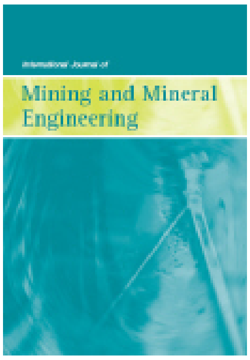

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An advanced overview of recent developments in tantalum, tin, and tungsten production in Rwanda

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An advanced overview of recent developments in tantalum, tin, and tungsten production in Rwanda

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Abstract: With the proliferation of advancements in high-tech devices, the availability and sustainable supply of tantalum, tin, and tungsten (3T) as raw materials may play a crucial role. There have been controversial arguments about the origin of Rwandan 3Ts. The authors believe that it is necessary to investigate their origins by concentrating on the geology, mining, and reforms that drive 3T massive production. The findings revealed that Rwanda became the world's largest tantalum producer with 51% between 2011 and 2015, and has remained in the top three worldwide producers since 2008. The exploitation of an abundance of rock-bearing 3T mineral deposits, mining sector reforms, and the successful implementation of supply chain regulations are primarily attributed to this expansion. Their consistent output is thought to be linked to the privatisation of the mining sector, which brought about modernisation and industrialisation, which contributed to the formalisation of artisanal and small-scale mining (ASM) and built the capacity of local miners.

Keywords: tantalum, tin, and tungsten; 3T; artisanal and small-scale mining; ASM; mineral; mineral traceability; coltan; cassiterite; high-tech devices; mineral supply chain; mining sector reform; mining in Rwanda.

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1 Introduction

Rwanda is a small country located in central Africa that is internationally recognised for its fast transformation: from the Tutsi genocide (Linda, 2016) to science and technology-based development (Linda, 2016; Murenzi, 2008, 2011; Musanabaganwa et al., 2019); from illiteracy to education for all (Murenzi, 2008; Nkurunziza et al., 2012; Ruxin and Habinshuti, 2011); from world food program-dependent to the most food-secure country in East Africa (Linda, 2011); from violence (Uvin, 1994) to tackling pandemics (Condo et al., 2020; Henley et al., 2021); from insignificant mineral production to the global largest producer of tantalum (Sanderson, 2015). It is one of the world's biggest producers of tantalum, tin, and tungsten (3T), minerals that are used to make electronics.

Tantalum (Ta) is mined as coltan (Abrams, 2012; Barume et al., 2016; Diemel and Cuvelier, 2015; Koch and Kinsbergen, 2018); tin (Sn) is mined as cassiterite (Macháček et al., 2022), and tungsten (W) is mined as wolfram (Diemel and Cuvelier, 2015). 3Ts are in the family of 4 minerals additional to gold, mainly referred to as conflict minerals (Mancheri et al., 2018; Sauer and Seuring, 2017; Van den Brink et al., 2019) and usually abbreviated as 3TGs (Koch and Kinsbergen, 2018). They are very essential for industries that make electronic devices (Barume et al., 2016; Van den Brink et al., 2019). They are also important for industries like aviation (Barume et al., 2016; Prendergast, 2009), automotive, aerospace, chemical processing, defense, medical, and metallurgy (Nassar, 2017). Very important and necessary are these minerals in the developed world and the world's largest economies, and in smart economies in SMART cities (Kumar and Dahiya, 2017).

Modern and SMART living standards demand a lot of high-technology devices across the globe, and the COVID-19 pandemic has shown the incomparable significance of communication devices, which triggered high demand and eventually required the massive production of 3Ts for manufacturing electronic devices (Deltalaine, 2020). Each of them has particular applications; for example, tungsten is used in manufacturing chips that allow cell phones to vibrate (Callaway, 2017) and is also widely used in aerospace and military applications (Ma et al., 2017; Ren et al., 2020). Its high melting point, tensile strength, thermal and electrical conductivity, and ability to retain strength at high temperatures (Leal-Ayala et al., 2015), allow it to be used in a wide range of high-temperature applications (Chisholm, 1982). These applications make it a widely needed element to manufacture materials for daily-use. Callaway (2017) notes that tin is used for solder connections, whereas tantalum is mainly used for electronic device capacitors (Baccolo, 2015). However, because 3T has been in high demand since the 1990s and there is intense competition among tech giants to manufacture advanced technological devices (Callaway, 2017), smugglers and militias in eastern DRC saw it as an opportunity to reach the market and began doing illegal mineral trading. Some great lake region (GLR) country members have also been accused of smuggling (Schütte, 2019), resulting in increased regulatory obligations by enacting different laws and certification standards for the companies and high-tech giants that use 3T from the Democratic Republic of the Congo (DRC) and its surrounding countries (Barume et al., 2016; Partzsch and Vlaskamp, 2016). The majority of those regulations issued in the Dodd-Frank Act of 2010, Section 1502, significantly reduced 3T production and exports from the region.

Since 2006, tantalum production in Rwanda has started rising (Fortier et al., 2018). Over the last two decades, the country has increased its activity in exploiting the rock-bearing abundance of the 3T mineral deposits (Hulsbosch et al., 2017; Tumukunde and Piestrzynski, 2018; Van Daele et al., 2018) and has established itself as one of the major exporters of 3T (Uwiduhaye et al., 2020), particularly tantalum. When other countries' production was shrinking due to Dodd-Frank Act embargos, Rwanda's production showed gradual growth up to the peak of 51% of global tantalum production. Mineral production kept growing at the same rate before and after the embargoes. This caught the attention of people all over the world, especially after the country produced more than half of the world's tantalum in concentrates (Sanderson, 2015).

