also shows that it can prolong the period during which facilities remain environmental liabilities if rehabilitation is delayed or new residues are generated (Bellenfant et al. 2013; IFC 2007; International Council on Mining and Metals 2025).

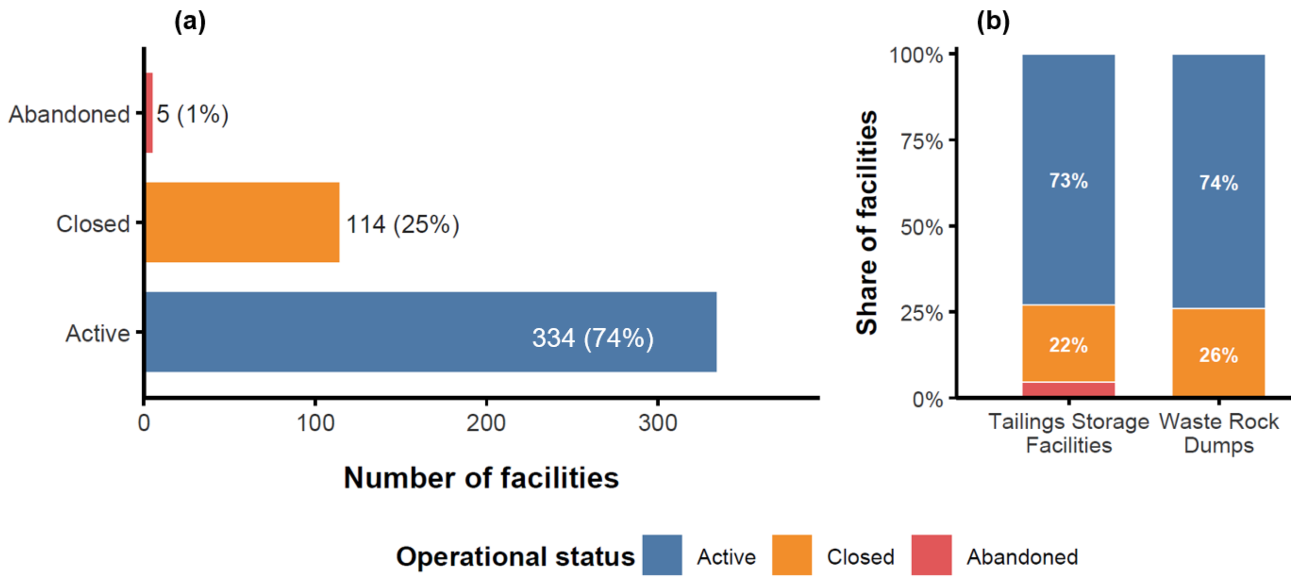

Figure 5 Operational status of the inventoried tailings storage facilities and waste rock dumps in the Congolese Copperbelt: (a) Distribution of facilities by operational status; (b) Comparison by facility type

The very low proportion of abandoned facilities should, however, be interpreted cautiously, as it is likely a minimum estimate rather than a true measure of abandonment. Some historical deposits may no longer appear as clearly engineered structures and it can be difficult to identify where they have been reworked, eroded, vegetated or transformed by subsequent land use. The liability associated with such abandoned waste is particularly concerning in the context of mine closure. Under the DRC mining legislation, operators are required to plan for site rehabilitation and to provide financial assurance for environmental rehabilitation, and these funds may be mobilised by the state if the title holder fails to meet closure obligations. However, where older waste facilities no longer have a clearly identifiable or solvent operator, liability may in practice revert to the public authorities, creating the kind of orphaned or residual closure liability. In the Congolese Copperbelt, abandoned mine waste therefore represents not only an environmental legacy, but also a governance and financing challenge, because long-term remediation and post-closure stewardship may ultimately fall to the state if responsibility cannot be effectively assigned and enforced.

3.2 Proximity of mining waste to sensitive receptors

Mapped TSFs and WRDs are generally not isolated from sensitive receptors. They occur at relatively short distances from water bodies and settlements, making the regional waste footprint embedded within inhabited and hydrologically connected landscapes. For TSFs, the median distance to the nearest water body is 2.8 km, and the median distance to the nearest settlement is 2.0 km. For WRDs, the corresponding median distances are 2.4 km and 1.9 km, respectively. At the lower end of the distribution, 10% of TSFs are located within 0.7 km of a water body and within 0.3 km of a settlement, while 10% of WRDs lie within 0.6 km of a water body and 0.4 km of a settlement. Even at the 75th percentile, most facilities remain within about 4 km of both receptor types (Figures 6 and 7). These proximity statistics do not in themselves demonstrate contamination, but they identify settings in which contaminant transfer and human exposure pathways are more plausible.