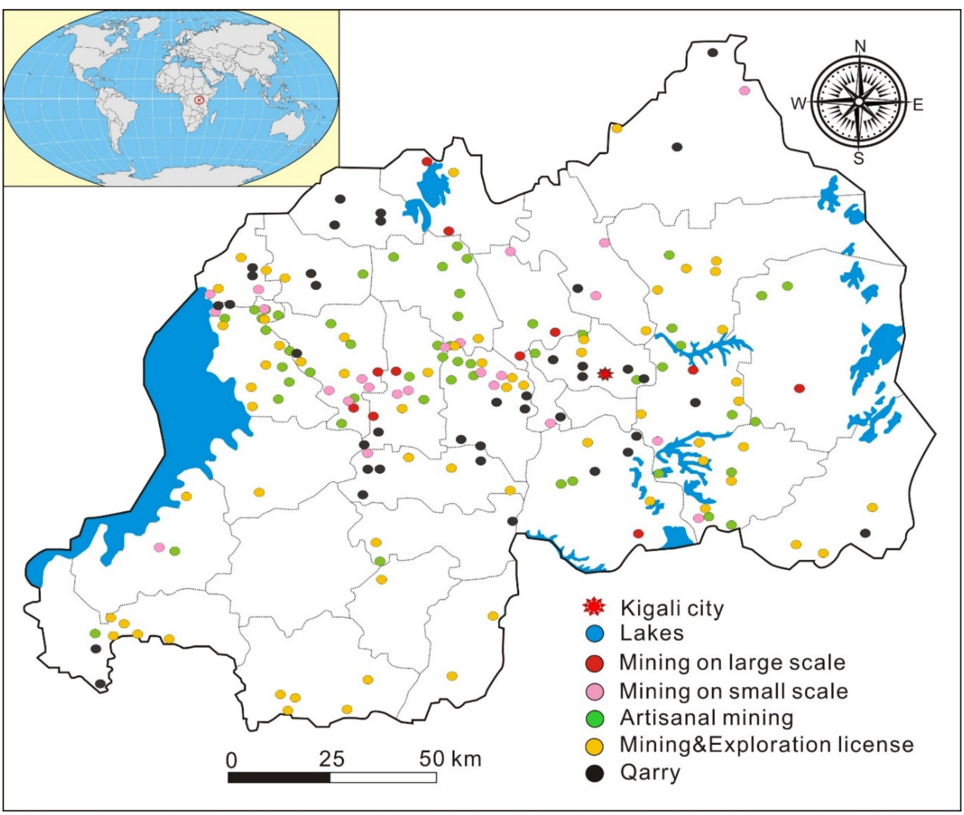
The majority of research on Rwandan mining activities focused on three areas: artisanal and small-scale mining (ASM) (e.g., Perks, 2016, 2019; Weldegiorgis and Ali, 2016), geology and geochemistry (e.g., Hulsbosch et al., 2017; Ngaruye, 2011;

Daele et al., 2018), and Tantalum production (e.g., Barume et al., 2016; Sanderson, 2015; Schütte and Uwe, 2020). However, there is still a gap in not studying all 3Ts at once and associating them with the factors explaining their abundant production. This paper looks at Rwanda's 3T production by focusing on the key factors, reforms, and recent events that lead to high mineral productivity.

2 Rwanda mining structure and developments

Since 2009, the GLR has supplied more than half of the world's tantalum in concentrates (Bleiwas et al., 2015; Fortier et al., 2018). Besides tantalum, they also produce a considerable amount of tin, tungsten, and gold. As a member of GLR and one of the world's largest producers of 3T (Uwiduhaye et al., 2020), Rwanda is a strategically significant country for high-tech giants and countries that consume a large amount of 3Ts. Although many miners in Rwanda fall into ASM (Figure 1), which focuses on the mining of cassiterite, coltan, and wolframite (Barume et al., 2016; Eslava, 2018; Perks, 2016), they are still very crucial to the world of advanced technology.

Figure 1 Classification of miners operating in Rwanda (see online version for colours)



Note: One filled-circle may stand for more than one mining companies.

Source: Modified after Trimble (2019)

In Rwanda, small-scale mining alone accounts for more than 80% of the total 3T output (Barreto et al., 2018). Not only extracting 3T but also focusing on the extraction of gold in some parts, such as the southwestern part of the country (Perks, 2014, 2016). Besides 3TGs, Rwanda exploits other mineral resources, including beryllium, peat, and industrial minerals such as amphibolite, granite, quartzite, volcanic rocks, clay, sand, and gravel (Dusengemungu et al., 2022). To support the mining activities sustainably, there was the establishment of the Rwanda mine, petroleum, and gas board (RMB) (Kuschminder et al., 2017) with the main aim of finding possible means to strengthen the mining sector and boost mineral export earnings, whereby it started with transparency of physical flow data of:

1 the production at the mine site that mining operators sell to mineral traders

2 the volume of minerals that traders are processing

3 the export volume by mineral traders.

The miners need these records to keep them safe from smuggling and to help them meet their international obligations.

Through reforming the mining sector, the main mining concessions increased to over 140 concessions across the country (Collins, 2019) from 11 main concessions in 2009 (Ngaruye, 2011; OGMR, 2009). This is due to the over 479% increase in the number of companies engaged in mining and quarrying activities between 2011 and 2014 (Barreto et al., 2018). This increase brings about the regularisation of all licensing processes, extraction, and supply chain accountability, whereby all the 3TG exports must pass through the due diligence requirements of conflict-free sourcing. As a result of this regularisation, 548 mining permits were given to 213 registered mining entities. Of these, 18% were cooperatives, and 2.4% were foreign-origin companies.

According to domestic mineral regulations, all mining companies must be registered in the cadastral mining system. This registration was based on the classification guidelines for mines. It started in 2016 with 335 companies (Barreto et al., 2018), among which 15% were registered for artisanal mining, 6% for small-scale mining, 2% for large-scale mining and 63% for mineral exploration and quarrying, and 14% were continuing to operate under the old licenses.