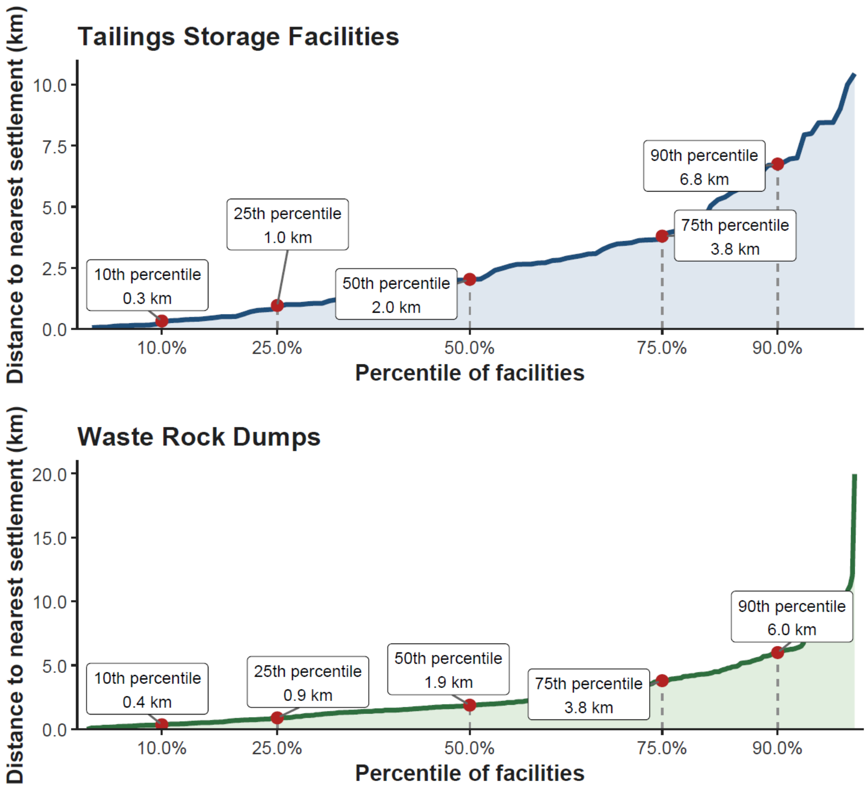

Figure 6 Distance of mapped tailings storage facilities and waste rock dumps to the nearest settlement in the Congolese Copperbelt

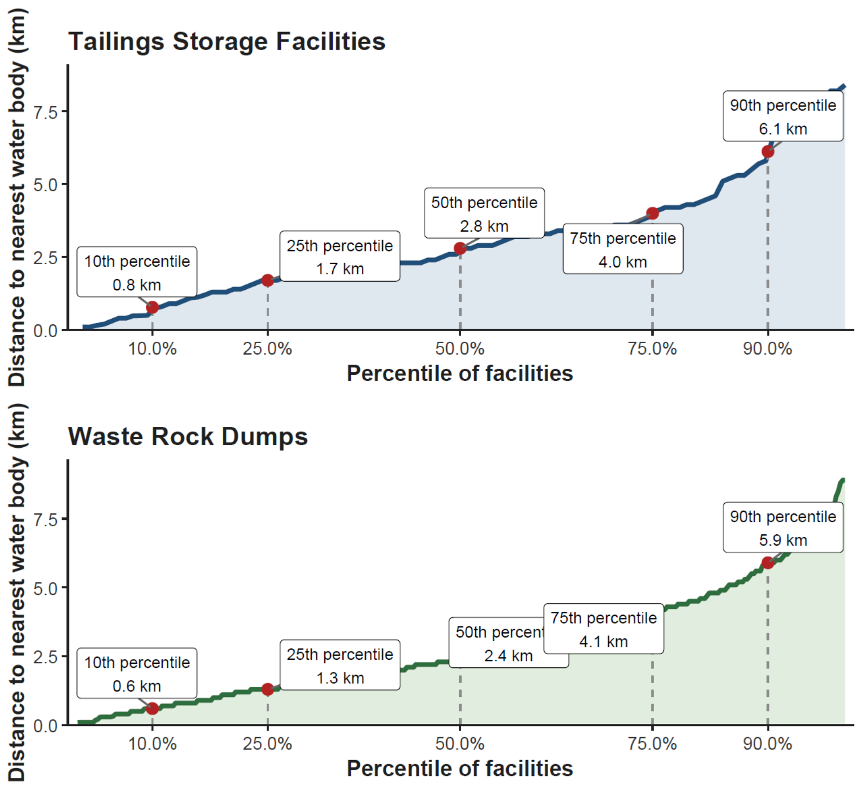

Figure 7 Distance of mapped tailings storage facilities and waste rock dumps to the nearest water body in the Congolese Copperbelt

The proximity pattern is particularly important because the relevant exposure mechanisms differ by receptor but can occur simultaneously within the same mining landscape. Near water bodies, TSFs and WRDs may contribute to contaminant transfer through seepage, run-off, erosion, sediment transport and, in some cases, accidental releases. The Catoca mine tailings spill in Angola is a clear regional example of how mine waste can affect hydrologically connected river systems far beyond the source area (Ruppen et al. 2023). Proximity to settlements raises concerns related to dust dispersion, direct human access, land-use conflict, and chronic exposure through soils, gardens and local water use. This is consistent with evidence showing contamination of water and food crops near mining areas in the Congolese Copperbelt (Kaniki & Tumba 2019; Kasongo et al. 2024; Muimba-Kankolongo et al. 2021).

For TSFs, contamination pathways are closely linked to the fine-grained nature of tailings, the presence of ponding water and the hydraulic behaviour of the impoundment. One important pathway is seepage, whereby contaminated porewater migrates through the base or embankments of the facility and enters surrounding soils, shallow groundwater or adjacent drainage lines. Where tailings contain sulphide minerals, oxidation may promote acidic drainage and increase the mobility of dissolved metals and sulphate, thereby extending contamination beyond the facility footprint. This is particularly relevant in the Congolese Copperbelt, where some operations have progressively reached deeper ore horizons containing mixed oxide–sulphide or sulphide mineralisation, potentially increasing the acid-generating potential of deposited tailings.

A legacy TSF near Kipushi is subject to ongoing erosion, which mobilises tailings material and transports it downslope toward a nearby stream and adjacent cropland (Figure 8). The facility covers approximately 322 ha and consists of dry, unvegetated tailings that are highly susceptible to water and wind erosion. During the dry season, the exposed surface becomes an important source of fugitive dust affecting densely settled areas located about 100 m from the deposit, including some houses constructed directly on the tailings. Informal ASM activities on semi-abandoned waste facilities are common, creating additional exposure risks for artisanal mine workers and reinforcing erosion phenomena.

Figure 8 Eroding legacy tailings deposit near Kipushi in the Congolese Copperbelt

For TSFs with ponding water, additional concerns arise because operational failures, overtopping or embankment instability can release large volumes of contaminated water and tailings over short periods. Even in the absence of catastrophic failure, erosion of embankment slopes and dried beaches can transport fine particles downslope.

For WRDs, the dominant pathways are often more diffuse but no less important. Waste rock is commonly heterogeneous, with variable grain size, mineral composition and permeability, and this allows rainwater to infiltrate deeply into the dump mass. Where potentially acid-generating rock is present, infiltration and oxidation can produce acidic leachate, metals and sulphate, which may emerge as toe seepage or enter shallow groundwater and nearby waterways. Because WRDs are typically elevated landforms with exposed slopes, they are also highly susceptible to surface erosion, gullying and sediment transport (Figure 9). In such cases, contamination may be transferred not only as dissolved constituents but also through the physical downslope movement of contaminated fine material into streams, floodplains, wetlands and agricultural soils.

Figure 9 Eroding waste rock dump observed during field visits in the Congolese Copperbelt. Eroded material is mobilised downslope and deposited in a nearby stream channel flowing through the village

WRDs can also be important sources of fugitive dust, particularly during the dry season, when exposed rock fragments and fine particles are mobilised by wind and deposited in surrounding residential and farming areas. In addition, because many WRDs are more accessible than TSFs and may lie close to settlements, roads or artisanal miners, they can create further exposure pathways through direct human contact, informal reworking, scavenging or the re-use of waste material for local construction or fill. These mechanisms are especially significant in the Congolese Copperbelt, where mining, settlement and small-scale livelihood activities often coexist in the same landscape (Park et al. 2019; Simate & Ndlovu 2014).

3.3 Environmental risk implications of mining waste facilities

Within the screening framework used in this study, facilities in the high-hazard class account for a disproportionate share of the mapped waste footprint. For TSFs, high-hazard facilities represent 6,606 ha, or about 70% of the total mapped TSF area. For WRDs, high-hazard facilities account for 8,374 ha, or about 63% of the total WRD footprint (Figure 10). This indicates that a large share of the regional waste area is concentrated in facilities that combine attributes associated with greater concern under the screening approach, including larger footprint, steeper slopes, limited vegetation cover, dust potential, ponding water or operational status. At the same time, exposure is distributed across all hazard bands, showing that even facilities of lower relative hazard may still be located close to sensitive receptors. Because the screening is based on remotely derived and secondary-source variables, the hazard classes should be interpreted as relative prioritisation categories rather than direct measures of site-specific failure probability or contamination severity.