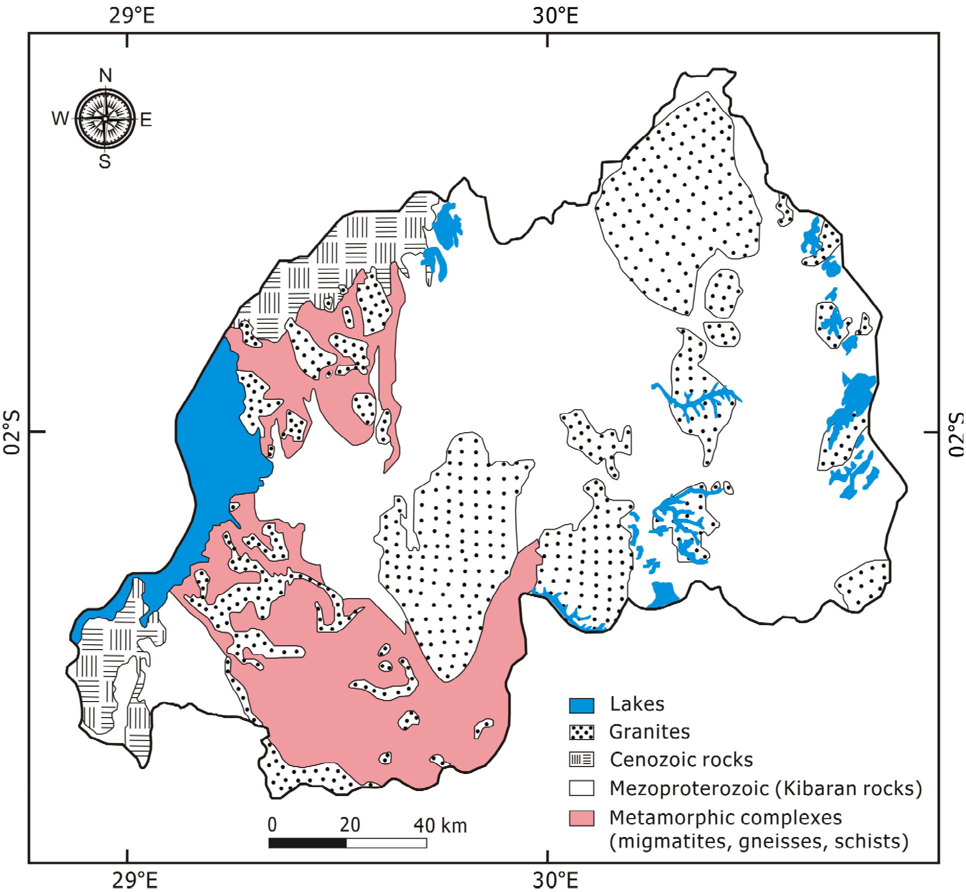
3 Mining activities

Since the beginning of mineral exploitation in Rwanda, mining activities have been gradually increasing. That increase is linked to five different influential aspects, as discussed below.

3.1 The 3T mineralisation

Since the mineral resources were focused on during the race to develop the country's economy, the geological features play a major role in discovering mineral deposits (Uwiduhaye et al., 2020). Rwanda is lithostratigraphically composed of metasedimentary rocks (Figure 2), which are tectonically part of the previously depicted 1,300 km long Kibaran Belt. It extends northeast from the Angola-DRC-Zambia border, through former Katanga (later divided into four provinces) and Kivu-Maniema in the DRC, to Burundi, Rwanda, southwest Uganda, and northwest Tanzania (Uwiduhaye et al., 2020). This Kibaran belt has many minerals related to granite intrusion, such as tin, tungsten, niobium-tantalum, etc. (Dewaele et al., 2011, 2013, 2015; Fernandez-alonso et al., 2012; Hulsbosch, 2019; Pohl et al., 2013; Uwiduhaye et al., 2020), giving Rwanda the advantage of being rich in Sn, W, Nb-Ta, and Au deposits (Hulsbosch et al., 2014; Muchez et al., 2014; Ngaruye, 2011).

Figure 2 Simplified geological map of Rwanda (see online version for colours)



Source: Modified after Hulsbosch et al. (2013, 2014), Nambaje et al. (2021b) Ndikumana et al. (2017, 2020), and Muchez et al. (2014)

Though the geodynamic setting of granite emplacement and deformation of the metasediments is still debated (Wouters et al., 2020), the metasedimentary rocks (especially in western Rwanda) were intruded by S-type granites (G1–3 granites) with dykes around 1,375 Ma, A-type granites around 1,205 Ma (Fernandez-alonso et al., 2012; Tack et al., 2010), and S-type tin granites (G4 granites) around 1,011 ± 18 to 976 ± 11 Ma (Nambaje et al., 2021b) yield world-class tin metallogenic province (Dewaele et al., 2016; Nambaje et al., 2021a; Pohl et al., 2013; Tack et al., 2010). A younger S-type granite intrusion (G5 granite) dated later at 614 ± 9 Ma (Nambaje et al., 2021b) is responsible for the high mineralisation of tin, tantalum, and tungsten (Ngaruye,

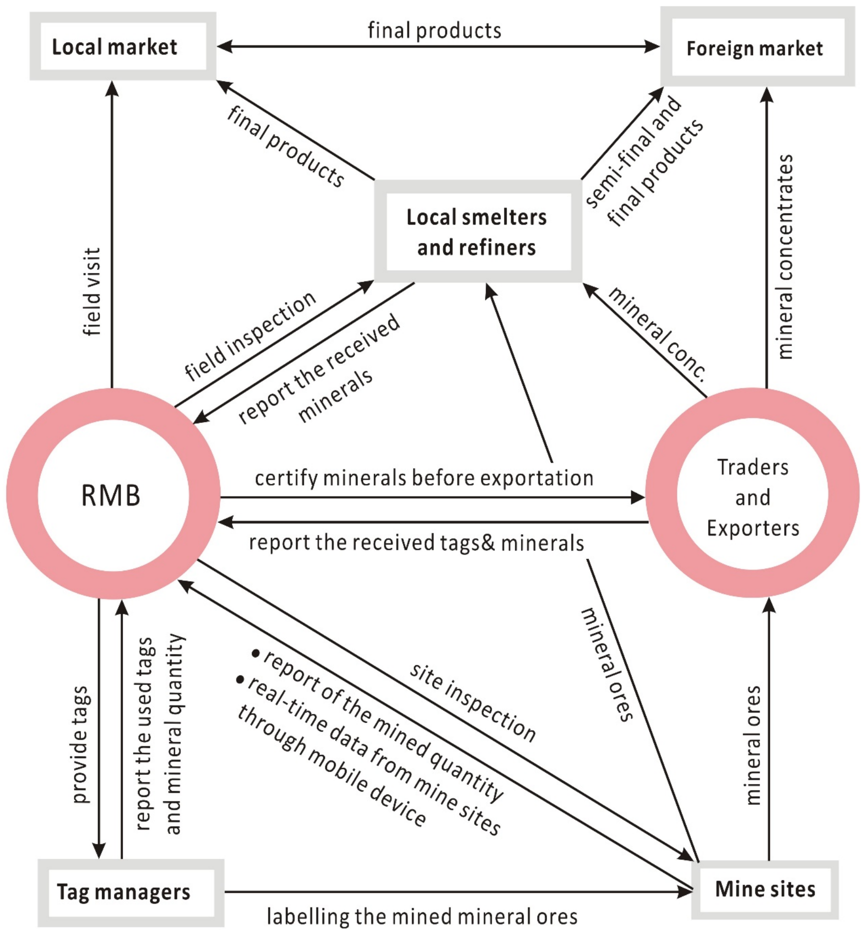
2011) that are hosted in pegmatites and quartz veins (Tack et al., 2010). Furthermore, the tin and niobo-tantalum bearing pegmatites and greisen deposits in Rwanda are associated with highly evolved peraluminous S-type granitic massive rocks (Ndikumana et al., 2020), and those evolved pegmatites are of LCT-type, which serves as a host for Sn-(Nb-Ta) mineralisation (Melcher et al., 2017).