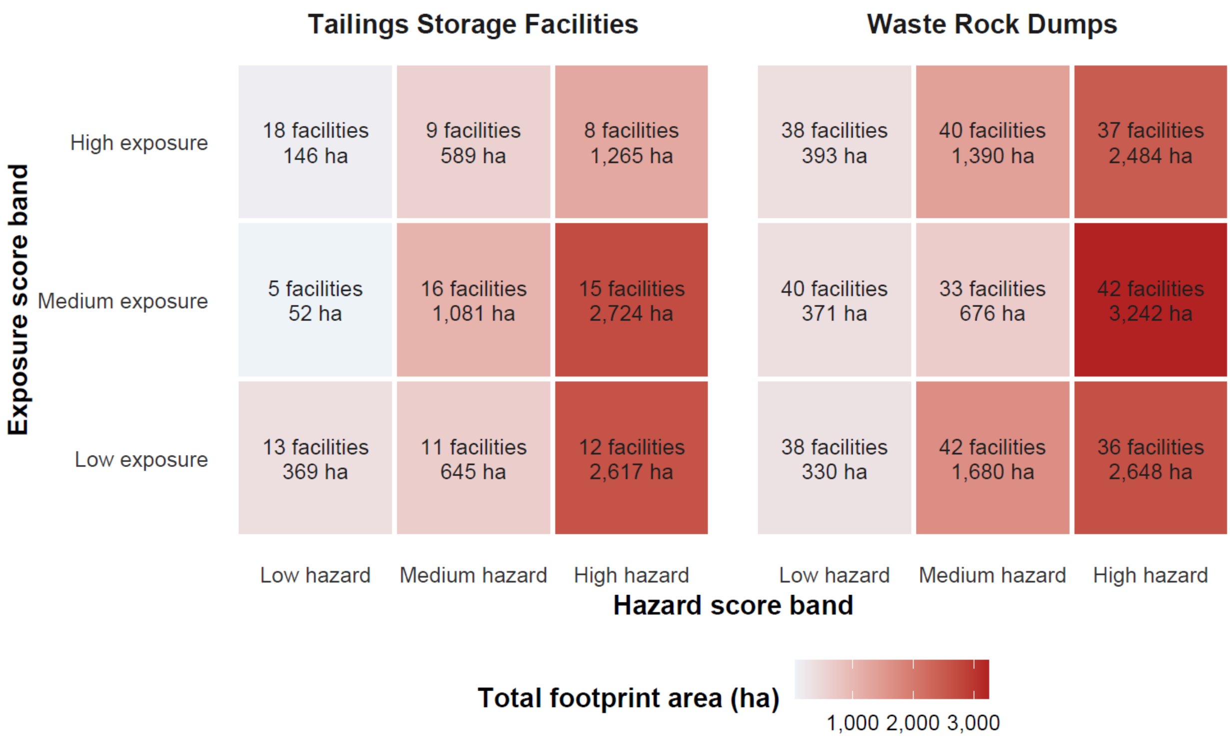

Figure 10 Cross-classification of mapped tailings storage facilities and waste rock dumps by hazard and exposure score bands in the Congolese Copperbelt

Large-footprint facilities matter because of their scale and potential consequences, but the distance analysis shows that smaller facilities may also be environmentally significant where they occur close to waterways, settlements or other sensitive receptors. The screening therefore points toward a two-level approach to prioritisation. First, major TSFs and WRDs with high-hazard scores require attention because of the scale of waste they contain and the magnitude of their possible long-term liabilities. Second, facilities that combine moderate or high hazard with strong receptor proximity deserve priority because they may create disproportionate impacts relative to their size. In practice, this means that environmental oversight should focus on priority waste complexes and exposure hotspots rather than only on the largest or best-known facilities.