According to the data presented by Muchez et al. (2014), the western part of Rwanda is dominated by Nb-Ta-Sn pegmatites and W-vein types; Sn-vein type deposits are based in the centre of the country; and then the eastern part is composed of an alternative form of 3Ts or mixed deposits. Most cassiterite is extracted from quartz veins and pegmatite veins (Nambaje et al., 2020). Though the hard rock-pegmatites of the western part (Gatumba) are still not evaluated for deposits (Dewaele et al., 2011; Muchez et al., 2014), it remains among the key areas of production of columbite-tantalite and cassiterite due to the exploitation of its deep weathered pegmatites and eluvial and alluvial deposits. Apart from being non-evaluated for mineral deposits, its reserves of columbite-tantalite in the 1980s were estimated to be around 950 tonnes and 2,400–3,400 tons of cassiterite (Muchez et al., 2014). With the continuing exploration, many mineral commodities with economic deposits are found in the entire country and have been exploited since the 1920s (NISR, 2019). Rwanda's production has stayed steady since the 1990s, and it is an important source of 3Ts for the high-tech industries. This is because Rwanda has rock-bearing mineral deposits; mineral exploration is growing; and discovered mineral resources are being used.

3.2 Mineral traceability control

Following the political instability and militias in eastern DRC, mineral traceability became a global concern, which required different regulations and rules to be implemented in the region. Since the emerging of conflict mineral-free status in the GLR as a response of mineral smuggling (Seay, 2012), which was thought to be linked to illegal armed groups operating in North Kivu (Abrams, 2012; Koch and Kinsbergen, 2018; Prendergast, 2009), GLR country members had to follow the different certification schemes and due diligence guidelines, such as those of the International Conference on the Great Lakes Region (ICGLR) Certification Mechanism, the Certified Trading Chains (CTC), and the Organisation for Economic Corporation and Development (OECD) (Barume et al., 2016). Implementing those regulations could ensure the development of a sustainable mineral supply chain that is impossible without resource governance (Herrington, 2013). As one of the countries mentioned in the Dodd-Frank Act, Rwanda initiated a fight against smuggling in the region by banning mineral trading on its border with the DRC (Hall, 2011) and handing back smuggled 70 tonnes of minerals to the DRC (Seay, 2012). Moreover, it implemented the entire certification standards and due diligence as mentioned in Dodd-Frank Act Section 1502 (Barreto et al., 2018; Fortier et al., 2018; Seay, 2012) and achieved significant success in implementing the Certified Trading Chain in 2011 (Kuschminder et al., 2017; Schütte et al., 2011). It launched anti-smuggling regulations in 2011 and integrated the regional certification mechanism (RCM) (Blore and Smillie, 2011) to ensure the minerals can be traced down to their origin (Eslava, 2018). Those regulations came to sustain the certification standards and tagging projects of 3Ts introduced by the International Tin Research Institute (ITRI) in the region (Barume et al., 2016). Therefore, the Rwanda implementation of RCM and domestic formalisation of 3T supply chains has been internationally recognised (Barreto et al., 2018), which has resulted in a decrease in pressure from legislators on mineral traceability regulations and traders. Having sustainable supply chain management (Sauer and Seuring, 2017) was crucial for Rwanda in order to maintain its presence in the international market. There were no other ways to keep that position except by complying with the required mineral traceability regulations, which were successful due to political stability within the country.

Figure 3 Mineral traceability control system in Rwanda (see online version for colours)



Recently, the ITRI tin supply chain initiative (iTSCi) has been criticised for the laundering of smuggled minerals and the failure to stop minerals from unvalidated DRC mines from entering the global supply chain. This questions its credibility and data transparency in the DRC (Global Witness, 2022). However, the authors investigated the field implementation process of the tagging system that has been strenuously practised in Rwanda since the launch of the Dodd-Frank Act of 2010 in line with the iTSCi guidelines (Barreto et al., 2018). They found a serious mineral traceability control system that traces minerals from the mine site up to the exportation stage (Figure 3). Its successful implementation ensures that the Rwanda-origin minerals can be traced and show the status of conflict-free financing, human rights abuses, or other malpractices in mineral supply chains. Approximately 92% of Rwanda's mines adopted traceability systems at the start (International Tin Association, 2011), increasing the trust of mineral traders and foreign investors to invest in the mining sector, which eventually made Rwanda the largest global tantalum producer (Sanderson, 2015). It becomes convenient for mineral traders and electronic device manufacturers, who were obligated to have conflict-free mineral status to trade minerals from Rwanda.

In addition to the implementation of the mineral traceability control system, there are other domestic and international factors that have led to an increase in Rwanda's mineral production, either directly or indirectly. Some of them are:

1 a significant increase in tantalum and tin prices between the 2009-2011 period, which motivated mining investors to increase production (Schütte, 2019)

2 companies invested in ASM supported partial mechanisation or semi-industrialisation (Schütte, 2019; Wakenge, 2018) and increased production

3 the international buyers engaged in mineral trading from the region increased significantly after the implementation of mineral sourcing regulations (Schütte, 2019).

3.3 Privatisation of the key mining sector assets

The high demand for 3Ts requires modernisation and industrialisation to meet international standards. Foreign investors were the first choice to think about because they could bring the investments, technologies, and innovations that could transform the Rwanda mining model into a semi- or full-mechanised operation (Perks, 2016). As long as the mining sector was a state-owned asset, it was not favourable for private investors to enter the mining market. Priority was given to the idea of privatising key mining assets so that foreign investors would be drawn to the country.

After colonisation, all mining companies were grouped into one publicly owned company, 'SOMIRWA'. Unfortunately, it went bankrupt in 1985 (MINIRENA, 2010). Then the artisanal mining cooperative 'COPIMAR' was formed in 1988 to revitalise the sub-sector, and after one year, REDEMI was formed to replace SOMIRWA (MINIRENA, 2013). To avoid the challenges met with previous formed companies, the government shifted its mining policies from a state-based to a market-based economy and privatised government-owned mines starting from REDEMI. This privatisation process continued up to 2006 (Nwapi, 2017). Even though there were problems right after privatisation, the management of privatised companies has gotten better. This has led to a rise in mining productivity, which is partly due to the rise in commodity prices (MINIRENA, 2010).

After privatisation, attracting foreign direct investment (FDI) was the key factor in leading the battle for modernisation (NISR, 2019). In the period of 2008–2012, the mining sector accounted for 14% of the total Rwanda FDI flow (Kambayire, 2013). That is, the privatisation of key mining assets and the liberalisation of mineral commodity export trading were critical to attracting foreign investment (Kuschminder et al., 2017; Perks, 2016). The country's rapid modernisation of infrastructure and investor friendliness plays a significant role in attracting expats and investors (Linda, 2016). To make it easier for foreign investors, mining strategies have been rewritten to be more in line with international principles and national development goals (NISR, 2019). All of the rules about the mining agenda have also been completely rewritten. This includes changes to the law, policies, tax system, and the way land is titled.

Additionally, before joining FDI, there was a call for locals to invest in mining and they had been promised the possible assistance to end the monopoly of REDEMI and COPIMAR, which were only buying and exporting minerals from Rwanda (Perks, 2016). The first rapid privatisation began earlier in 2004, and it continued up to 2006, when six major concessions were handed entirely to private companies. In 2013, only two concessions (Gatumba and Rutongo) were still maintained as joint ventures with the government (Perks, 2016). The idea of privatisation comes along with protecting the legitimate interests of mining investors. Because of this, all companies selling minerals on the exploration licence were suspended in 2016 (Eslava, 2018) and were asked to operate according to their trading licences or choose to apply for new licences according to their interest. Companies were open to consulting with RMB to access the entire country's research and exploration findings on mineral deposits.

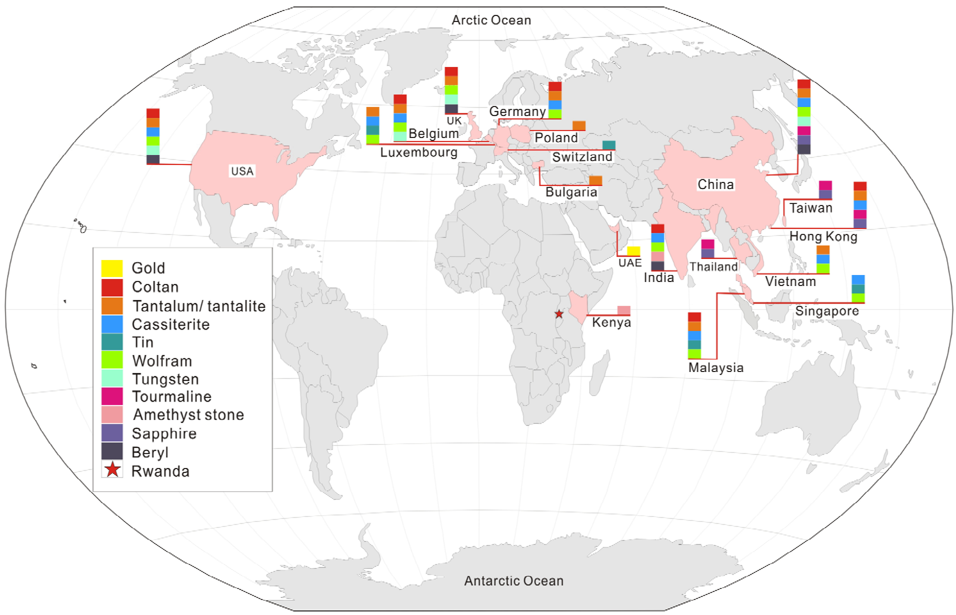
3.4 Empowering ASM

ASM activities occupy ample space in the mining sectors of many mineral-rich countries (Ofosu et al., 2020) and have a significant contribution to global mineral output (Hassen, 2022). Like in other countries, many Rwandan miners fall into the ASM category (Macháček and Dušková, 2016), and their contribution to mineral production remains very significant because ASM is still the largest producer of 3T (Eslava, 2018). So, the empowerment of this category can ensure the sustainability of mineral production, as they make up the majority component of mineral exportation (Macháček and Dušková, 2016). Many reforms have been made to strengthen the capacity of ASM so that they can have sustainable production. The big problem that ASM in Rwanda suffered was the knowledge and skills gap in daily workers, caused by the insufficiently skilled local workforce after privatisation. To tackle this problem

1. training has been given to ASM miners
2. there was the establishment of a mining engineering school in the Integrated Polytechnic Regional College (IPRC) that operates under Rutongo Mining School, which produces graduates who have practical skills in mining, mineral identification, and mineral processing
3. there was the establishment of a mining and geology school in the University of Rwanda, College of Science and Technology, which produces graduates with a strong ability to perform the needed skills in the mining industries.

The RMB, which oversees subsurface resources, implements national mining policies and strategies and supervises and monitors all natural resource protection and promotion operations (Jordon, 2017). It trained ASM and encouraged banks to provide loans to miners and traders (NISR, 2019). The biggest problem was getting all mining companies, exploration companies, and mineral trading companies to register, even the smallest ones that had been ignored in the past. Individual and small-scale miners who had less money to invest were helped to form cooperatives to improve their mining skills and finances. At present, this coalition is considered one of the roots of the increasing mineral exporters up to the 25 companies from 2 in 2007, which means that they multiplied over 12 times and supplied more than 18 foreign markets (Figure 4), reflecting the annual 3Ts production growth.

Figure 4 The market of minerals from Rwanda (see online version for colours)



Source: Data from Rwanda Development Board (Rwanda Development Board, n.d.)

The opening of mineral exports to private traders coincides with mining policy reform and revision, such as those of:

1 2008, which focused on granting licences for mineral extraction and traders, establishing taxes, and strengthening regional anti-smuggling efforts (World Bank, 2014)

2 2014, which aimed to formalise ASM (Nwapi, 2017) and complete geological works to identify mineral prospecting targeted areas that will be useful for ASM and private investors

3 2018 that aimed to improve mineral extractive governance, accountability, safety, and environmental protection (Stevens, 2018), as well as require companies to submit mine development plans (Schütte and Uwe, 2020).

The information gathered with the help of the first new policies became the basis for initialising the modernisation process of the cadastral system (Perks, 2016). Additionally, there was a piloting of the certified trading chains (CTC) approach from 2008 to 2011 (Blore and Smillie, 2011) to emphasise artisanal processes in ethical production, and they joined the International Conference of the GLR Regional Initiative on Natural Resources (RINR), which had a mission to formalise the ASMs. Those changes may reflect the post-conflict nature mentioned in perks (Perks, 2016) and support the continuous enhancement of formalising ASM to ensure the steady growth of domestic productivity and exportation opportunities (Mcdoom, 2011). Currently, the ASM is receiving field workers who have passed through organised training on mining activities or have graduated from mining engineering and geology schools that were established to boost ASM professionalism.