3.4 Towards sustainable copper–cobalt mining waste management in the Democratic Republic of the Congo.

The DRC already has several important elements on which a more sustainable mining waste management system can be built. The first strength lies in the existence of a legal and regulatory framework that links mining activity to environmental responsibility, rehabilitation, closure and post-closure obligations. The second strength is the growing availability of geospatial information and screening tools, including the regional inventory and dashboard developed for the DRC mining sector authorities through this study, which can support inspection planning and closure follow-up while also strengthening local multi-stakeholder dialogues involving the private sector (https://cartowaste.geoprojet-rdc.de). Increasing international attention to mine waste governance, integrated closure and responsible mineral supply chains creates additional incentives for operators and regulators to improve practice and transparency (IFC 2007; Global Tailings Review 2020; OECD 2023). This is further reinforced by strategic dialogues among policy makers on this topic, for example through recent events organized by the Intergovernmental Forum on Mining (IGF). In addition, some legacy facilities may represent an opportunity for controlled re-mining, allowing partial reduction of historical waste volumes while recovering residual copper and cobalt, provided that such retreatment is accompanied by proper environmental controls and renewed closure planning (Bellenfant et al. 2013; Kursunoglu et al. 2025).

At the same time there are major weaknesses and threats in the DRC's current mining waste management system. First, waste governance remains constrained by incomplete inventories, uneven documentation and limited corporate disclosures, which means that some facilities, especially historical and legacy deposits, may remain outside effective supervision. Second, environmental oversight is still often oriented toward individual facilities, whereas the present results suggest that many of the relevant impacts are territorial and cumulative, affecting shared hydrological, ecological and settlement systems. Third, closure is not yet fully operationalised as a life cycle process. Most facilities are still active, sometimes for decades, a substantial number are closed but not necessarily environmentally stabilised, and some legacy or abandoned sites may have no clearly identifiable responsible operator. These weaknesses create threats for the DRC's population, ecosystems, state authorities and business operators. They increase the risk that long-term liabilities accumulate faster than they are rehabilitated, that chronic pollution pathways remain insufficiently controlled and that some legacy burdens eventually revert to the state as orphaned environmental liabilities. They also create reputational and governance risks in a context where copper and cobalt production is increasingly scrutinised under international supply chain due diligence expectations (Asia-Pacific Economic Cooperation 2018; Measham et al. 2024; RDC 2018a, 2018b).

Our findings point to several priorities for action. First, the regional inventory should be institutionalised as a living baseline for mining waste oversight. In this respect, the dashboard developed in this study should be considered a preliminary operational tool toward more sustainable management by mining sector authorities. Ideally, it should be updated at least once a year and progressively enriched with additional information on the geotechnical and geochemical properties of facilities. This is necessary because sustainable management cannot rely on location and footprint alone; it also requires information on slope stability, seepage conditions, acid-generating potential, metal mobility and the evolution of facility condition over time (IFC 2007; Kaniki & Tumba 2019). Second, oversight should move from a site-by-site logic towards a corridor- and risk-based approach that targets priority waste complexes, cumulative exposure zones and facilities whose liability status is uncertain. Third, closure planning should be strengthened from the operational phase onward through progressive rehabilitation, clearer closure criteria, and stronger follow-up of financial assurance and post-closure obligations. Finally, re-mining of legacy waste should be supported only where it contributes to risk reduction and is accompanied by clear timelines, new residue management plans and enforceable rehabilitation commitments. These priorities convert fragmented data into a practical management pathway: identify waste complexes, verify technical conditions, assign responsibility, sequence interventions, and link screening results to rehabilitation and post-closure stewardship.

4 Conclusion

This study provides the first harmonised regional inventory of copper–cobalt mining waste facilities in the Congolese Copperbelt. We showed that mining waste is embedded within densely inhabited and hydrologically connected mining landscapes where environmental exposure, closure-related risks and long--term liabilities may accumulate over time. Taken together, our findings suggest that more sustainable mining waste management in the DRC will depend on moving beyond fragmented inventories and site-by-site oversight toward a regional, risk-based and life cycle approach. This requires stronger implementation of closure and rehabilitation obligations, clearer allocation of long-term responsibility and better prioritisation of facilities and waste complexes that combine elevated hazard with strong receptor proximity. The next step is to use the inventory and dashboard to translate fragmented site information into cumulative-impact management, with clear responsibilities for operators, practical priorities for regulators and more transparent information for affected communities. In this context, the inventory and dashboard should be seen as practical starting points for a more structured system of environmental supervision, closure follow-up and long-term management.

Acknowledgement

This study was conducted within the framework of the bilateral development cooperation program between the German Federal Institute for Geosciences and Natural Resources (BGR) and the Ministry of Mines of the

Democratic Republic of the Congo, which supports responsible mining and improved governance. It forms part of the 2024–2027 project phase, Economic Development and Responsible Supply Chains in the Congolese Mining Sector II. Within this framework, BGR and its Congolese partners commissioned the current study to develop a remote sensing-based inventory of TSFs and WRDs in the Congolese Copperbelt and to examine their environmental risk implications in support of mine closure, post-closure management and environmental oversight.

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