3.5 Industrialisation

Based on the significant contribution of mining activities to the country's economic growth, mineral resources are considered the economic pillar to drive industrialisation, diversification, and overall economic transformation. This may be done by attracting more investors to boost the country's mineral exports, employment, and revenues (Barreto et al., 2018). The mining sector has been listed among the country's sectors that should help the country reach middle-income country (MIC) status by 2035 (The World Bank in Rwanda, 2022). The economic growth that has its roots in industrialisation is reliable and sustainable. That is why Rwanda wanted to focus on mineral industrialisation to build a strong economy because it was losing 40% of potential revenue by exporting raw minerals. To minimise the loss, the government turned the mining sector into a vibrant, dynamic, and efficient industry that could boost the country's economic growth. Currently, the refineries for gold and tin reside in the country, both of which can process a large amount of minerals from across the region. The establishment of refineries boosts mining and quarrying activities by 18.2% in 2019. So far, the entry of the Aldango gold refinery and LuNa tin smelter, which are the only mineral processing factories in the country, is the right step towards the goals of 2024 of earning $1.5 billion annually and becoming a regional mineral processing hub. The presence of refineries drives modernisation as they add value to the minerals from the region before exportation to reduce the loss that occurs when exporting raw minerals.

3.5.1 Gold refining

The Aldango gold refinery was established in 2017 and started operating in March 2019 at the Kigali Special Economic Zone. It is qualified to process gold (Figure 5) from across the African continent due to its processing capacity of 6 tonnes per month (Adira, 2019). It intends to boost the efforts of many African countries to fetch more revenues from their natural resources, which is a relief to African nations whose large amounts of gold were being exported without adding value (Adira, 2019). This refinery complies with the international mineral due diligence standards, such as the UN, OECD, ICGLR, and local standard mechanisms. It comes as a result of the modernisation and industrialisation race in the sector.

Figure 5 Some of the products of Aldango gold refinery in Rwanda (see online version for colours)

3.5.2 Tin smelting

LuNa Smelter is a high-quality African tin producer plant constructed in Karuruma, Rwanda, to process cassiterite into finished tin products. It was built in 1980 but struggled with many problems, including the bankruptcy of 1985 and shutting down during the genocide against Tutsi in 1994. However, it was utterly revived after its privatisation in 2018, which in turn boosted modernisation, refurbishment, and launched smelting of high-grade tin ingots up to 99.96% Sn and other minerals recovered from the refining process, such as tantalum concentrates. With the ability to process 15 tonnes of cassiterite per day, it is expected to process cassiterite and coltan from the whole continent.

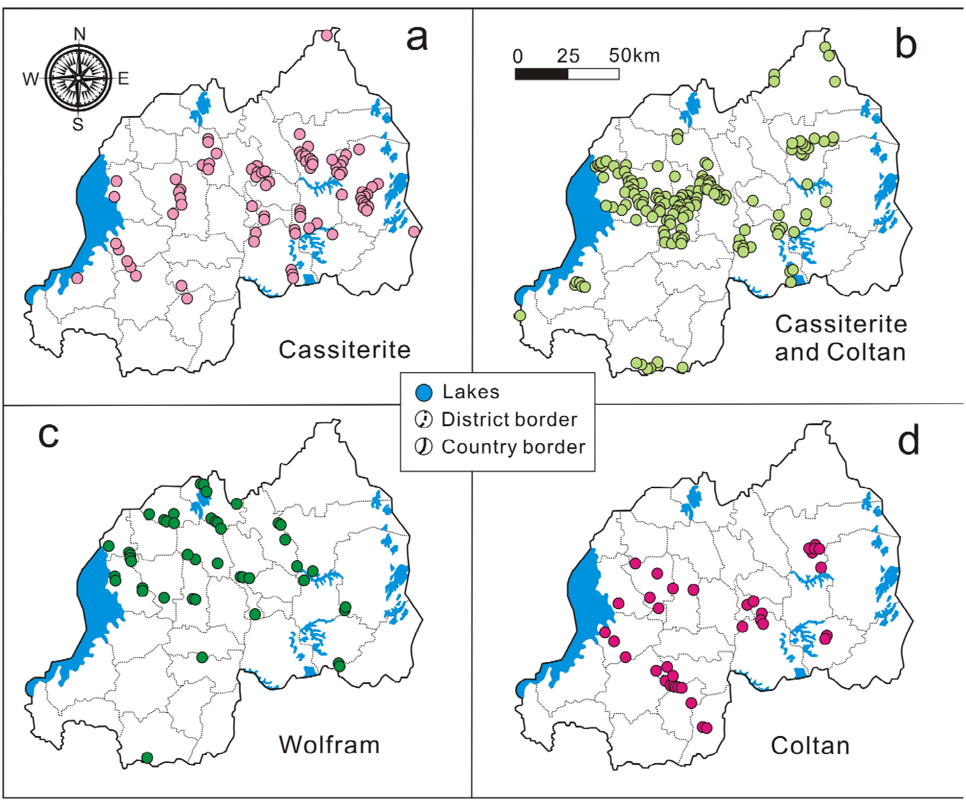
Due to the high demand for raw ores from this smelter, it also opened its mine sites to strengthen and encourage local miners to increase production capability. It is the first responsible minerals assurance process (RMAP) conformant tin smelter in Africa (Daniel, 2020; Guest Contributor, 2020), and its activities have already boosted the entire industrial and mining sector of East Africa, especially the development of the new 3T mining projects. Its lab has the ISO 17025: 2017 certification and is set up to analyse ores, concentrates, and exploration samples, especially for 3T and lithium.

Furthermore, it is the first Conflict-Free Tin Smelter in Africa fully aligned with OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas (Guest Contributor, 2020). To pilot the Ore Source blockchain tool, it built a partnership with different entities, including Minespider, Google, RMB, and European Raw Materials Alliance (ERMA), to promote responsible raw materials supply throughout the world. LuNa Smelter is also recognised by the responsible minerals initiative (RMI) as a conflict-free smelter, making it the only tin smelter in East Africa to qualify for the RMAP. The smelter activities became a solution not only to cutting off the loss of exporting concentrate ores but also increased employment in the country as it employs more than 140 people within in the smelter. It made the local market for mineral ores more stable and gave local people a reason to invest in mining.

4 Growth of mineral ore production

Rwanda began artisanal mining, smelting, and mineral trading in the early 1930s (Newbury, 1980; Vansina, 2004). In the 1980s, the critical discussion on mineral production centred on how to boost the production of mineral elements that are more valuable in high-technology device manufacture, recognising tungsten, tantalum, and niobium as essential elements (Hayes and McCullough, 2018). After that, such minerals were extracted worldwide. Numerous projects found probable sources of such elements. Rwanda followed suit in 1996 by opening its mineral resources to foreign traders (Perks, 2016). Since 1999, the mining sector has undergone several reforms and grown at least 10% annually (Deltalaine, 2020).

Figure 6 The 3TS active mining sites in Rwanda (see online version for colours)



Source: Modified after Barreto et al. (2018), NISR (2019) and Trimble (2019)

The gradual growth of mining activities marked the post-privatisation. By taking example in 2010, cassiterite was extracted from about 85 mines, wolframite at 52 mines, and coltan at 26 mines, and the remaining mines were producing at least two mixed commodities for each (International Tin Association, 2011). That means all 3Ts were extracted from more than 163 sites. Five years later, the number of companies and mine sites showed significant increases, whereby cassiterite, coltan, and wolframite in total were mined by at least 302 mining companies that operated at a total of 842 main mine sites equivalent to over five times. The rising number of companies was not proportional to the mining capacity and abilities. Then, they consolidated to form cooperatives in order to become more efficient and professional. As a result, the number of companies fell to 250 in 2017 (Kuschminder et al., 2017). The reduction of companies did not affect production because the mine sites increased by about 370%, from 842 to 3,113 sites (Figure 6).

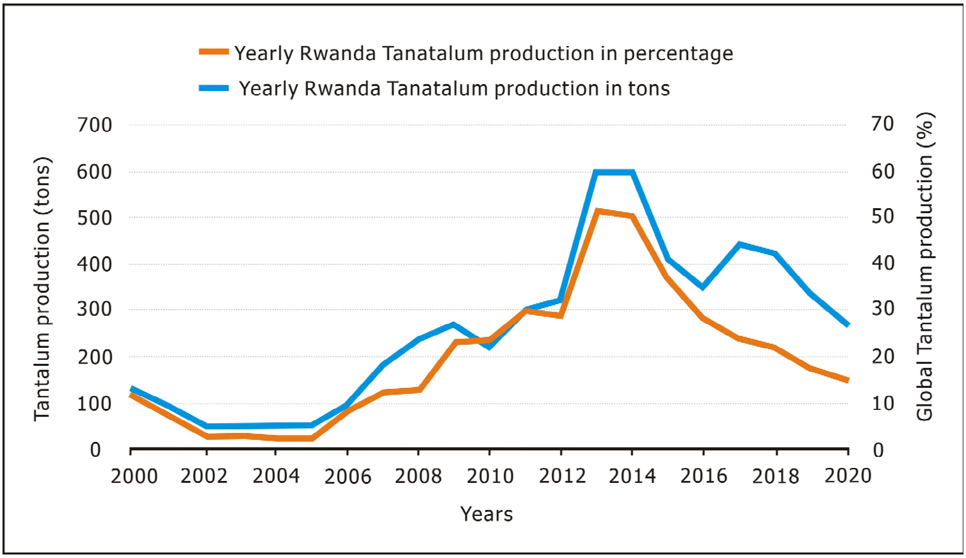
If we consider the period from 2010 to 2017, the mine sites multiplied 19 times. Thus, it increased the country's mineral production and, consequently, this increase has contributed to shifting the global geographical distribution of tantalum sources (Bleiwas et al., 2015; Fortier et al., 2018; Sanderson, 2015), which made the annual mineral production estimation of 8000 to 9000 tons per year (NISR, 2019; World Bank, 2014).

4.1 Tantalum and niobium (columbite-tantalite) ore production

Tantalum minerals can be found in more than 50 different chemical compositions (Barume et al., 2016). Its essential properties include super acid corrosion resistance, ductility, biocompatibility, and a high melting point (Lim, 2016). Its ability to efficiently store and release electrical charge has made it a super element with highly specialised applications in a wide range of industries (Nassar, 2017). Some of the most well-known industries are the ones that manufacture electronic devices (Lindagato et al., 2022; Macháček et al., 2022) and other modern technological materials that were discussed in the introduction part. A large part of the produced tantalum is used in manufacturing electronic devices, especially in storing electrical charges (Callaway, 2017; Deltalaine, 2020) of communication devices, mostly mobile phones (Baccolo, 2015), and other materials in the category of electronics (Niu et al., 2020) rely on tantalum capacitors. Despite the development of alternatives to tantalum capacitors that show promising results (Roos, 2001; US Geological Survey, 2021), the advancement of modern technology still needs a lot of tantalum for their production such as 5G network and electric vehicles (Lindagato et al., 2022). Rwanda marked a huge increase in 3Ts production in 2012 and attracted many traders and investors, and it is therefore critical to highlight that the estimated increase was 146% for tantalum and 138% for niobium (Yager, 2012), which is believed to be the root of producing up to 51% of global tantalum in 2013 (Figure 7) from 12% in 2000 (Sanderson, 2015).

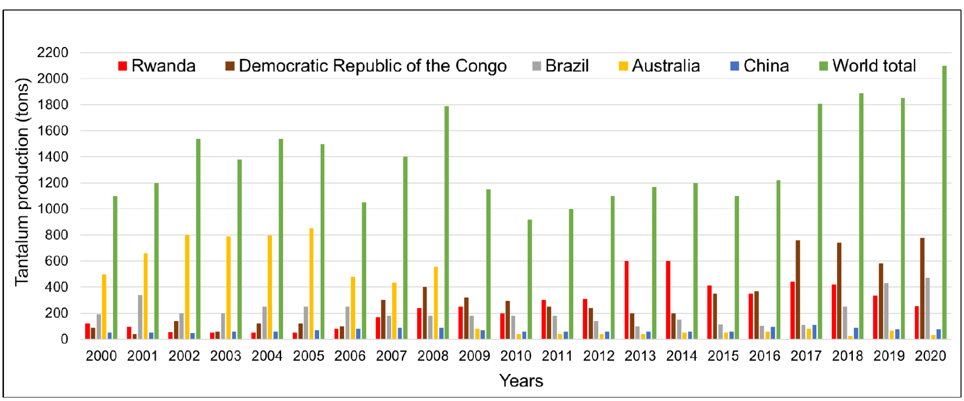
Nevertheless, it has remained among the top three global leading producers of tantalum since 2008 (Figure 8). This high production has raised global concerns about the origin. However, the huge increase in mine sites and mineral traders may justify the massive production of tantalum. Because Rwanda makes much tantalum, many countries import a lot of it. In 2020, 34% of all tantalum and niobium imports to the USA came from Rwanda.

Figure 7 The production of tantalum in concentrates in Rwanda (see online version for colours)



Source: Date from Garside (2021) and Sanderson (2015)

Figure 8 The leading global producers of tantalum contained in concentrates (see online version for colours)



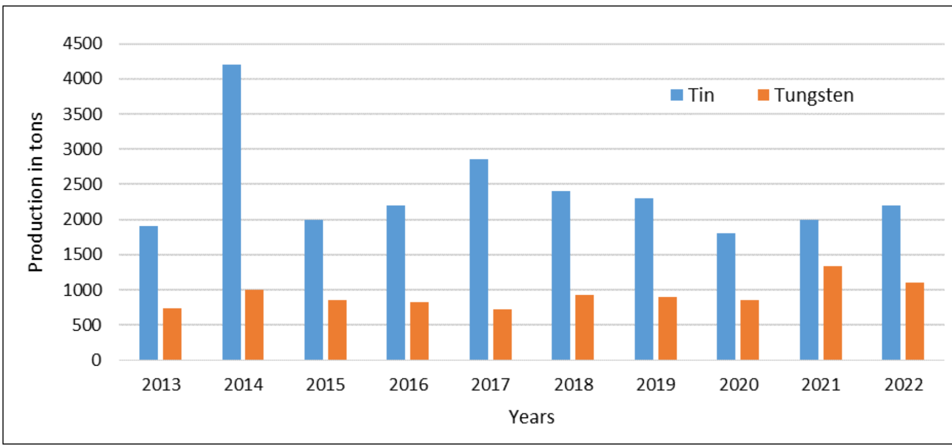
Source: Garside (2021), Sanderson (2015) and US Geological Survey (2022)

Tantalum is always geologically paired with Niobium as twins because of their similar physical and chemical properties (Schulz and Papp, 2014), and sometimes they are mined in a combined format called columbite-tantalite. This niobium ore concentrate is used to produce high-temperature-resistant alloys (Deltalaine, 2020; Siqueira-gay and Sánchez, 2020), special stainless steels, and superconductors (Callaway, 2017). In Rwanda, niobium was mined by 44 producers in 2011 (Yager, 2012), and amounted to approximately 250 tonnes (Kanzira and Mukamurenzi, 2012), which goes up from time to time due to the entry of FDI (Kambayire, 2013; National Bank of Rwanda, 2012, 2017).

4.2 Tin and Tungsten ore production

Tin and tungsten are critical minerals to be produced in abundance due to their applications and has a long history in Rwanda. According to Kanzira and Mukamurenzi (2012), it was mined by 104 out of 39 producers of tungsten in 2011, and its volume tripled from 473 tonnes in 2009 to 1,300 tonnes in 2010 (Macháček and Dušková, 2016). Since 2012, the role played by Rwanda in the global production of tin and tungsten has become more significant (Figure 9) because its production accounts for 3% of tin and 2% of tungsten globally (Barreto et al., 2018). Furthermore, Rwanda is the seventh largest exporter of tungsten ores and the twelfth largest exporter of tin ores (US Geological Survey, 2021).

Figure 9 Production of Tin and Tungsten contained in concentrates in Rwanda (see online version for colours)



Source: Data from US Geological Survey (2023)

Even though there were problems with privatising ASM, such as domestic pressure to get rid of informality to bring in more money (World Bank, 2014), increasing private sector investment increased production and made a big difference in both microeconomics and macroeconomics (Barreto et al., 2018).

The mining sector is still ranked second for foreign exchange earnings (Jordon, 2017). Its contribution is significant and promising to sustain economic growth, secure the basic needs of local inhabitants, and improve the workers' living standards (Macháček and Dušková, 2016). Its employment increased two times within a decade and accounts for 2% of the country's total employment (NISR, 2019). At present, it employs more than 60,000 people (National Bank of Rwanda, 2016; Yager, 2019), whose income supports more than 170,000 livelihoods (Deltalaine, 2020). Despite COVID-19, which posed a challenge to the mineral supply chain (Perks and Schneck, 2021; Zhu et al., 2021), Rwandan mineral revenues reached $733 million in 2020. Total mineral exports are increasing, and their contribution to GDP increased from 0.1% in 2000 to 2.5% in 2018 (NISR, 2019).

5 Conclusions

This article discussed some of the facts that can contribute to showcasing the sources of minerals in Rwanda, and its findings show that Rwanda's tantalum production rose to 51% of the global total production and has remained among the top 3 global tantalum producers since 2008. This growth can primarily be attributed to the political stability favourable for the investment, the exploitation of an abundance of rock-bearing 3T mineral deposits, mining sector reforms, and the successful implementation of domestic and international supply chain regulations. The steady growth of 3T production has a direct link to the privatisation of the mining sector, which brought modernisation and industrialisation that financially and skilfully supported the formalisation of ASM and built the capacity of domestic miners. Together with the above-discussed factors, the opening up of gold refineries and tin smelters encouraged people to engage in mining activity and increased the stability of the local market. Thus, mining employment increased by up to 60,000 people, and other mineral productivity, such as tungsten and tin, increased by up to 2% and 3% of global production, respectively.

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List of acronyms

ASM	artisanal and small-scale mining
COPIMAR	Coopérative de Promotion de l'Industrie Minière Artisanale au Rwanda
CTC	certified trading chains
DRC	Democratic Republic of the Congo
ERMA	European Raw Materials Alliance
FDI	foreign direct investment
GLR	great lake region
ICGLR	International Conference on the Great Lakes Region
IPRC	Integrated Polytechnic Regional College
ITRI	International Tin Research Institute
iTSCi	ITRI tin supply chain initiative
MIC	middle income country

OECD	Organisation for Economic Corporation and Development
SOMIRWA	Société Minière du Rwanda
REDEMI	Régie d'Exploitation et de Développement des Mines
RCM	regional certification mechanism
RINR	regional initiative on natural resources
RMAP	responsible minerals assurance process
RMB	Rwanda mines, petroleum and gas board
RMI	responsible minerals initiative
UN	United Nations
3T	tin, tungsten and tantalum
3TG	tin, tungsten, tantalum and gold.